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10/25/06 BdMtg Item 10
303(d) List
Deadline: 10/20/06 5pm

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BARNUM TIMBER COMPANY
P.O. BOX 1365
1610 HIGHLAND AVENUE
EUREKA, CALIFORNIA 95502-1365
[707] 442-1761
FAX [707] 442-5510

October 18, 2006

RECEIVED
OCT 2006
SWRCB
Executive Ofc.

VIA EMAIL

Song Her
Clerk to the Board
State Water Resources Control Board
Executive Office
1001 I Street
Sacramento, CA 95814

RE: COMMENT LETTER—2006 FEDERAL CWA SECTION 303(d) LIST

REDWOOD CREEK, HUMBOLDT COUNTY

Dear Board Members:

I represent Barnum Timber Company, hereafter "Barnum," a landowner in the Redwood Creek watershed in Humboldt County, California. I have previously provided information to the State Water Board regarding conditions in Redwood Creek in response to the public solicitation for comments and information on proposed revisions of the federal Clean Water Act section 303(d) list of water quality limited segments.

My comments were apparently disregarded by your staff, as the recommendation is being made to list Redwood Creek as temperature and sediment impaired under CWA 303(d). A reproduction of my comment letter dated January 17, 2006 in the staff reports leading up to your October 25, 2006 meeting left out three pages of my cover letter and all of the attachments. I have checked my original email submission and the entire letter and attachments were submitted to your staff prior to the close of the public comment period. Perhaps your staff lost portions of my comment letter and thus did not respond to my substantive comments. In any case, I request that you remove Redwood Creek from the 303(d) list or delay your decision until your staff can fully evaluate the true conditions of that water body and respond to Barnum's comments in an adequate manner.

In response to the information provided about Redwood Creek in your staff report, I offer the following comments:

1. The fact sheet for sedimentation states that a sediment TMDL has been developed for Redwood Creek. In the EPA's guidance for TMDLs, development of a TMDL is justification for removal from the 303(d) list. Therefore, you should remove Redwood Creek from the 303(d) list for sediment.

2. Your staff erred significantly in its logic discussed in the fact sheet when it stated that "the weight of evidence indicates there is sufficient justification in favor of placing this water segment-pollutant combination" on the 303(d) list. The import of all previous submissions made by Barnum Timber Company regarding Redwood Creek have been to notify your staff that the original State Water Board and EPA listings of Redwood Creek for sediment were based upon faulty data. The primary premise relied upon by the State Water Board for listing Redwood Creek for both sediment and temperature was that fish populations in Redwood Creek were diminished over some level in the past. Barnum Timber Company's submissions have all been aimed to inform your staff of this mistake, and to supply information that demonstrates 1) that Redwood Creek's fish populations are as healthy or healthier than any time in the documented past; 2) that the fish population data that the SWB staff has heretofore referred to is useless because it is anecdotal and contains no actual population census data; 3) that the current productivity of Redwood Creek for salmonids is as high or higher than any other level documented for any stream in the Pacific Northwest; and, 4) that fish populations and water quality conditions are naturally cyclical and current conditions do not exhibit any abnormality.

3. The staff comment noted above regarding the "weight of evidence" analysis is curious because no such analysis is described or documented in the staff reports. Prior to adopting your staff recommendation, please require your staff to produce the "weight of evidence" analysis and provide it to the public for adequate review. How the public to provide comments on a staff analysis that is not available? Is there a written "weight of evidence" analysis? Or, was the data for Redwood Creek simply weighed in staff's mind and only the conclusion presented? In any case, please provide evidence of exactly what evidence was weighed by staff so the public can determine the relative weight of various lines of evidence.

4. A pollution control scheme is already in place to ensure that Redwood Creek is not adversely affected by discharges that could significantly impact the sediment or temperature conditions of Redwood Creek. The pollution control scheme is mandated by the California Forest Practices Act, which governs the primary land use in Redwood Creek, forestry operations. EPA's guidance for delisting waterbodies from the 303(d) list allows for delisting if other regulatory controls that address the impairment(s) are in place.

5. Reducing the many-thousands of pages of comment and data provided by Barnum Timber Company on the sediment and temperature listing of Redwood Creek to a few incomplete sentences and even fewer words as a response by your staff is irresponsible. Barnum has been long requesting of the State Water Board to provide an objective review of the conditions of Redwood Creek in regards to the alleged temperature and sediment impairment: It is unfortunate that the current review disregarded this request yet again. I request that you provide a review and document that your staff has reviewed the available information.

6. The temperature criteria established in previous temperature impairment listings of Redwood Creek is unreasonably low, impossible to achieve and is premised upon presence of fish species that don't exist in Redwood Creek. Your staff has concluded that coho salmon temperature criteria are necessary for Redwood Creek without conducting an analysis to determine if the physical characteristics of Redwood Creek are capable of producing viable populations of coho salmon. For example, Redwood Creek, upstream of Prairie Creek, is a confined linear stream. Also, a very steep stretch of stream channel exists just upstream of Bridge Creek, which is a natural cascade barrier that prevents coho from accessing the upper 2/3 of Redwood Creek. Because of this barrier, occasional sightings of coho in upper Redwood Creek are likely strays and coho-based criteria are inapplicable. In any event, your staff needs to conduct a rational analysis of the physical conditions of Redwood Creek before it can determine temperature or sediment impairment and what beneficial uses require protection. I have included a report (Attachment 1) that may be valuable for your staff as they conduct an analysis of the physical conditions of Redwood Creek.
7. I am attaching yet more information (Attachments 2 & 3) that has become available since the last public comment period that demonstrates Redwood Creek is producing salmonids in record numbers. This data, collected in two reports by the California Department of Fish and Game, demonstrates that the logic employed by the State Water Board and EPA in listing Redwood Creek for sediment and temperature if flawed.

Barnum has been concerned about the listing of Redwood Creek as an impaired water body under Section 303(d) of the Clean Water Act since its original listing in 1993. Since that time, Barnum has endeavored to gather and assimilate all available information relating to conditions in Redwood Creek. Barnum submits this information to assist you in making better informed decisions regarding Redwood Creek and other North Coast water bodies, particularly in deciding whether, in fact, Redwood Creek should continue to be listed as impaired. Please take the time to fully review the information provided. This compilation of information is likely the most comprehensive ever assimilated regarding conditions of a California water body and has been produced over a time spanning nearly a decade at a cost of several hundred thousand dollars.

Barnum believes, based upon the scientific information available, that Redwood Creek is not impaired by sediment, temperature or any other pollutant; that, in fact, Redwood Creek is today in as good a condition as has existed in the historical past and is a healthy and productive water body.

If there are any questions regarding the information provided, please contact me. My address and telephone numbers are shown on the letterhead. My email address is s_horner@cox.net.

Thank you for the opportunity to assist you in making fully informed decisions.

Sincerely,

Stephen R. Horner
General Manager

Attachments:

1. *Investigation of the Physical and Biological Conditions Affecting Fish Passage Success at Culverts and Waterfalls. DOE/BP-36523-1*
2. *2005 Annual Report Upper Redwood Creek Juvenile Salmonid (Smolt) Downstream Migration Study, 2000-2005 Seasons Project 2a5*
3. *2005 Annual Report Lower Redwood Creek Juvenile Salmonid (Smolt) Downstream Migration Study, 2004-2005 Seasons Project 2a7*

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State of California
The Resources Agency
DEPARTMENT OF FISH AND GAME

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2005 ANNUAL REPORT

LOWER REDWOOD CREEK
JUVENILE SALMONID (SMOLT) DOWNSTREAM MIGRATION STUDY
2004 – 2005 Seasons
PROJECT 2a7

Prepared by

Michael D. Sparkman
Northern California, North Coast Region

Anadromous Fisheries Resource Assessment and Monitoring Program

September 21, 2006

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LOWER REDWOOD CREEK
JUVENILE SALMONID (SMOLT) DOWNSTREAM MIGRATION STUDY
2004 - 2005 Seasons
PROJECT 2a7 [1/]

Prepared by

Michael D. Sparkman
Northern California, North Coast Region

ABSTRACT

Juvenile anadromous salmonid trapping was conducted for the second consecutive year in lower Redwood Creek, Humboldt County, California during the spring/summer emigration period (April – August). The purpose of the study was to describe juvenile salmonid out-migration from the majority of the Redwood Creek basin, and to estimate smolt population abundances for wild 0+ Chinook salmon, 1+ steelhead trout, 2+ steelhead trout, and 1+ coho salmon using mark/recapture methods. The long term goal is to monitor the status and trends of out-migrating juvenile salmonid smolts in Redwood Creek in relation to watershed conditions and restoration activities in the basin; and to provide data needed for Viable Salmonid Population (VSP) Analysis.

A rotary screw trap was deployed on April 18th 2005 and trapped 118 d out of a possible 130 d. Days missed trapping were estimated to have negligible effects on trap captures and population estimates. The trap captured 10,827 0+ Chinook salmon, 11 1+ Chinook salmon, 1,345 0+ steelhead trout, 2,033 1+ steelhead trout, 417 2+ steelhead trout, 53 0+ coho salmon, 39 1+ coho salmon, 9 cutthroat trout, and 2 0+ pink salmon to total 14,736 individuals. Trap catches in YR 2005 were much lower (by 83%) than catches in YR 2004, with percent reductions ranging from 43 to 93% for a given species at age. Weekly trapping efficiencies averaged 11.7% for 0+ Chinook salmon, 4.4% for 1+ steelhead trout, 4.3% for 2+ steelhead trout, and 5.2% for 1+ coho salmon. The total population estimate with 95% confidence intervals was 131,164 (117,259 – 145,069) for 0+ Chinook salmon, 32,901 (24,967 – 40,835) for 1+ steelhead trout, 8,754 (4,975 – 12,533) for 2+ steelhead trout, and 183 (56 – 309) for 1+ coho salmon. Population estimates in YR 2005 were also much lower than estimates determined in YR 2004, with percent reductions ranging from 55 to 76%. The largest reduction occurred with 0+ Chinook salmon, which I attribute to: 1) high bedload mobilizing flows during egg incubation in spawning redds, 2) large decrease in adult spawners upstream of the trap site, or 3) a combination of the two factors. Peak population emigration in YR 2005 occurred during June-July for 0+ Chinook salmon, and April-May for 1+ steelhead trout, 2+ steelhead trout, and 1+ coho salmon. Weekly population emigration for each species at age followed trends of actual catches.

Twenty-seven pit tagged 0+ Chinook salmon fingerlings released at the upper trap site (RM 33) were recaptured 29 miles downstream at the second trap (RM 4) in lower Redwood Creek. Travel time ranged from 1.5 – 19.5 d and averaged 7.5 d, and travel rate ranged from 1.5 – 19.3 mi/d and averaged 8.2 mi/d. On average, 0+ Chinook salmon migrated 29 miles downstream faster than 1+ and 2+ steelhead trout did in YR 2004 and YR 2005. Fifty-two percent of the recaptured 0+ Chinook salmon fingerlings in YR 2005 showed positive growth in FL and Wt, 18% showed a decrease in Wt, 48% showed no change in FL, and 30% showed no change in Wt. Growth was positively related to travel time and travel time explained more of the variation in growth than any other variable tested. The percent change in FL ranged from 0.0 – 17.1 and averaged 3.6, and percent change in Wt ranged from - 7.7 – 46.0 and averaged 9.6. The final size of recaptured pit tagged 0+ Chinook salmon was positively related to the initial size at tagging and release.

[1/] This paper should be referenced as: Sparkman MD. 2006. Lower Redwood Creek juvenile salmonid (smolt) downstream migration study, study year 2005. CDFG, AFRAMP, Annual Report 2005 2a7: 105 p.

INTRODUCTION

This report presents results of the second consecutive year of juvenile salmonid downstream migration trapping in lower Redwood Creek, Orick, California during the spring/summer emigration period. The study was conducted by the California Department of Fish and Game's Anadromous Fisheries Resource Assessment and Monitoring Program (CDFG AFRAMP) in YRS 2004 and 2005. Funding for YR 2004 was provided by the department's Steelhead Report Card Program and AFRAMP, and in YR 2005 funding was provided by the Steelhead Report Card Program, AFRAMP, and the Federal Restoration Grant Program.

The initial impetus for this study was to determine how many wild salmon and steelhead smolts were emigrating from the majority of the Redwood Creek basin before entering the Redwood Creek estuary and Pacific Ocean. The 'majority' of the Redwood Creek basin includes all anadromous waters upstream of the first major tributary (Prairie Creek, river mile RM 3.7) to Redwood Creek. Areas downstream of Prairie Creek are generally not used for spawning by adult salmonids; thus, the only smolt production the trap will miss is from Prairie Creek. Prior to our trapping in lower Redwood Creek, Humboldt State University (YR 2001) and the United States Fish and Wildlife Service (USFWS) (YR 2003) operated a rotary screw trap in lower Redwood Creek nearby the present trapping site. Their efforts did not produce smolt population estimates but did collect data on species presence/absence, temporal distribution of out-migration, and fork lengths and weights of captured fish. In YR 2004, CDFG AFRAMP was able to successfully determine juvenile Chinook salmon and steelhead trout emigrant smolt population estimates from the majority of Redwood Creek for the first time in Redwood Creek's anadromous salmonid monitoring history. Additionally, AFRAMP and the Redwood Creek Landowners Association (RCLA) have successfully determined smolt population estimates for juvenile Chinook salmon and steelhead trout emigrating from upper Redwood Creek for the past six consecutive years (Sparkman 2005). Prior to our studies on juvenile salmonid downstream migration and smolt abundance in Redwood Creek, scientific studies which quantified anadromous salmonids within the Redwood Creek watershed were primarily limited to the estuary (juveniles) and Prairie Creek (adults and juveniles).

Adult salmon and steelhead populations are difficult to monitor in Redwood Creek because the adult fish migrate upstream during fall or late fall (dependent upon stream flow and whether the mouth is open to the ocean), winter and early spring. Thus, when the adults are present, the stream flow is often high and unpredictable, which limits the reliability and usefulness of any adult weir. Additionally, the streamflow during this time period often carries large amounts of suspended sediments, which render visual observations of adult fish and redds (eg spawning surveys) unreliable and unlikely for long term monitoring. Scientific studies which focus on salmonids in tributaries to Redwood Creek are less affected by these processes, however, the tributaries are less likely to adequately represent or account for the majority of the salmonid populations in Redwood Creek because the majority of adult salmon and steelhead spawn in the mainstem. A possible exception is the Prairie Creek watershed which probably accounts for a considerable amount of the coho salmon production in Redwood Creek. Tributaries to Redwood Creek are often steep, with limited anadromy (RNP 1997, Brown 1988). Additionally, some of the tributaries can dry up prior to late summer, which cause the juvenile fish to migrate into the mainstem of Redwood Creek.

Determining and tracking smolt numbers over time is an acceptable, useful, and quantifiable measure of salmonid populations which many agencies (both state and federal), universities, consultants, tribal entities, and timber companies perform each year. Juvenile salmonid out-migration can be used to assess: 1) the number of parents that produced the cohort (Roper and Scarnecchia 1999, Ward 2000, Sharma and Hilborn 2001, Ward et al. 2002, Bill Chesney pers. comm. 2005), 2) redd gravel conditions (Cederholm et al. 1981, Holtby and Healey 1986, Hartman and Scrivener 1990), 3) in-stream habitat quality and watershed health (Tripp and Poulan 1986, Hartman and Scrivener 1990, Hicks et al. 1991, Bradford et al. 2000, Sharma and Hilborn 2001, Ward et al. 2002), 4) restoration activities (Everest et al. 1987 *in* Hicks et al. 1991, Slaney et al. 1986, Tripp 1986, McCubbing and Ward 1997, Solazzi et al. 2000, Cleary 2001, Ward et al 2002, McCubbing 2002, Ward et al. 2003), 5) over-winter survival (Scrivener and Brown 1993 *in* McCubbing and Ward 1997, Quinn and Peterson 1996, Solazzi et al. 2000, McCubbing 2002, Ward et al. 2002, Giannico and Hinch 2003), and 6) future recruitment to adult populations (Holtby and Healey 1986, Nickelson 1986, Ward and Slaney 1988, Ward et al. 1989, Unwin 1997, Ward 2000).

Site Description

Redwood Creek lies within the Northern Coast Range of California, and flows 67 miles through Humboldt County before reaching the Pacific Ocean (Figure 1). Headwaters originate at an elevation of about 5,000 ft and converge to form the main channel at about 3,200 feet. Redwood Creek flows north to northwest to the Pacific Ocean, and bisects the town of Orick in Northern California. The basin of Redwood Creek is 179,151 acres, and about 49.7 miles long and 6.2 miles wide (Cashman et. al 1995).

Geology

The Redwood Creek watershed is situated in a tectonically active and geologically complex area, and is considered to have some of the highest uplift and seismic activity rates in North America (CDFG NCWAP 2004).

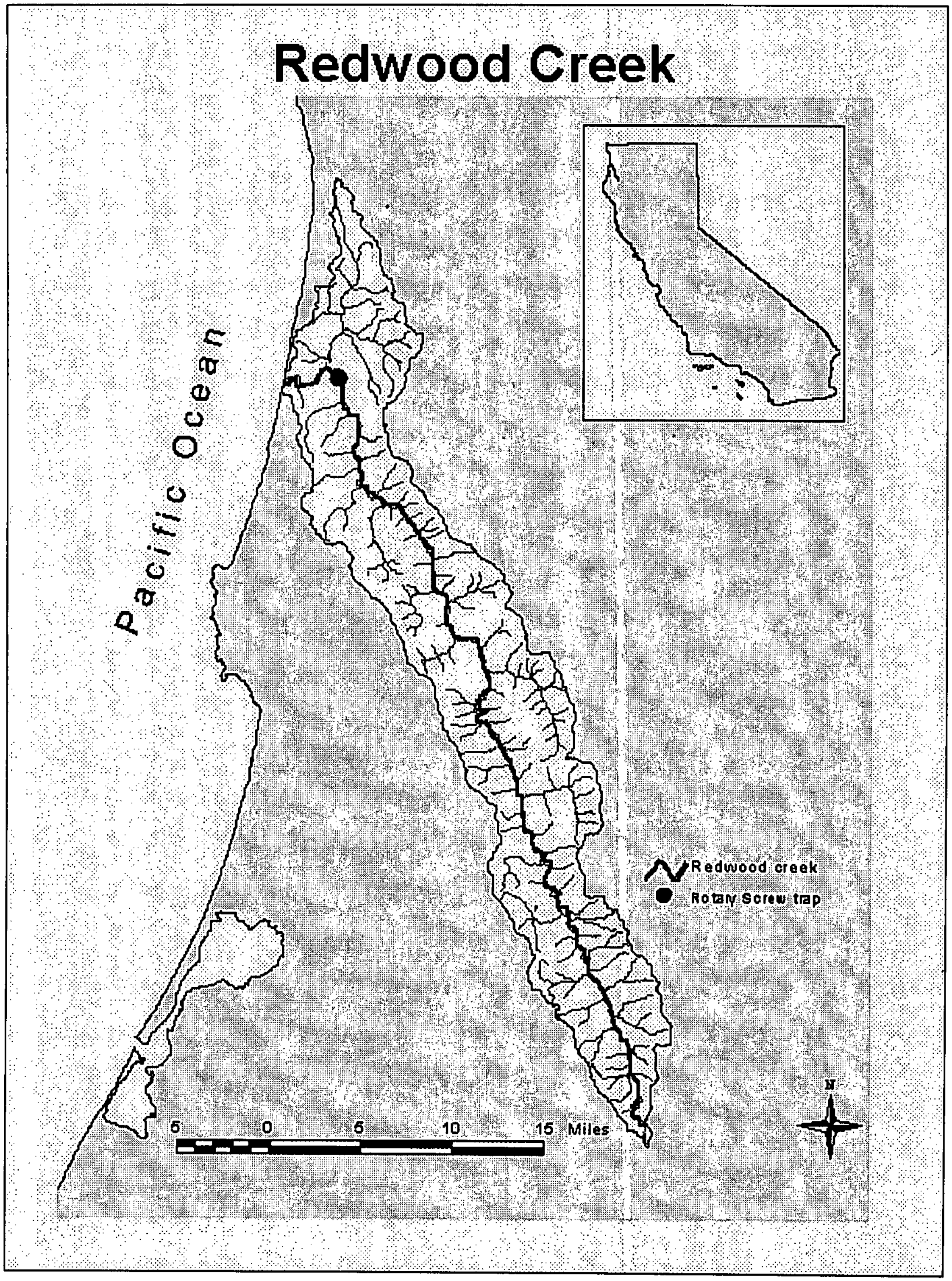

Figure 1. Redwood Creek watershed with rotary screw trap location (RM 4), Humboldt County, CA. (scale is slightly inaccurate due to reproduction process, Charlotte Peters pers. com. 2001).

The geology of the Redwood Creek basin has been well-studied and mapped (Cashman et. al 1995).

> "Redwood Creek drainage basin is underlain by metamorphic and sedimentary rocks of the Franciscan assemblage of Late Jurassic and Early Cretaceous age and by shallow marine and alluvial sedimentary deposits of late Tertiary and Quaternary age. These units are cut by a series of shallowly east-dipping to vertical north to northwest trending faults. The composition and distribution of bedrock units and the distribution of major faults have played a major part in the geomorphic development of the basin. Slope profiles, slope gradients, and drainage patterns within the basin reflect the properties of the underlying bedrock. The main channel of Redwood Creek generally follows the trace of the Grogan fault, and other linear topographic features are developed along major faults. The steep terrain and the lack of shear strength of bedrock units are major contributing factors to the high erosion rates in the basin" (Cashman et al. 1995).

Climate and Annual Precipitation

The climate of Redwood Creek basin varies dependent upon location within the watershed and season. Coastal areas have a moderate climate due to proximity to the ocean, and differ from inland areas (i.e. upper Redwood Creek) which experience higher and lower temperatures. Summers are typically cool and moist on the coast, and hot and dry inland. Snow fall is common during winter months in the upper basin and relatively rare in the lower basin.

The United States Geological Survey (USGS) operates a rain gage in lower Redwood Creek, about 850 m downstream of the current trapping site. Rainfall records cover the periods of 1987 – 2005 to total 19 years (Redwood National Park, in house data, 2005; Vicki Ozaki pers. comm. 2005). Annual precipitation ranges from 77 cm (30 in.) to 204 cm (80 in.), and averages 137 cm (54 in.). Most (91%) of the rainfall in Redwood Creek occurs from November through May, with peak monthly rainfall occurring in December and January (Appendix 1). However, in some years relatively large amounts of rainfall may occur in November, February, March (as in YR 2005), April, and May as well. Rainfall in WY 2005 (118.8 cm or 46.8 in.) was nearly equal to rainfall in WY 2004, and about 14% less than the 19 year average (Appendix 1).

The 19 year average monthly rainfall during the majority of the trapping season (April – July) totaled 24.2 cm (9.5 in.) (Table 1). Total monthly rainfall during this period of trapping in YR 2005 (39.9 cm or 15.7 in.) was 1.7 times greater than rainfall for the 19 year average, and 3.9 times greater than rainfall during the trapping season in YR 2004 (Table 1). Rainfall in April, 2005 was 1.4 times greater than the 19 year average for April; and rainfall in June 2005 was 2.1 times greater than the historic average for June (Table 1). Rainfall in May, 2005 was 6.4 times greater than rainfall in May, 2004; and rainfall in June, 2005 was 14 times greater than rainfall in June, 2004.

Table 1. Comparison of 19 year average monthly rainfall with average monthly rainfall in YR 2004 and YR 2005 during the majority of the trapping period, lower Redwood Creek, Orick, California (USGS 2005).

	Monthly Precipitation (cm)		
Month	Historic	YR 2004	YR 2005
April	12.6	7.1	17.6
May	7.8	2.4	15.3
June	3.3	0.5	7.0
July	0.4	0.1	0.0
Total:	24.2	10.2	39.9
Average:	6.0	2.5	10.0

* Data courtesy of Redwood National Park, Vicki Ozaki pers. comm. 2005.

Stream Discharge

A USGS gauging station (#11482500) is located about 850 m downstream of the trap site in lower Redwood Creek. The gauging station is downstream of the confluence of Prairie Creek with Redwood Creek, thus the station is influenced by Prairie Creek stream flow. Stream flow records for the Orick gage cover the periods of 1911 – 1913, 1953 – 2005, and total 54 years (Thomas C Haltom pers. comm. 2005; USGS 2005). High stream flows usually occur from November through May, and typically peak in January (Appendix 2). However, the months of December, February, March, and April can experience high flows as well. Using all years' data, mean monthly discharge is 1,007 cfs, and ranges from 37 – 2,496 cfs (Thomas C Haltom pers. comm. 2005, USGS 2005) (Appendix 2). Preliminary data for water year 2005 show that the average monthly discharge was 800 cfs, and ranged from 25 – 2,138 cfs. The highest average monthly discharge in WY 2005 occurred in April. Average stream discharge in WY 2005 was about 21% less than the 54 year historic average and 6% less than the average for WY 2004.

The 54 year average monthly flow during the majority of the trapping season (April – July) equaled 550 cfs, and ranged from 86 – 1,223 cfs (Thomas C Haltom pers. comm. 2005, USGS 2005) (Table 2). Average monthly discharge from April – July, 2005 (1,087 cfs) was higher than the historic average by a factor of 1.98, and higher than the average for YR 2004 by a factor of 4.25 (Table 2, data from USGS 2005). The probability of the average flow during the trapping period being greater than 1,087 cfs (based upon the 54 years of record) equaled 5.6% (USGS 2005).

Table 2. Comparison of 54 year average monthly stream discharge with average monthly discharge in WY 2004 and WY 2005 during the majority of the trapping period in lower Redwood Creek, Orick, California (USGS 2005).

	Monthly Stream Discharge (cfs)		
Month	Historic	WY 2004	WY 2005
April	1,223	602	2,138
May	636	271	1,400
June	254	109	613
July	86	41	195
Average:	550	256	1,087

Overstory

The overstory of Redwood Creek is predominately second and third growth Redwood (*Sequoia sempervirens*) and Douglas Fir (*Pseudotsuga menziesii*), mixed with Big Leaf Maple (*Acer macrophyllum*), California Bay Laurel (*Umbellularia californica*), Incense Cedar (*Calocedrus decurrens*), Cottonwood (*Populus spp.*), Manzanita (*Arctostaphylos spp.*), Oak (*Quercus spp.*), Tan Oak (*Lithocarpus densiflorus*), Pacific Madrone (*Arbutus menziesii*), and Red Alder (*Alnus rubra*). The lower portion of Redwood Creek (ie within Redwood National Park boundaries) contains old growth Redwood, mixed with second growth redwood and other tree species.

Understory

Common understory plants include: dogwood (*Cornus nuttallii*), willow (*Salix lucida*), California hazelnut (*Corylus rostrata*), lupine (*Lupinus spp.*), blackberry (*Rubus spp.*), plantain (*Plantago coronopus*), poison oak (*Toxicodendro diversilobum*), wood rose (*Rosa gymnocarpa*), false Solomon's seal (*Smilacina amplexicaulis*), spreading dog bane (*Apocynum spp.*), wedgeleaf ceanothus (*Ceanothus spp.*), bracken fern (*Pteridium aquilinum*), blackcap raspberry (*Rubus spp.*), and elderberry (*Sambucus spp.*), among other species.

Redwood Creek History (Brief)

Redwood Creek watershed has experienced extensive logging of Redwood and other commercial tree species. By 1978, 81% of the original forest was logged, totaling 66% of the basin area (Kelsey et al. 1995). Most, if not all, of the remaining old growth Redwood is contained within Redwood National Park, which is about 200 m upstream of the trap site. In conjunction with clear-cut logging, associated road building, geology types and geomorphic processes (eg debris slides and earthflows), and flood events in 1955 and 1964, large amounts of sediments were delivered into the stream channel (Madej and Ozaki 1996) with a resultant loss of stream habitat complexity (filling in of pools and flattening out of the stream channel, Marlin Stover pers. comm. 2000). Additional high flows occurred in 1972, 1975, and 1995 as well, and have helped influence the current channel morphology of Redwood Creek. The downstream migrant trap in lower Redwood Creek is located in an area of gravel aggredation.

Redwood Creek has been listed as sediment and temperature-impaired under section 303(d) of the Clean Water Act (CWA 2002; SWRCB 2003; USEPA 2003).

Federal ESA Species Status

Chinook (King) salmon (*Oncorhynchus tshawytscha*), coho (Silver) salmon (*O. kisutch*), steelhead trout (*O. mykiss*), and cutthroat trout (*O. clarki clarki*) are known to inhabit Redwood Creek. This study and the study in upper Redwood Creek also show that pink salmon (*O. gorbuscha*) are present in Redwood Creek. Chinook salmon (KS) of Redwood Creek belong to the California Coastal Chinook Salmon Evolutionarily Significant Unit (ESU), and are listed as "threatened" under the Federal Endangered Species Act (Federal Register 1999a). The definition of threatened as used by National Oceanic and Atmospheric Administration (NOAA) and the National Marine Fisheries Service (NMFS) is "likely to become endangered in the foreseeable future throughout all or a significant portion of their range" (NOAA 1999). Coho salmon (CO) belong to the Southern Oregon/Northern California Coasts ESU and were classified as "threatened" (Federal Register 1997) prior to the Chinook salmon listing. Steelhead trout (SH) fall within the Northern California Steelhead ESU, and are also listed as a "threatened" species (Federal Register 2000). Coastal cutthroat trout (CT) of Redwood Creek fall within the Southern Oregon/California Coasts Coastal Cutthroat Trout ESU, and were determined "not warranted" for ESA listing (Federal Register 1999b). Despite ESU listings of Redwood Creek anadromous salmonid populations, relatively little data exists concerning abundance and population sizes, particularly for juvenile (and adult) life history stages. Historically, the most prolific species was most likely the fall/early winter-run Chinook salmon.

Purpose

The purpose of this project is to describe juvenile salmonid downstream migration from the majority of the Redwood Creek basin, and to determine emigrant population sizes for wild 0+ (young-of-year) Chinook salmon (Ocean type), 1+ (between 1 and 2 years old) steelhead, 2+ (2 years old and greater) steelhead, and 1+ coho salmon smolts. The primary long term goal is to monitor the status and trends of out-migrating juvenile salmonid smolts in Redwood Creek in relation to watershed condition and restoration activities in the basin; and to provide data needed for Viable Salmonid Population

Viability (VSP) analysis. An additional goal is to document the presence or absence of 1+ Chinook salmon (Stream type). Specific study objectives were as follows:

1) Determine the species composition and temporal pattern of downstream migrating juvenile salmonids.
2) Enumerate species out-migration.
3) Determine population estimates for downstream migrating 0+ Chinook salmon, 1+ steelhead trout, 2+ steelhead trout, and 1+ coho salmon.
4) Record fork length (mm) and weight (g) of captured fish.
5) Investigate 0+ Chinook salmon, 1+ steelhead trout, and 2+ steelhead trout travel time and growth as they migrate from the upper trap to the lower trap (or estuary) using passive integrated transponder tags (Pit Tags).
6) Collect and handle fish in a manner that minimizes mortality.
7) Statistically analyze data for significance and trends.
8) Compare data between study years.
9) Link data collected from the lower trap, upper trap, and estuary (Redwood National Park) to provide a more complete study on the life history and abundance of emigrating juvenile salmonids (smolts) in Redwood Creek.

METHODS AND MATERIALS

Trap Operations

A stock E.G. Solutions (5 foot diameter cone) rotary screw trap was set in lower Redwood Creek (RM 4) on April 18, 2005 at the same location as in YR 2004. The trap's livebox was slightly modified by adding perforated plates (2 mm diameter) on the sides and bottom of the livebox to dissipate livebox water velocities. The debris wheel at the downstream end of the trap was made non-operational to prevent the smaller fry from being transported back into the river. The trap was located about 1/3 mile upstream of the confluence of Prairie Creek with Redwood Creek, and positioned in a run habitat type just downstream of a low gradient riffle. The trap was scheduled to be set on April 1st (same time the trap was set in YR 2004), however, continuous high stream flows precluded trap placement and deployment. The rotary screw trap was set on April 18th, and operated continually (24 hrs/day, 7 days a week) through August 26th except for 12 days (May 9, 10, 17 - 22, and June 18 - 21) due to high flow events. Trapping methods were nearly identical to those used for the upper trap (RM 33) (Sparkman 2005). During periods of high flows and debris loading in the livebox, we moved the trap to the side of the stream and raised the cone. The trap was re-set as soon as possible into the thalweg of the stream, and every attempt was made to maintain the trap's position in the thalweg. On one particular high flow event (May 17th – 22nd), the average daily stream discharge rose from 1,670 cfs to 3,530 cfs. The trap's cone was raised the previous day (May 16th) after removing fish from the livebox. Between the evening of May 18th and the morning of May 19th, a large tree (about 60 ft long) floated downstream and snagged one of the steel cables which connected the trap to the anchor (fence posts for the left side of the river). The trap, facing upstream, spun to the right and was diagonal to the current (Appendix 3). The water level was so high that the tops of the fence posts were nearly underwater. We pulled the trap to the side of the stream using a winch, and then disconnected the cable from the pontoon of the rotary screw trap. The cable then slid around the tree, and the tree floated downstream. Although the fence posts were under high pressure (from the trap and tree) and nearly underwater, they held and didn't excessively bend, break, or dislodge.

During periods of lesser stream flows, weir panels were used with the rotary screw to: 1) keep the trap's cone revolutions relatively high, and 2) maintain good trap efficiencies by directing fish into the cone area. The weir panels were set to fall down under any unexpected, high stream flows. Weir panels were first installed on July 17th, and positioned at an angle to each of the trap's pontoons. Rock weirs were used with the weir panels for the right side of the stream. Additional weir panels were later added to increase the overall length, and by August 12th, the weir panels were 66 ft long on the right bank side (includes rock weir), and 60 ft long on the left bank side (Appendix 4). Prior to the end of the study, plastic drop cloths were fastened to the weir panels to force more water into the cone area; this increased the cone revolutions greatly, and enabled trapping to the end of the catch distribution and study period.

The trapping season in YR 2005 was extended (to August 26th) compared to YR 2004 because: 1) stream flow was adequate for operating the trap, and 2) juvenile salmonids were emigrating beyond July 27th. The end date for trapping is determined by examining the catch distribution (when the right tail of the distribution nears zero), and in the case for lower Redwood Creek, stream flow. Lower Redwood Creek at the trapping site can become completely dry near the end of July or the beginning of August, thus preventing any remaining smolts from entering the estuary until rains occur. However, in YR 2005, Redwood Creek had relatively good stream flow well beyond the middle of August.

To summarize, the YR 2005 trapping season, particularly March - May, can be characterized as working in and out of high flow events and handling large amounts of debris in the livebox; and towards the end of the study, weir panels were extensively used.

Biometric Data Collection

Fishery technicians occasionally removed debris (e.g. alder cones, leaves, sticks, detritus, large amounts of filamentous green algae, etc) from within the livebox at night to reduce trap mortalities the following morning. The trap's livebox was emptied at 09:00 every morning by 2 - 4 technicians. Young of year fish were removed first and processed before 1+ and 2+ fish to decrease predation or injury to the smaller fish. Captured fish (0+ fish first, then 1+ and older) were placed into 5 gal. buckets and carried to the processing station. At the station, fish were placed into a 23.5 gal. ice chest modified to safely hold juvenile fish. The ice chest was adapted to continually receive fresh water from the stream using a 3,700 gph submersible bilge pump. The bilge pump connected to a flexible line (ID 4 cm or 1.6 in.) that connected to a manifold with four ports. "Y" type hose adapters were connected to each port. Garden hoses connected to the hose adapters, with one line feeding the ice chest, and four lines feeding recovery buckets for processed fish. Additional garden hoses were connected to the hose adaptors to quickly fill buckets if needed and to relieve any excess pressure. Plumbing inside the ice chest consisted of two PVC pipes: one that served to dissipate the stream water into the ice chest, and the other to drain excess water. The water lines to the recovery buckets were elevated above the recovery buckets so that the fresh water would also provide increased aeration. The system worked very well, did not require additional battery operated aerators, and decreased total fish processing time.

Random samples of each species at age (eg 0+ KS, 0+ SH, etc.) were netted from the ice chest for examination, enumeration, and biometric data collection. Each individual fish was counted by species at age, and observed for trap efficiency trial marks. Marked fish from the upper trap were tallied separately from the marked fish used to determine trap efficiencies for the lower trap. Every 1+ and 2+ steelhead trout captured were scanned for pit tags and observed for elastomer marks. 0+ Chinook salmon with upper caudal fin clips (secondary mark for the pit tag) were also scanned (interrogated) for pit tags.

Fork Lengths/Weights

Fish were anesthetized with MS-222 prior to data collection in 2 gal. dishpans. Biometric data collection included 30 measurements of fork length (mm) and wet weight (g) for random samples of 0+ Chinook salmon (0+ KS), 1+ Chinook salmon (1+ KS), 1+ and greater cutthroat trout (CT), 1+ steelhead trout (1+ SH); 2+ and greater steelhead trout (2+ SH), 0+ coho salmon (0+ CO), and 1+ coho salmon (1+ CO). Only fork lengths were taken from 0+ steelhead trout (0+ SH). A 350 mm measuring board ($\pm$ 1 mm) and an Ohaus Scout ll digital scale ($\pm$ 0.1 g) were used in the study. Fork lengths were taken every day of trap operation, and fork length frequencies of 0+ and older steelhead trout coho salmon, and Chinook salmon were used to determine age-length relationships at various times throughout the trapping period. Scales were occasionally read to verify age class cutoffs. 0+ Chinook salmon and 1+ steelhead trout weights were taken 2 - 4 times per week. 0+ and 1+ coho salmon and 2+ steelhead trout weights were taken nearly every day of trap operation and collection due to expected, low sample sizes. Individuals were weighed in a tared plastic pan (containing water) on the electronic scale. The scale was calibrated every day prior to data collection. After biometric data was collected, fish were placed into 5 gal. recovery buckets which received continuously pumped fresh stream water. Young of year fish were kept in separate recovery buckets from age 1+ and older fish to decrease predation or injury. When fully recovered from anesthesia, 0+ juvenile fish were transported 80 m downstream of the trap site and released in the margin of the stream; and aged 1 and older fish were transported 125 m downstream of the trap site and released near the middle of the stream.

Developmental Stages

We visually determined developmental stages (e.g. parr, pre-smolt, smolt) for every 1+ Chinook salmon, 1+ steelhead trout, 2+ steelhead trout, 1+ coho salmon, and 1+ (and greater) cutthroat trout captured using the following criteria:

- Parr designated fish that had obvious parr marks present and no silvering of scales.

- Pre-smolt designated individuals with less obvious parr marks, showed some blackening of the caudal fin, and were in the process of becoming silver colored smolts. Pre-smolt was considered in-between parr and smolt.

- Smolt designated fish that were very silver in coloration (i.e. smoltification), had little to no parr marks present, and had blackish colored caudal fins.

Discerning developmental stages is subjective; however, I attempted to minimize observer bias by individually training (and checking) each crew member and having all crew members follow the same protocol. The most difficult stages to separate were for those fish which fell between smolt and pre-smolt.

Population Estimates

The number of fish captured by the trap represented only a portion of the total fish moving downstream in that time period. Total salmonid out-migration estimates (by age and species) were determined on a weekly basis for 0+ Chinook salmon, 1+ steelhead trout, 2+ steelhead trout, and 1+ coho salmon using mark-recapture methodology described by Carlson et al. (1998). The population estimate for 2+ steelhead trout in YR 2004 was re-calculated on a weekly basis to compare with the estimate in YR 2005. The new point estimate fell within the 95% confidence interval for the original estimate, and is considered more realistic and less biased (with few recaptures population models may overestimate population size).

The approximately unbiased estimate equation for a 1-site study was used to determine total population size (U_h) in a given capture and trapping efficiency period (h). Variance was computed, and the value was used to calculate 95% confidence intervals (CI) for each weekly population estimate. The weekly population estimate (U_h) does not include catches of marked releases in the "C" component (or 'u_h') of the equation, and any short term handling mortality was subtracted (Carlson et al. 1998). Trap efficiency trials were conducted one to six times a week for 0+ Chinook salmon, 1+ Chinook salmon, 1+ steelhead trout, 2+ steelhead trout, and 1+ coho salmon. Data was combined and run through the equation to determine the weekly estimate (for a complete description of estimation methods and model assumptions see Sparkman 2004a). The Carlson et al. (1998) model and my methods were (favorably) peer reviewed in 2003 (Phil Law, CDFG Biometrician, pers. comm. 2003).

Partial fin clips were used to identify trap efficiency trial fish by squaring the round edge (or tip) of a given fin (caudal, pectoral) with scissors. Fish used in efficiency trials were given partial fin clips while under anesthesia (MS-222), and recovered in 5 g buckets which received fresh stream water (via the plumbing system). Clip types for 0+ Chinook salmon, 1+ steelhead trout and 2+ steelhead trout were different than those used at the upper trap. Clips for 2+ steelhead trout were stratified by week such that marked fish of one group (or week) would not be included in the following weekly calculation (however, no out of strata captures occurred in YR 2004, nor in YR 2005). I did not stratify clips for 0+ Chinook and 1+ steelhead trout because four years of data (when I did stratify clips) at the upper trap showed that nearly all of the recaptures (99.4%) occurred in the correct strata. The few fish that were recaptured out of strata had little to no effect on the weekly and total population estimates (Phil Law, personal comm. 2003). 0+ Chinook salmon, 1+ Chinook salmon, 1+ steelhead trout, and 1+ coho salmon were given lower caudal partial fin clips, and 2+ steelhead trout were given right or left pectoral partial fin clips. Once recovered from anesthesia, the fish were placed in mesh cages in the stream for at least 1 - 2 hrs to test for short term delayed mortality (Carlson et al. 1998). Fin clipped 0+ Chinook salmon were released in fry habitat 183 m upstream of the trap, and clipped 1+ and 2+ steelhead trout, 1+ coho salmon and 1+ Chinook salmon were released into a pool (with woody debris) 152 m upstream of the trap. Fin clipped fish were released upstream of the trap after the livebox was emptied (eg 1300 – 1800), and in some instances, the fish were manually released at night. Night releases were conducted to possibly increase the catch of efficiency trial marked fish, however, trap efficiencies for night releases did not significantly vary from day releases.

Additional Experiments

Re-migration

In YR 2004, we marked and released 223 2+ steelhead trout and 577 1+ steelhead trout at the upper trap site with a plastic elastomer (Northwest Marine Technology, P.O. Box 427, Ben Nevis Loop Road, Shaw Island, Washington 98286 USA) to investigate travel time between the upper trap (RM 33) and lower trap (RM 4) in Redwood Creek. These marks also served to show if the marked fish residualized in the stream in YR 2004 to be later caught as 2 or 3 year old fish migrating downstream in YR 2005. Every 1+ and 2+ steelhead trout captured at the lower trap in YR 2005 were examined for elastomer marks. Mark retention was assumed to be nearly 90% within 16 months (Fitzgerald et al. 2004).

Travel Time and Growth

We marked 37 2+ steelhead trout and 146 1+ steelhead trout at the upper trap site with plastic elastomer in YR 2005 to investigate travel time from the upper trap to the lower trap (a distance of 29 miles). We applied the elastomer marks subdermally using a hypodermic needle on the underside of both lower jaws while fish were under anesthesia (MS-222). 0+ Chinook salmon were generally too small to safely mark. Marked fish were treated as batches, with a unique color combination for each week of release. Partial fin clips (upper caudal) were applied to each elastomer marked fish in order to discern elastomer mark releases in YR 2004 from YR 2005. Although some of the YR 2004 elastomer marked juveniles also had partial upper caudal fin clips, the fins should have regenerated by YR 2005. Each batch of marked fish was held in the stream for 24 hours (at the upper trap site) to test for any delayed mortality prior to release, and released into the stream at the upper trap's downstream release site.

Plastic elastomer has limitations because individual fish cannot be uniquely identified when marks are used for batches of fish, and the mark is rather difficult to apply for fish under 80 mm (FL). Pit tags offer the ability of individual recognition by using numbers unique to each tag (and marked fish). In YR 2005 we used Pit Tags to investigate both travel time and growth of tagged fish as they migrated downstream from the upper trap and captured at the lower trap or estuary (David Anderson, pers. comm. 2005). We found pit tagging to be easier and faster than applying elastomer. A more thorough examination of the pit tag data and subsequent results is forthcoming (Sparkman, In progress).

Pit tags used in the study were 11.5 mm long x 2 mm wide, and weighed 0.09 g (ALLFLEX USA, Inc., PO BOX 612266, Dallas/Ft Worth Airport, Texas). Pit tags were applied to randomly selected 1+ steelhead trout (n = 147), 2+ steelhead trout (n = 46) and 0+ Chinook salmon smolts (FL ≥ 70 mm, n = 555) using techniques shown by Seth Ricker (CDFG, pers. comm. 2005). The number of pit tag groups released downstream was 21 for 0+ Chinook salmon, 13 for 1+ steelhead trout, and 17 for 2+ steelhead trout. Fish were anesthetized with MS-222, and measured for FL (mm) and Wt (g) prior to tagging. A scalpel (sterilized with a 10:1 solution of water to Argentyne; Argent Chemical Laboratories, 8702 152nd Ave. N.E., Redmond, WA, 98052) was used to make a small incision (2 - 3 mm long) into the body cavity just posterior (about 3 - 5 mm) to a pectoral fin. The incision was dorsal to the ventral most region of the fish to help prevent the tag from exiting the incision. Tags were also sterilized with Argentyne, and then inserted by hand into the body cavity via the incision. Glue was not used to close the incision after tag placement because previous experience with tagging showed it was unnecessary (Seth Ricker, pers. comm. 2005). Pit tagged 0+ Chinook salmon were also given a small partial upper caudal fin clip to aid in recognizing a tagged fish so that technicians at the lower trap and estuary did not have scan every 0+ Chinook salmon they captured. Some of the 1+ and 2+ steelhead trout also had partial fin clips because we tagged recaptures from trap efficiency trials to increase sample size. After tag application, fish were held in a livecar in the stream for a period of 34 hrs to test for delayed mortality. 0+ Chinook salmon were kept separately from 1+ and 2+ steelhead trout. All pit tagged fish were manually released at night downstream of the upper trap site. Field crews at the upper trap, lower trap, and estuary had hand held pit tag readers (ALLFLEX USA, Inc., PO BOX 612266, Dallas/Ft Worth Airport, Texas) so that they could scan and identify pit tagged fish; and perform necessary fork length and weight measurements.

Physical Data Collection

A staff gage with increments in hundredths of a foot was used to measure the relative stream surface elevation (hydrograph) at the trap site from April 19th – August 26th, 2005. The gage was read every morning at 0900 to the nearest one-hundredth of a foot prior to biometric data collection. A graphical representation of the data, along with average daily stream discharge data from the O'Kane gaging station (USGS 2005), is given in Appendix 5.

Stream temperatures were recorded with an Optic StowAway® Temp data logger (Onset Computer Corporation, 470 MacArthur Blvd. Bourne, MA 02532) placed behind the rotary screw trap. A second probe was deployed at the same location for comparison. Both probes gave similar results (Ave. = 14.7 °C), therefore only data from one probe is reported. The probes were placed into a PVC cylinder with holes to ensure adequate ventilation and to prevent influences from direct sunlight. Probes were set to record stream temperatures (°C) every 60 minutes and recorded about 3,700 measurements per probe over the course of the study. The shallowest stream depth during which measurements were taken (in August) was about three feet. The maximum weekly average temperature (MWAT) and maximum weekly maximum temperature (MWMT) for YRS 2001 - 2005 were determined following methods described by Madej et al. (2005). MWAT is defined as the maximum value of a 7-day moving average of daily average stream temperatures, and MWMT is the maximum value of a 7-day moving average of daily maximum stream temperatures (Madej et al. 2005).

Statistical Analyses

Numbers Cruncher Statistical System software (NCSS 97) (Hintze 1998) was used for linear correlation, regression/ANOVA output, single factor ANOVA, chi-square, and descriptive statistics.

Linear regression was used to estimate the catch for each species at age for days when the trap was not operating by using data before and after the missed day(s) catch. The estimated catch (except for 0+ steelhead) was then added to the known catch in a given stratum and applied to the population model for that stratum (Roper and Scarnecchia 1999).

Linear correlation was used to determine if weekly trapping efficiencies for 0+ Chinook salmon, 1+ steelhead trout, and 2+ steelhead trout changed over time (weeks). Regression was used to test for influences of physical variables (average weekly gage height and average weekly stream discharge) on weekly trapping efficiencies for a given species at age. Regression and correlation models did not include any combination of the independent variables (eg average temperature, average daily discharge, gage height, and trapping week number) in a given model or test because they were highly correlated with one-another (Correlation, $p < 0.00005$, r ranged from 0.79 – 0.95).

The 0+ Chinook salmon population estimate was partitioned into classes of fry (newly emerged and post-emergent fry, FL < 45 mm) and fingerlings (FL > 44 mm) each week of a given year using fork lengths and weekly population estimates. The percentage of juvenile Chinook salmon per size class each week was then multiplied by the corresponding weekly population estimate (which included recaptures of marked fry and fingerlings) to estimate the population of fry and fingerlings. The FL cutoff between fry and fingerlings was determined by examining FL histograms from six years of trapping in upper Redwood Creek (FL nadir ranged from 42 – 45 mm, mean = 44 mm) and two years of trapping in lower Redwood Creek (FL nadirs = 43 and 44mm, mean = 43.5 mm), from trapping Chinook salmon redds in Prairie Creek (emergent fry fork length per redd (n = 4) ranged from 35 – 43, and averaged 39 mm) (Sparkman 1997 and 2004b), and from information gathered in the literature (Allen and Hassler 1986, Healey 1991, Bendock 1995, Seiler et al. 2004). Allen and Hassler (1986) summarized that newly emerged Chinook salmon fry range from 35 – 44 mm FL, Healey (1991) reported that Chinook salmon fry FL's normally range from 30 – 45 mm, Bendock (1995) used a FL ≤ 40 mm for fry, and Seiler et al. (2004) used a fry cutoff of 40 mm FL. Therefore, the 45 mm FL cutoff for fry in Redwood Creek was similar to that used in other studies.

Regression and correlation were also used to test for influences of average weekly stream temperature, stream discharge, gage height, and trapping week number on population emigration by week for 0+ Chinook salmon, 1+ steelhead trout, 2+ steelhead trout, and 1+ coho salmon. As in previous tests, combinations of independent variables were not included in the model due to high correlations.

Descriptive statistics were used to characterize the mean FL (mm) and Wt (g) of each species at age on a study year and weekly basis. Linear correlation was used to test if the average weekly FL and Wt of each species at age increased, decreased or didn't change over the study period in YR 2004 and YR 2005 (excluding 0+ steelhead weight). The lack of data in any given week was due to: 1) differences in trap deployment time among study years, 2) no catches occurred, or 3) sample size was too low to generate a reliable average. Single factor ANOVA (or non-parametric equivalent, Kruskal-Wallis One-Way ANOVA on Ranks) was used to test for significant variation in weekly FL's and Wt's among study years 2004 and 2005.

I determined a ' rough' estimate of growth rate in FL and Wt for 0+ Chinook salmon and 0+ steelhead trout in YR 2004 and YR 2005 generally following methods by Bendock (1995). I used the first weekly average in FL and Wt with a sample size ≥ 25 and the last weekly average in the season with a sample size greater than ≥ 25. The first average was subtracted from the last average, and divided by the number of days from the first day after the weekly average to the last day of the last weekly average. For example, in YR 2005 growth in FL was calculated by subtracting 49.1 mm (Ave. for 4/16 – 4/22) from 95.3 mm (Ave. for 8/20 – 8/26) and then dividing by 126 days. Thus, the growth rate would cover the period of 4/23 – 8/26. The resultant growth rate is not an individual growth rate, but more of a 'group' growth rate. The calculated values were then compared to values put forth by Healey (1991) and Bendock (1995) for juvenile Chinook salmon in other streams.

Chi-square was used to test for differences in the proportions of pre-smolt and smolt designations for captured 1+ steelhead trout and 2+ steelhead trout in YR 2005 with captures in YR 2004. Parr stage was not included in the tests because at least one of the values in the contingency tables was less than 5, which can cause the tests to be inaccurate (NCSS 97).

Descriptive statistics were used to characterize FL, Wt, travel time (d), travel rate (mi/d), and various growth indices (Percent Change in Growth, Absolute Growth Rate, Specific Growth Rate, and Relative Growth Rate) for all pit tagged fish recaptured at the lower trap. Average growth values were also determined for recaptured pit tagged fish that showed positive (excludes negative and zero growth) and negative (excludes positive and zero growth) growth. The weight of the pit tag (0.09 g) was subtracted from the final recorded weight to obtain the true weight of the fish. Measurement uncertainties for FL and Wt were assumed to be $\pm$ 1 mm and $\pm$ 0.1 g, therefore final FL's and Wt's needed to be greater than the initial FL and Wt by this amount to constitute a real change in size.

Travel time is defined as the difference (in days) from the recapture date to initial release date, and equals the period of growth for recaptured individuals. Since pit tagged fish were released at night (eg 2100) and recaptured at some date in the morning by the lower trap (when the crew checks the trap at 0900) the earliest recorded travel time could be 0.5 days (or 12 hours). Travel rate is the travel time divided by 29 miles (the distance between the upper and lower traps). For the following equations, t_1 is the initial date, t_2 is the ending or recapture date, Y_1 is fish size at t_1, and Y_2 is the fish size at t_2 (Busacker et al. 1990).

Percent change in growth is defined as (Busacker et al. 1990):

1) $\% \text{ change in growth} = ((Y_2 - Y_1)/ Y_1) \times 100$

Absolute growth rate (AGR) is defined as (Busacker et al. 1990):

2) $\text{Absolute growth rate} = (Y_2 - Y_1)/(t_2 - t_1)$

where $t_2 - t_1$ equals the number of days from initial release (at the upper trap) to subsequent recovery at the lower trap. Thus, absolute growth rate is expressed as mm per day or g per day.

Specific growth rate (SGRsc) is defined as (Busacker et al. 1990):

3) $\text{Specific growth rate (scaled)} = [(\log_e Y_2 - \log_e Y_1)/(t_2 - t_1)] \times 100$

Specific growth rate is expressed as a scaled number (by multiplying specific growth by 100). Thus, if the specific growth rate scaled equaled 0.741 %(mm per day), the un-scaled value would equal 0.00741 mm per day.

Relative growth rate (RGR) is defined as (Busacker et al. 1990):

4) Relative Growth Rate = $(Y_2 - Y_1)/[Y_1(t_2 - t_1)]$

Relative growth rate is a growth rate that is relative to the initial size of the fish, and units for FL are in mm/mm/d and for Wt are in g/g/d. Therefore, if the relative growth rate equaled 0.003 mm/mm/d, then we would say that the fish grew 0.003 mm per mm of fish per day.

Travel time, travel rate, and growth for all recaptured pit tagged 0+ Chinook salmon smolts (n = 27) were modeled using linear regression. These parameters for 1+ and 2+ steelhead trout could not be modeled due to low recaptures. Independent variables for travel time and travel rate (dependent variables in this case) included fish size at time 1 or time 2, water temperature during a specific migration period (average of data from both traps), and stream discharge during a specific migration period (average of data from both traps). Independent variables for modeling growth (dependent variable) included travel time, travel rate, average water temperature, and average stream discharge. Stream temperature and stream discharge were not included together in any regression models because they were highly correlated ($p < 0.001$). During the travel time and growth experiments (6/3 – 8/10), average daily stream temperatures at the upper trap site ranged from 11.0 – 22.4 °C (51.8 – 72.3 °F) and average daily stream discharge ranged from 13 - 309 cfs. Average daily stream temperatures at the lower trap site ranged from 12.2 – 20.0 °C (54.0 – 68.0 °F) and average daily stream discharge ranged from 63 - 1,620 cfs. Thus, the experiments were conducted over a fairly wide range in values for discharge and stream temperature.

Minimum, average, and maximum stream temperatures for each day during the trapping period were determined from data collected by the temperature probes. Descriptive statistics were used to determine the average stream temperature during the course of the study. Single factor ANOVA was used to test for significant variation in average monthly stream temperature among YR 2004 and YR 2005; and for variation among average daily stream temperature among study years. Tests utilized truncated and non-truncated data. Data was truncated to match the period (dates) of measurements each year for a more equivalent comparison. Linear correlations were used to test if the average daily (24 hour) stream temperature increased or decreased over the study period in YRS 2004 and 2005. Regression was used to examine the relationship of the daily stream gage height on average daily stream temperature in YR 2005.

If data violated tests of statistical assumptions, data was transformed with Log (x+1) to approximate normality (Zar 1999). For tests involving ANOVA, the non-parametric equivalent was used (Kruskal-Wallis One-Way ANOVA on Ranks). Power is defined as the probability of correctly rejecting the null hypothesis when it is false (Zar 1999). The level of significance (Alpha) for each statistical test was set at 0.05.

RESULTS

The rotary screw trap could not be deployed on April 1st as in study YR 2004 because of continuous high flow events (Appendix 5). The rotary screw trap was set on April 18th, operated from 4/18/05 - 8/26/05, and trapped 118 nights out of a possible 130. Excluding the initial 17 days of missed trapping, the trapping rate in YR 2005 was 91% compared to 97% for YR 2004. Days missed trapping in YR 2005 occurred in May (n = 8), and June (n = 4).

Species Captured

Juvenile Salmonids

Species captured in YR 2005 included: juvenile Chinook salmon (*Oncorhynchus tshawytscha*), juvenile coho salmon (*O. kisutch*), juvenile steelhead trout (*O. mykiss*), coastal cutthroat trout (*O. clarki clarki*), and juvenile pink salmon (*O. gorbuscha*). A total of 14,746 juvenile salmonids were captured in YR 2005 (Figure 2).

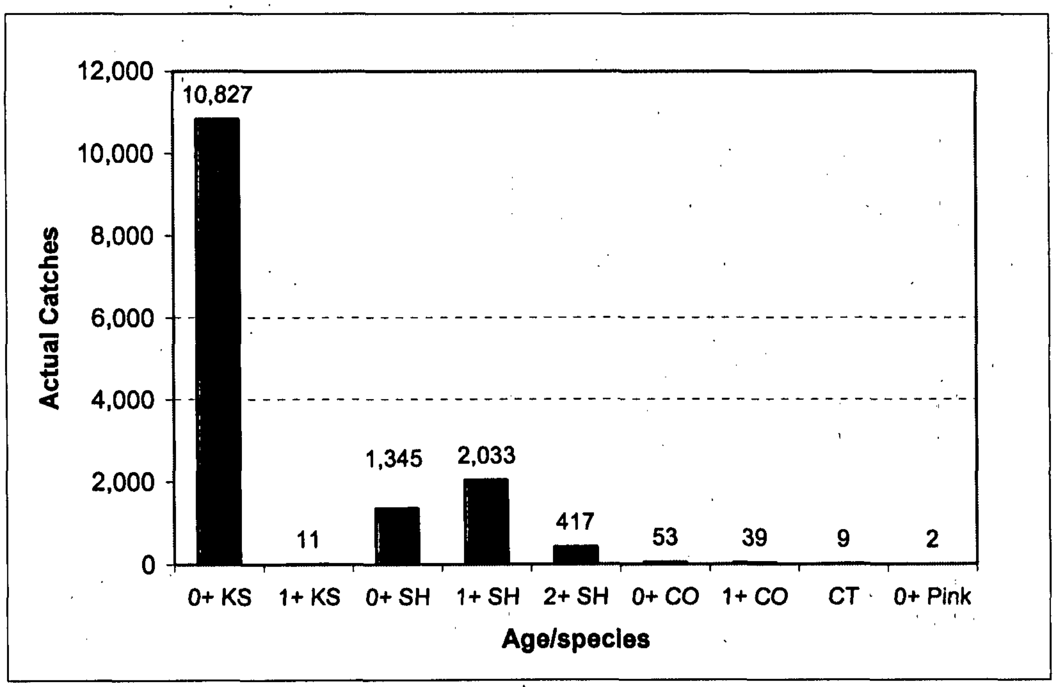

Figure 2. Total juvenile salmonid trap catches (n = 14,746) from April 19th through August 26th, 2005, lower Redwood Creek, Humboldt County, CA. Numeric values above columns represent actual catches. 0+ KS = young-of-year Chinook salmon, 1+ KS = age 1 Chinook salmon, 0+ SH = young-of-year steelhead trout, 1+ SH = age 1 and older steelhead trout, 2+ SH = age 2 and older steelhead trout, CT = cutthroat trout, 0+ Pink = young-of-year pink salmon.

Trap catches of juvenile salmonids in YR 2005 were much less (83%) than trap catches in YR 2004 (Table 3). The greatest reduction in catches in YR 2005 occurred with 0+ steelhead trout (93%) and 0+ Chinook salmon (82%). 1+ Chinook salmon trap catches in YR 2005 was 5.5 times greater than in YR 2004.

Table 3. Comparison of juvenile salmonid trap catches in YR 2004 with YR 2005, lower Redwood Creek, Humboldt County, CA.

	Actual Catches		
Age/species*	YR 2004	YR 2005	Percent reduction in YR 2005
0+ KS	61,778	10,827	82.5
1+ KS	2	11	-
0+ SH**	18,642	1,345	92.8
1+ SH	6,371	2,033	68.1
2+ SH	907	417	54.0
0+ CO	202	53	73.8
1+ CO	69	39	43.5
CT	37	9	75.7
0+ Pink	NC***	2	-
Total:	88,088	14,736	83.3

* Age/species definitions are the same as in Figure 2.
** Includes a small, but unknown percentage of young-of-year cutthroat trout.
*** Denotes not counted.

Miscellaneous Species

The trap caught numerous species besides juvenile anadromous salmonids in YR 2005, including: prickly sculpin (*Cottus asper*), coast range sculpin (*Cottus aleuticus*), sucker (*Catostomidae* family), three-spined stickleback (*Gasterosteus aculeatus*), juvenile (ammocoete) lamprey and adult Pacific Lamprey (*Entosphenus tridentatus*) (Table 4).

Amphibian catches included coastal (Pacific) giant salamander (*Dicamptodon tenebrosus*), rough skinned newt (*Taricha granulosa granulosa*), red legged frog (*Rana aurora draytonii*), and tailed frog tadpole (*Ascaphus truei*) (Table 4). Numerous aquatic and semi-aquatic invertebrates were also captured in the trap.

Table 4. Comparison of miscellaneous species captured in YR 2004 with catches in YR 2005, lower Redwood Creek, Humboldt County, CA.

	Number Captured	
Species Captured	YR 2004	YR 2005
Prickly Sculpin	68	140
Coast Range Sculpin	502	212
Sucker	156	89
3-Spined Stickleback	7,225	215
Adult Pac. Lamprey	13	3
Juvenile Lamprey	154	84
Possible River Lamprey	0	0
Pac. Giant Salamander	4	8
Painted Salamander	0	0
Rough Skinned Newt	2	3
Red-Legged Frog	0	2
Yellow-Legged Frog	0	0
Tailed Frog	0	1

Juvenile Salmonid Captures

Catches of 0+ Chinook salmon, 0+ steelhead trout, 1+ steelhead trout, 2+ steelhead trout, 0+ coho salmon and 1+ coho salmon in YR 2005 were variable over time, with apparent multi-modal catch distributions for each species at age.

0+ Chinook salmon daily catches in YR 2005 (Total = 10,827) ranged from 0 - 581 individuals, and averaged 91 fish per day. Daily catches in YR 2004 (Total = 61,778) ranged from 0 – 2,196 and averaged 547 per day. Daily 0+ Chinook salmon captures in YR 2005 expressed as a percentage of total 0+ Chinook salmon catch in YR 2005 ranged from 0.0 – 5.4%, and averaged 0.8%. The peak catch in YR 2005 occurred on 7/18/05 compared to 6/17/04 in YR 2004.

0+ steelhead trout daily catches in YR 2005 (Total = 1,345) ranged from 0 - 119 individuals, and averaged 11 per day. Daily catches in YR 2004 (Total = 18,642) ranged from 0 – 639 and averaged 154 per day. Daily 0+ steelhead captures in YR 2005 expressed as a percentage of total 0+ steelhead catch in YR 2005 ranged from 0.0 – 8.8% and averaged 0.8%. The peak catch in YR 2005 occurred 5/08/05 compared to 6/11/04 in YR 2004.

1+ steelhead trout daily catches in YR 2005 (Total = 2,033) ranged from 0 - 94, and averaged 17 per day. Daily catches in YR 2004 (Total = 6,371) ranged from 0 – 213 and averaged 56 per day. Daily 1+ steelhead trout captures in YR 2005 expressed as a percentage of total 1+ steelhead trout catch in YR 2005 ranged from 0.0 - 4.6% and averaged 0.8%. The peak catch in YR 2005 occurred on 5/3/05 compared to 5/29/04 in YR 2004.

2+ steelhead trout daily catches in YR 2005 (Total = 417) ranged from 0 - 27, and averaged three individuals per day. Daily catches in YR 2004 (Total = 907) ranged from 0 – 39 and averaged eight per day. Daily 2+ steelhead trout captures in YR 2005 expressed as a percentage of total 2+ steelhead trout catches in YR 2005 ranged from 0.0 – 6.5%, and averaged 0.8%. The peak catch in YR 2005 occurred on 5/03/05 compared to 5/16/04 in YR 2004.

0+ coho salmon daily catches in YR 2005 (Total = 53) ranged from 0 - 3 individuals, and averaged 0.4 fish per day. Daily catches in YR 2004 (Total = 202) ranged from 0 – 15 and averaged 2 per day. Daily 0+ coho salmon captures in YR 2005 expressed as a percentage of total 0+ coho salmon catch in YR 2005 ranged from 0.0 – 5.7% and averaged 0.8%. Peak catches in YR 2005 occurred 6/24/05, 7/19/05 and 7/27/05 compared to 7/18/04 in YR 2004.

1+ coho salmon daily catches in YR 2005 (Total = 39) ranged from 0 - 7 individuals, and averaged 0.3 fish per day. Daily catches in YR 2004 (Total = 69) ranged from 0 – 7 and averaged 0.6 fish per day. Daily 1+ coho salmon captures in YR 2005 expressed as a percentage of total 1+ coho salmon catch in YR 2005 ranged from 0.0 – 18.0% and averaged 0.8%. Peak catches in YR 2005 occurred 5/06/05 compared to 4/16/04 in YR 2004.

Days Missed Trapping

The trap was not set on April 1st (as in YR 2004) and therefore initially lacked 17 days of trapping. In YR 2004, trap catches during these 17 days equaled 12% of the total catch for 0+ Chinook salmon, 0% for 1+ Chinook salmon, 3% for 0+ steelhead trout, 7% for 1+ steelhead trout, 11% for 2+ steelhead trout, 3% for 0+ coho salmon, 26% for 1+ coho salmon, and 5% for cutthroat trout. At the population level in YR 2004, trap catches during the 17 days expanded to 10% of the total population estimate for 0+ Chinook salmon, 3.4% for 1+ steelhead trout, 11% for 2+ steelhead trout, and 13% for 1+ coho salmon.

Twelve days were not trapped (after trap deployment) in YR 2005 due to high flow events and high debris loads in the livebox. Days missed trapping did not appear to influence the total catch or population estimate of 0+ Chinook salmon, 1+ steelhead trout and 2+ steelhead trout to any large degree (Table 5). However, an estimated 14% of the 1+ coho salmon population and 15% of the 0+ steelhead trout catch would have been missed if the estimated catches were not added to the known or actual catches in the population model.

Table 5. The estimated catch and expansion (population level) of juvenile anadromous salmonids considered to have been missed due to trap not being deployed (n = 12 d) during the emigration period of April 19th through August 26th (as a percentage of total without missed days in parentheses), lower Redwood Creek, Humboldt County, CA., 2005.

Age/spp.*	Catch	Population Level
0+KS	466 (4.3%)	3,815 (3.0%)
1+KS	0 (0.0%)	-
0+ SH	204 (15.1%)	-
1+ SH	100 (4.9%)	1,222 (3.9%)
2+ SH	30 (7.2%)	351 (4.0%)
0+CO	4 (7.5%)	-
1+CO	5 (12.8%)	40 (21.9%)
CT	0 (0.0%)	-

* Age/species abbreviations are the same as in Figure 2.
Note: Regression methods were used to estimate the number of fish caught when the trap was not operating. The estimated catches were then added to the known catches for a given stratum (week) and used in the population estimate for that stratum (Roper and Scarnecchia 1999).

0+ Chinook salmon

0+ Chinook salmon were captured in each week during the trapping period in YR 2005 (Figure 3). Peak catches in YR 2005 occurred during the week of 7/16 – 7/22, with a smaller peak occurring 6/4 – 6/10; peak catches in YR 2004 occurred during 6/18 – 6/24 and 4/9 – 4/15. The pattern of catches over time showed emigration in YR 2005 was extended beyond the ending date for YR 2004.

Catches by month (not shown) also show the between-year variation in the catch distribution; the highest percentage of the total catch in YR 2005 occurred in July (61%) compared to June (47%) in YR 2004. The months of June and July accounted for 83% of the total catch in YR 2005, compared to May and June, 2004 which accounted for 79% of the total catch.

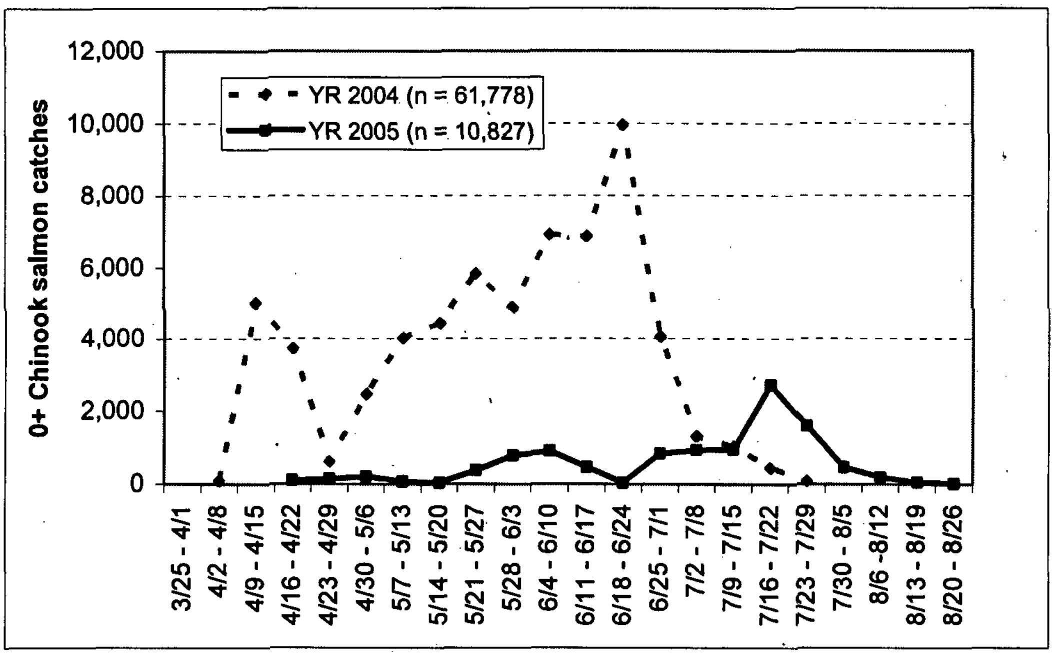

Figure 3. Comparison of 0+ Chinook salmon captures by week in YR 2005 with catches in YR 2004, lower Redwood Creek, Humboldt County, CA.

1+ Chinook salmon

1+ Chinook salmon catches were low in each study year, however catches in YR 2005 were much higher than in YR 2004 (Figure 4). 1+ Chinook salmon were captured in four of the 19 weeks of trap operation in YR 2005. Peak catches in YR 2005 occurred during 4/30 – 5/6, compared to 5/7 – 5/14 in YR 2004. 1+ Chinook salmon were captured in April and May in YR 2005, and May in YR 2004.

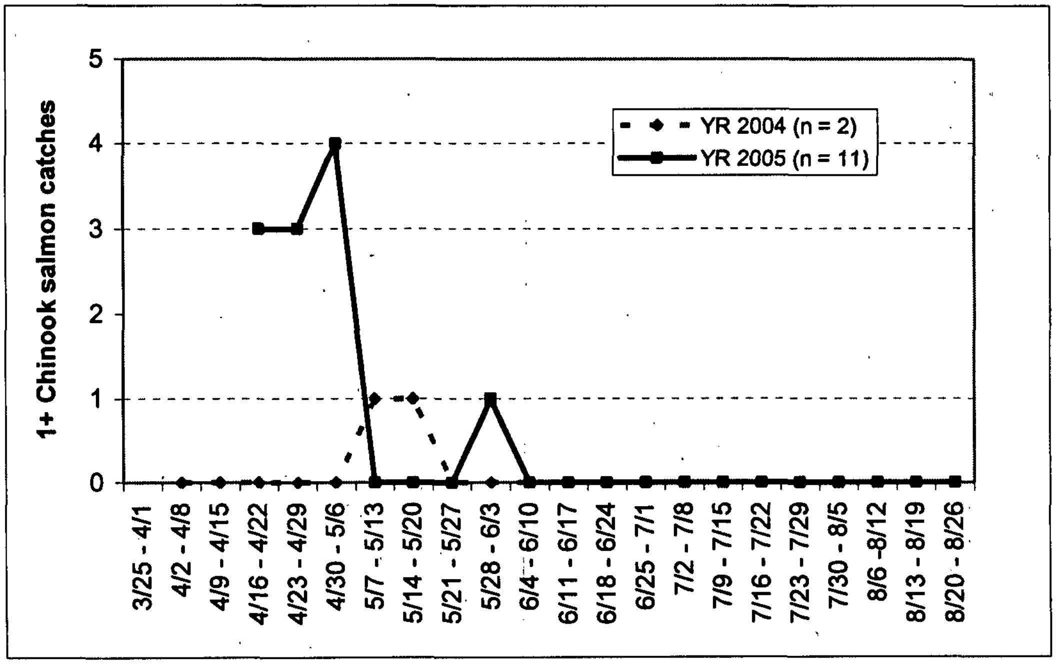

Figure 4. Comparison of 1+ Chinook salmon catches in YR 2005 with catches in YR 2004, lower Redwood Creek, Humboldt County, CA.

0+ Steelhead trout

0+ steelhead trout were captured in each week during the trapping period in YR 2005 (Figure 5). Trap catches peaked during 5/7 – 5/13 in YR 2005 and 6/11 – 6/17 in YR 2004. On a monthly basis, the greatest number of catches occurred in May (n = 515 or 38% of total) in YR 2005, and June (n = 9,947 or 53% of total) in YR 2004. The months of May and July accounted for 65% of the total catch in YR 2005, compared to June and July, 2004, which accounted for 80% of the total catch.

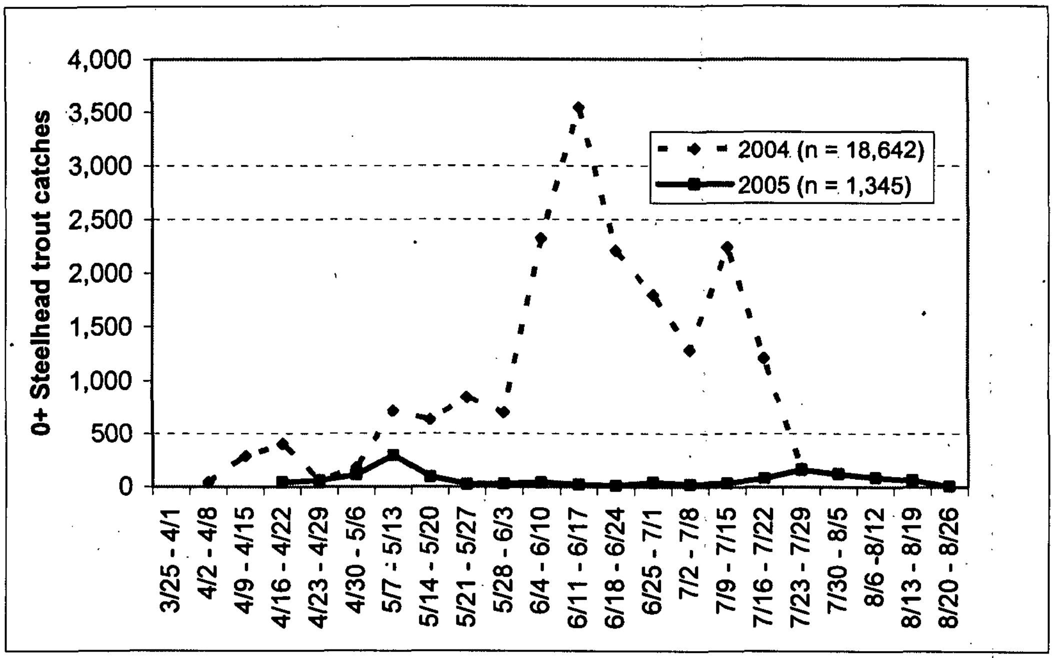

Figure 5. Comparison of 0+ steelhead trout captures in YR 2005 with catches in YR 2004, lower Redwood Creek, Humboldt County, CA.

1+ Steelhead trout

1+ steelhead trout were captured in each week during the trapping period in YR 2005 (Figure 6). Trap catches peaked during 4/23 – 5/6 in YR 2005, with smaller peaks occurring 5/28 – 6/3 and 7/30 – 8/5; in YR 2004, trap catches peaked during 5/14 – 5/20. Catches in four weeks in YR 2005 matched weekly catches in YR 2004 (Figure 6). The pattern of catches over time showed emigration in YR 2005 was extended beyond the ending date for YR 2004.

On a monthly basis, the greatest number of catches occurred in April (n = 690 or 34% of total) in YR 2005, and May (n = 3,004 or 47% of total) in YR 2004. The months of April and May accounted for 63% of the total catch in YR 2005, compared to May and June, 2004 which accounted for 75% of the total catch.

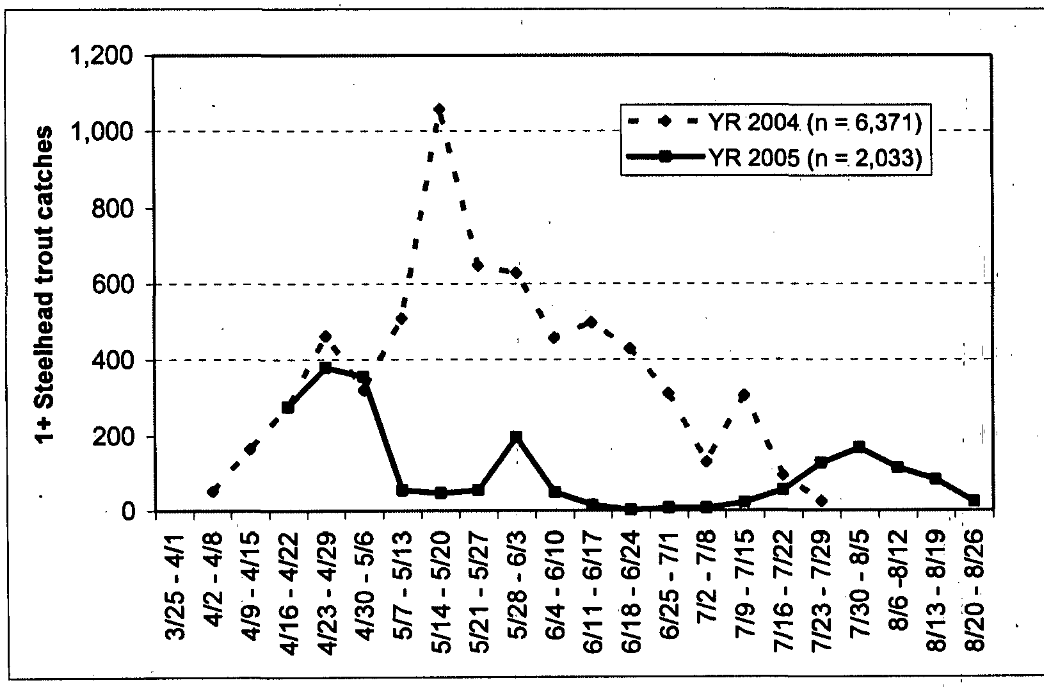

Figure 6. Comparison of 1+ steelhead trout catches in YR 2005 with catches in YR 2004, lower Redwood Creek, Humboldt County, CA.

2+ Steelhead trout

2+ steelhead trout were captured in each week during the trapping period in YR 2005 (Figure 7). Trap catches peaked during 4/30 – 5/6 in YR 2005, with a smaller peak occurring 5/28 – 6/3; in YR 2004, trap catches peaked during 5/14 – 5/20. In only a few weeks were catches comparable among study years. The pattern of catches over time showed emigration in YR 2005 was extended beyond the ending date for YR 2004.

On a monthly basis, the greatest number of catches for both trapping years occurred in May (n = 169 or 40% of total in YR 2005; n = 515 or 57% of total in YR 2004). The months of April and May accounted for 70% of the total catch in YR 2005, compared to May and June, 2004 which accounted for 78% of the total catch.

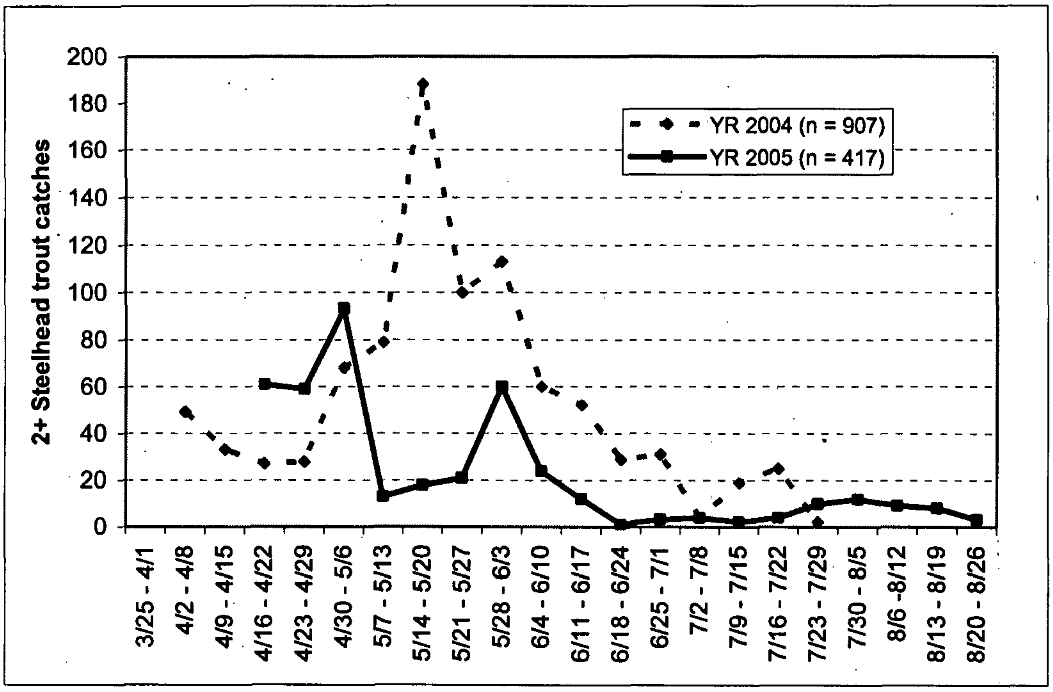

Figure 7. Comparison of 2+ steelhead trout catches in YR 2005 with catches in YR 2004, lower Redwood Creek, Humboldt County, CA.

0+ Coho salmon

0+ coho salmon were captured in 15 of 19 weeks of trap operation in YR 2005 (Figure 8). Peak catches occurred during 7/16 – 7/29 in YR 2005, and 5/14 – 5/20 and 7/16 – 7/22 in YR 2004 (Figure 8). The pattern of catches over time showed emigration in YR 2005 was extended beyond the ending date for YR 2004.

On a monthly basis, the greatest number of catches for both study years occurred in July (n = 20 or 38% of the total in YR 2005; n = 71 or 35% of the total in YR 2004). The months of June and July accounted for 58% of the total catch in YR 2005, compared to May and July, 2004 which accounted for 67% of the total catch.

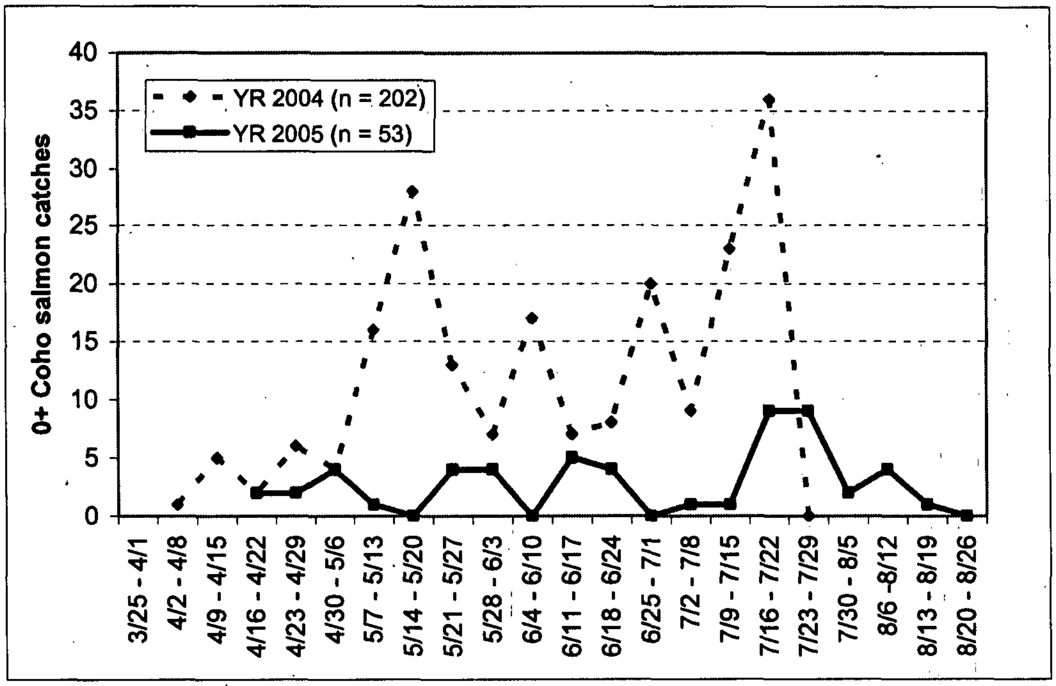

Figure 8. Comparison of 0+ coho salmon catches in YR 2005 with catches in YR 2004, lower Redwood Creek, Humboldt County, CA.

1+ Coho salmon

1+ coho salmon were caught nearly each week prior to week 6/4 – 6/10 in YR 2005 (Figure 9). Peak catches in YR 2005 occurred during 4/30 – 5/6, with a smaller peak occurring 5/21 – 5/27; in YR 2004, peak catches occurred 4/30 – 5/6, with smaller peaks occurring 4/16 – 4/22 and 5/28 – 6/3 (Figure 9).

On a monthly basis, the greatest number of catches for both study years occurred in May (n = 21 or 54% of the total catch in YR 2005; n = 43 or 62% of the total catch in YR 2004). The months of April and May accounted for 100% of the total catch in YR 2005, and 97% of the total catch in YR 2004.

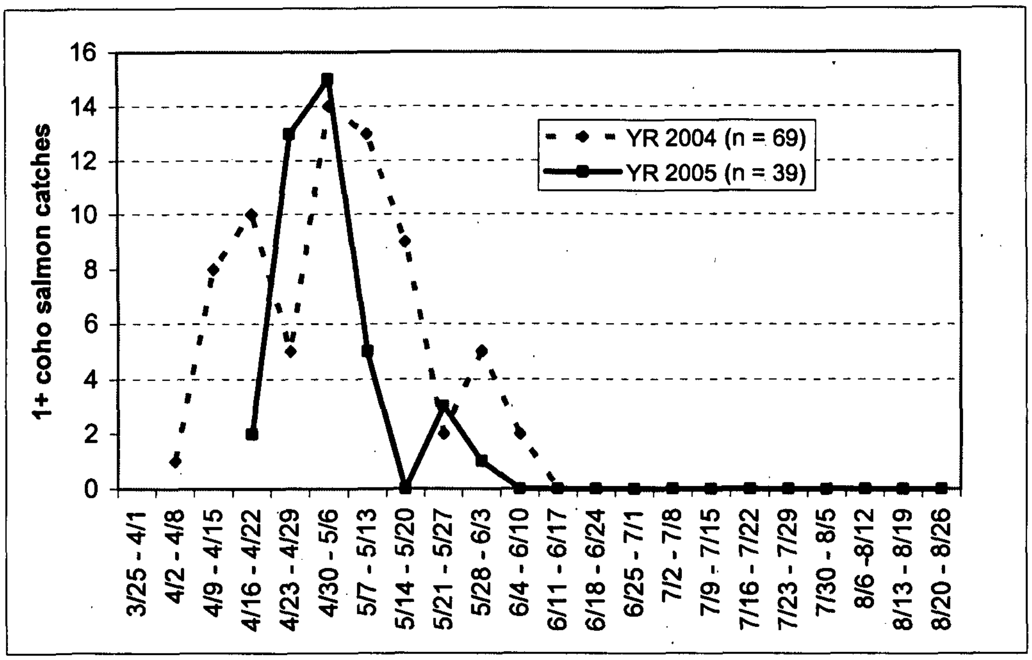

Figure 9. Comparison of 1+ coho salmon catches in YR 2005 with catches in YR 2004, lower Redwood Creek, Humboldt County, CA.

Cutthroat trout

Cutthroat trout catches were low in each study year, however catches in YR 2004 were much higher than catches in YR 2005 (Figure 10). Cutthroat trout were captured in six of 19 weeks of trap operation in YR 2005. No definitive peak in catches occurred in YR 2005, however, in YR 2004 a peak in catch occurred during 5/14 – 5/20 (Figure 10).

Catches of cutthroat trout by month were low in YR 2005. In YR 2004, May accounted for 49% of the total catch.

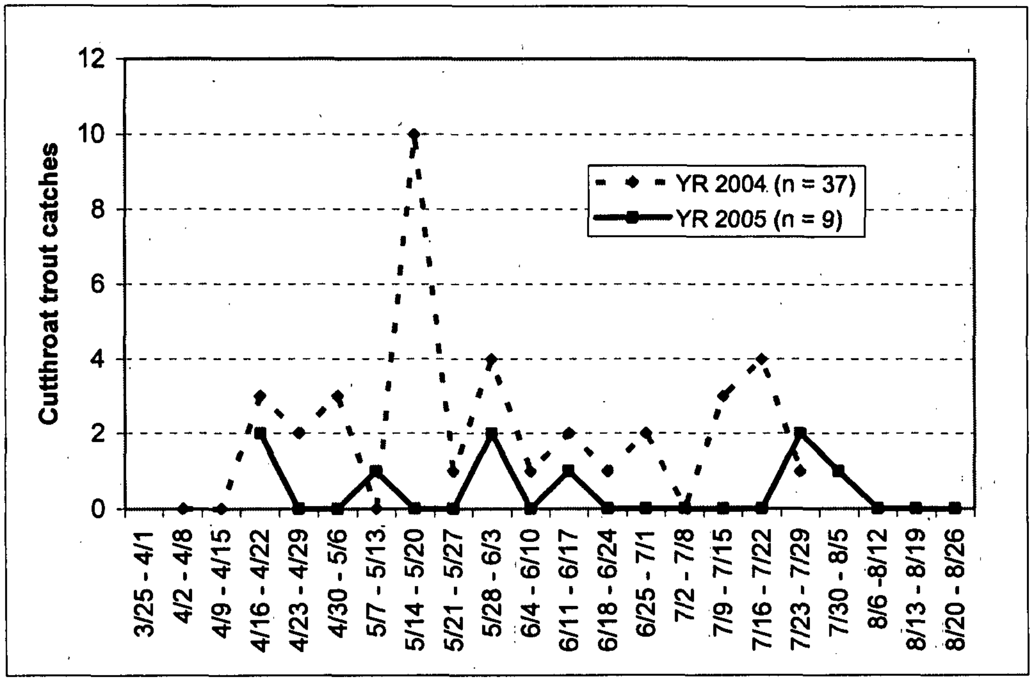

Figure 10. Comparison of cutthroat trout catches in YR 2005 with catches in YR 2004, lower Redwood Creek, Humboldt County, CA.

Trapping Efficiencies

0+ Chinook salmon

We fin clipped and released 5,150 young-of-year Chinook salmon upstream of the trap site during 85 efficiency trials over the course of trapping in YR 2005. The average number used in our weekly trials (includes 2- 6 efficiency trials) was 271, and ranged from 11 – 600 per week. Weekly trapping efficiencies in YR 2005 ranged from 5.0 – 31.4%, and averaged 11.7% (Table 6). Average trapping efficiencies among study years were similar.

0+ Chinook salmon weekly trap efficiencies in YR 2005 significantly increased over time (Correlation, $p = 0.002$, $r = 0.66$, positive slope, power = 0.93), and were negatively related to gage height (Regression, $p = 0.005$, $R^2 = 0.38$, negative slope, power = 0.86) and stream discharge (log x+1 transformation) (Regression, $p = 0.0006$, $R^2 = 0.51$, negative slope, power = 0.98).

Table 6. 0+ Chinook salmon trapping efficiency in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

	0+ Chinook salmon trap efficiency (percentage)		
	Weekly trapping efficiency		
Study Year	Range	Average	Seasonal
2004	7.3 - 20.7	11.9	11.9
2005	5.0 - 31.4	11.7	9.6

1+ Steelhead trout

We fin clipped and released 1,127 one-year-old steelhead trout upstream of the trap site during 70 efficiency trials over the course of trapping in YR 2005. The average number used in our weekly trials (includes 2 - 6 efficiency trials) was 59, and ranged from 2 – 189 individuals per week. Weekly trapping efficiencies in YR 2005 ranged from 0.0 – 7.7%, and averaged 4.4% (Table 7). The average trapping efficiency in YR 2005 was about 53% less than the average for YR 2004 (Table 7).

1+ steelhead trout weekly trap efficiencies in YR 2005 did not significantly change over time (Correlation, $p = 0.87$, $r = 0.04$, positive slope, power = 0.05). Weekly trap efficiencies were also not related to gage height (Regression, $p = 0.63$, $R^2 = 0.01$, negative slope, power = 0.07) or stream discharge (Regression, $p = 0.97$, $R^2 = 0.00$, positive slope, power = 0.05).

Table 7. 1+ steelhead trout trapping efficiency in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

	1+ steelhead trout trap efficiency (percentage)		
	Weekly trapping efficiency		
Study Year	Range	Average	Seasonal
2004	4.8 – 37.5	9.4	7.9
2005	0.0 – 7.7	4.4	4.6

2+ Steelhead trout

We fin clipped and released 306 two-year-old steelhead trout upstream of the trap site during 58 efficiency trials over the course of trapping in YR 2005. The average number used in our weekly trials (includes 1 - 5 efficiency trials) was 16, and ranged from 1 – 48 individuals per week. Weekly trapping efficiencies in YR 2005 ranged from 0.0 – 33.3%, and averaged 4.3% (Table 8). The average trapping efficiency in YR 2005 was about 25% less than the average for YR 2004 (Table 8).

The correlation of week number on 2+ steelhead trout weekly trap efficiencies, and the regressions of gage height and stream discharge on 2+ steelhead trout weekly trap efficiencies did not pass statistical assumptions (even with transformation), and results were not valid.

Table 8. 2+ steelhead trout trapping efficiency in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

	2+ steelhead trout trap efficiency (percentage)		
	Weekly trapping efficiency		
Study Year	Range	Average	Seasonal
2004	0.0 – 25.0	5.8	3.6
2005	0.0 – 33.3	4.3	2.3

1+ Coho salmon

We fin clipped and released 22 one plus-year-old coho salmon upstream of the trap site during 12 efficiency trials over the course of trapping in YR 2005. The average number used in our weekly trials (includes 1 - 4 efficiency trials) was 3, and ranged from 1 – 7 individuals per week. Weekly trapping efficiencies in YR 2005 ranged from 0.0 – 20.0%, and averaged 5.2% (Table 9). The average weekly trapping efficiency in YR 2005 was 1.4 times greater than the average for YR 2004 (Table 9).

Table 9. 1+ coho salmon trapping efficiency in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

	1+ coho salmon trap efficiency (percentage)		
	Weekly trapping efficiency		
Study Year	Range	Average	Seasonal
2004	0.0 – 25.0	3.7	3.6
2005	0.0 – 20.0	5.2	9.1

Population Estimates

0+ Chinook salmon

The population estimate (or production) of 0+ Chinook salmon emigrating past the trap in lower Redwood Creek in YR 2005 equaled 131,164 individuals with a 95% CI of 117,259 – 145,069 (Table 10). Population estimate error (or uncertainty) equaled ± 10.6%. Population emigration in YR 2005 was markedly lower than emigration in YR 2004 (N = 554,890; 95%CI 493,160 – 616,620) by 76% (Table 10).

Monthly population emigration peaked in July (N = 77,386 or 59% of total) in YR 2005 compared to June (N = 292,155 or 53% of total) in YR 2004. The two most important months for emigration in YR 2005 were June and July (N = 108,597 or 83% of total) compared to May and June (N = 431,623 or 78% of total) in YR 2004.

Table 10. 0+ Chinook salmon population estimates in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

Study Year	0+ Chinook salmon
2004	554,890 (± 11.1%)
2005	131,164 (± 10.6%)

Population emigration on a weekly basis shows the decrease in abundance in YR 2005 and differences in the migration pattern among study years (Figure 11). The greatest peak in weekly migration in YR 2005 occurred during 7/16 – 7/22 (N = 29,766), compared to 6/18 – 6/24 (N = 110,980) in YR 2004. The pattern of population emigration (similar to the catch distribution) over time showed emigration in YR 2005 was extended beyond the ending date for YR 2004 (7/29).

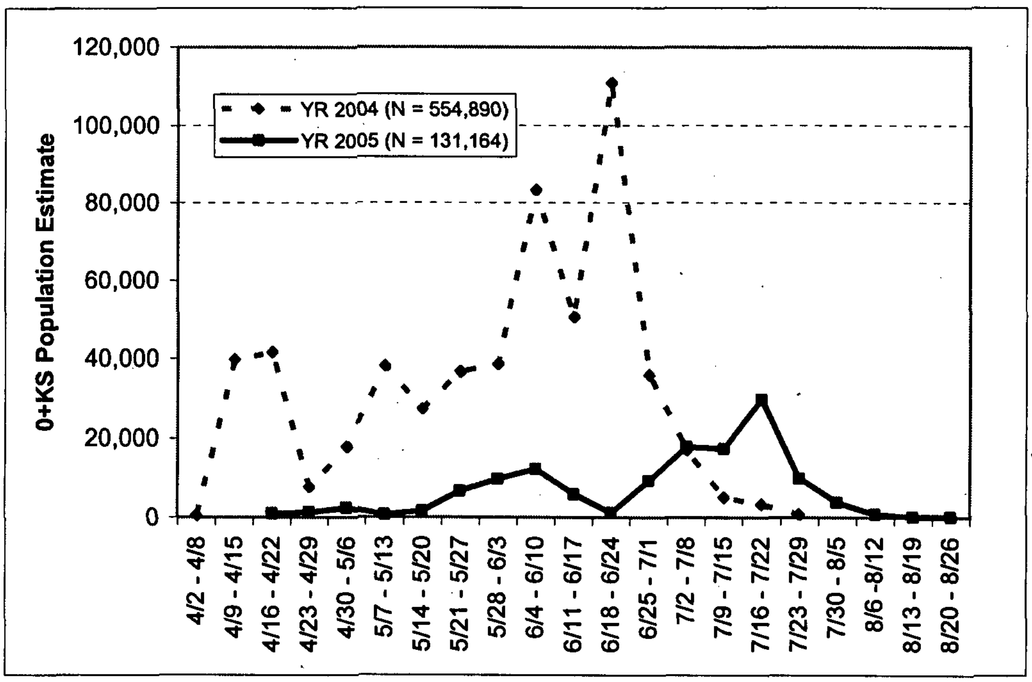

Figure 11. 0+ Chinook salmon population emigration by week in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA. Age/species abbreviation is the same as in Figure 2.

The population of 0+ Chinook salmon emigrants consisted of both fry (FL < 45 mm) and fingerlings (FL > 44 mm) in YR 2004 and YR 2005 (Figure 12). The number (and percentage) of fry in YR 2005 (N = 2,052 or 1.6% of total population) was much less than in YR 2004 (N = 82,854 or 15% of total population). The migration of fry in YR 2005 peaked 4/30 – 5/6 (N = 739), compared to 4/9 – 4/15 (N = 37,972) in YR 2004. The last fry to migrate past the trap site in YR 2005 occurred on 5/28, compared to 5/21 in YR 2004.

Fingerling migration was low in the beginning of trapping each study year, increased over time each year, and peaked during 7/16 – 7/22 (N = 29,766) in YR 2005 and 6/18 – 6/24 (N = 110,980) in YR 2004 (Figure 12). The total number of fingerlings in YR 2005 equaled 129,113 (or 98.4% of total population estimate) compared to 472,306 (or 85% of total population estimate) in YR 2004.

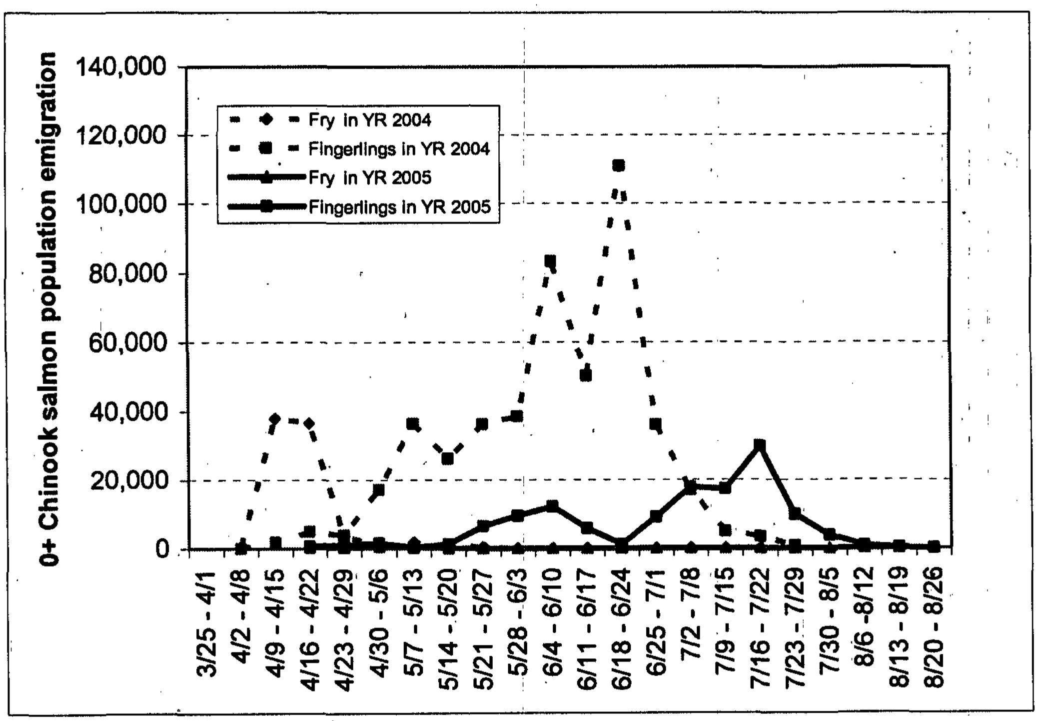

Figure 12. Estimated 0+ Chinook salmon fry and fingerling abundance and migration timing in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

1+ Steelhead trout

The population estimate (or production) of 1+ steelhead trout emigrating past the trap in lower Redwood Creek in YR 2005 equaled 32,901 individuals with a 95% CI of 24,967 – 40,835. Population estimate error (or uncertainty) equaled ± 24.1%. Population emigration in YR 2005 was 57% lower than emigration in YR 2004 (N = 77,221; 95% CI = 64,649 – 89,792) (Table 11).

Monthly population emigration peaked in April (N = 11,192 or 34% of total) in YR 2005 compared to May (N = 32,926 or 43% of total) in YR 2004. The two most important months for emigration in YR 2005 were April and May (N = 22,238 or 68% of total) compared to May and June (N = 58,680 or 76% of total) in YR 2004.

Table 11. 1+ steelhead trout population estimates in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

Study Year	1+ steelhead trout
2004	77,221 (± 16.3%)
2005	32,901 (± 24.1%)

Population emigration on a weekly basis shows the decrease in abundance in YR 2005 compared with YR 2004 (Figure 13). The greatest peak in weekly migration occurred during 4/30 – 5/6 (N = 7,494) in YR 2005, compared to 5/14 – 5/20 (N = 9,985) in YR 2004. Emigration during 6/11 – 7/15 in YR 2005 was much lower than emigration during the same time period in YR 2004 (Figure 13). The pattern of population emigration over time showed emigration in YR 2005 was extended beyond the ending date for YR 2004 (7/29) (Figure 13).

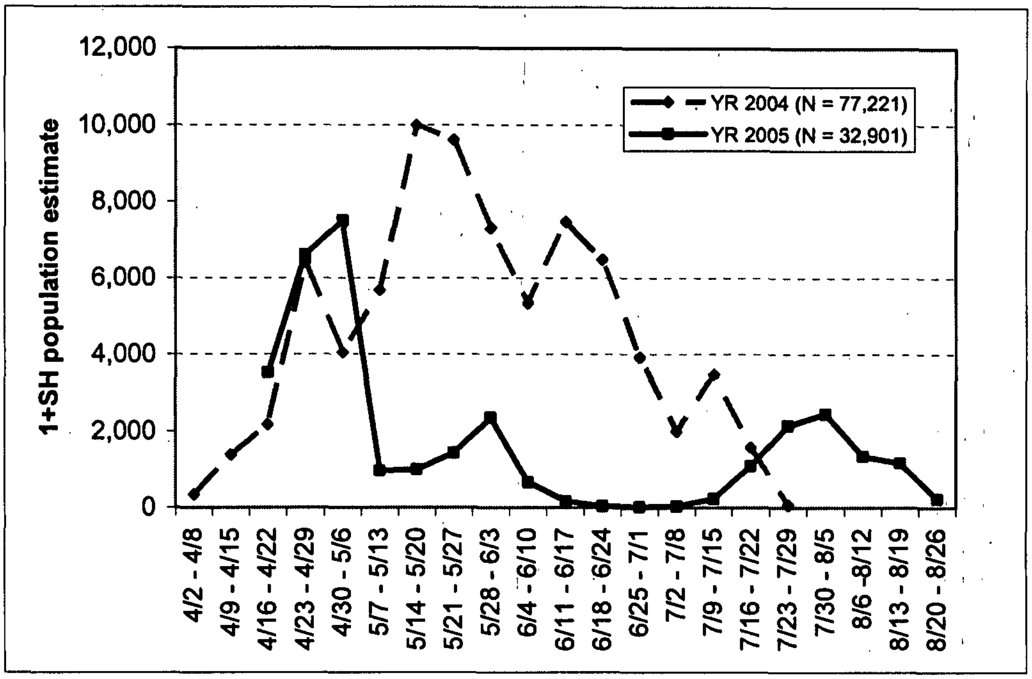

Figure 13. 1+ steelhead trout population emigration by week in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA. Age/species abbreviation is the same as in Figure 2.

2+ Steelhead trout

The population estimate (or production) of 2+ steelhead trout emigrating past the trap in lower Redwood Creek in YR 2005 equaled 8,754 individuals with a 95% CI of 4,975 – 12,533. Population estimate error (or uncertainty) equaled ± 43.2%. Using point estimates, population emigration in YR 2005 was 55% lower than emigration in YR 2004 (N = 19,353; 95% CI = 11,918 – 26,788) (Table 12).

Monthly population emigration peaked in May for both study years (N = 3,738 or 43% of total in YR 2005; N = 11,956 or 62% of total in YR 2004). The two most important months for emigration in YR 2005 were April and May (N = 6,391 or 73% of total) compared to May and June (N = 15,688 or 81% of total) in YR 2004.

Table 12. 2+ steelhead trout population estimates in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

Study Year	2+ steelhead trout
2004	19,353 (+ 38.4%)
2005	8,754 (+ 43.2%)

Population emigration on a weekly basis shows the decrease in abundance in YR 2005 compared with YR 2004 (Figure 14). The greatest peak in weekly migration occurred during 4/30 – 5/6 for both study years (N = 2,232 in YR 2005; N = 3,604 in YR 2004) (Figure 14). The pattern of population emigration over time showed emigration in YR 2005 was extended beyond the ending date for YR 2004 (Figure 14).

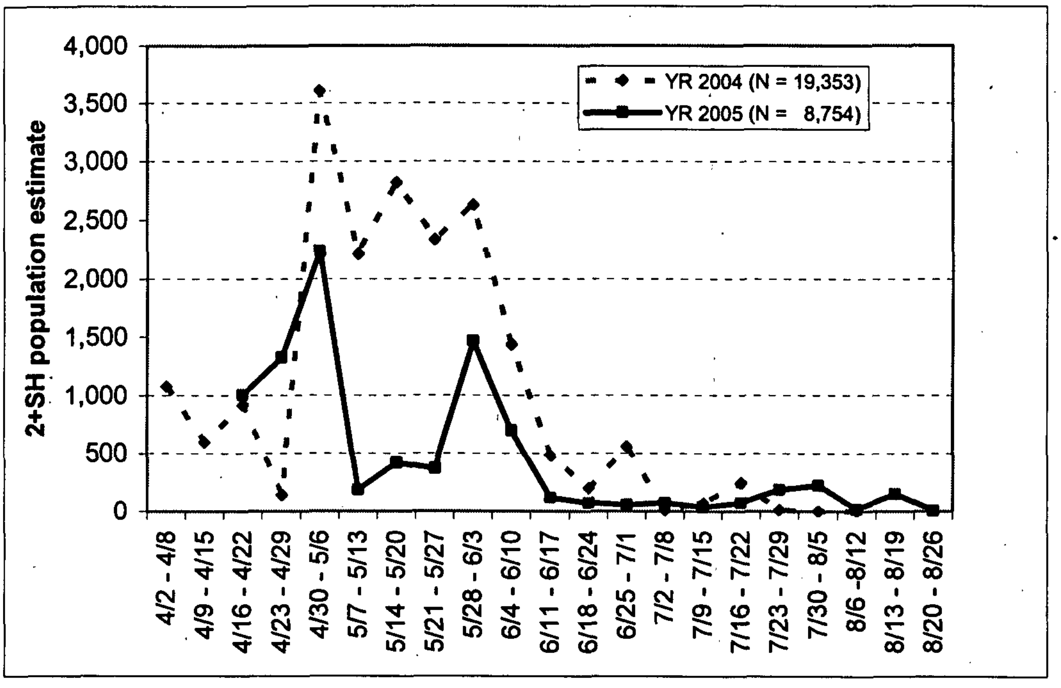

Figure 14. 2+ steelhead trout population emigration by week in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA. Age/species abbreviation is the same as in Figure 2.

1+ Coho salmon

The population estimate (or production) of 1+ coho salmon emigrating past the trap in lower Redwood Creek in YR 2005 equaled 183 individuals with a 95% CI of 56 – 309. Population estimate error (or uncertainty) equaled ± 69.3%. Using point estimates, population emigration in YR 2005 was 66% lower than emigration in YR 2004 (N = 535; 95% CI = 197 – 872) (Table 13).

Monthly population emigration peaked in May for both study years (N = 126 or 69% of total in YR 2005; N = 373 or 70% of total in YR 2004). The two most important months for emigration in both study years were April and May (N = 182 or 99% of total in YR 2005; N = 525 or 98% of total in YR 2004).

Table 13. 1+ coho salmon population estimates in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

Study Year	1+ coho salmon
2004	535 (± 63.2%)
2005	183 (± 69.3%)

Population emigration on a weekly basis shows the decrease in abundance in YR 2005 compared with YR 2004 (Figure 15). The majority of migration during both study years occurred prior to the end of May. The greatest peak in weekly migration occurred during 5/7 – 5/13 (N = 80) in YR 2005 and 4/30 – 5/6 (N = 182) in YR 2004 (Figure 15).

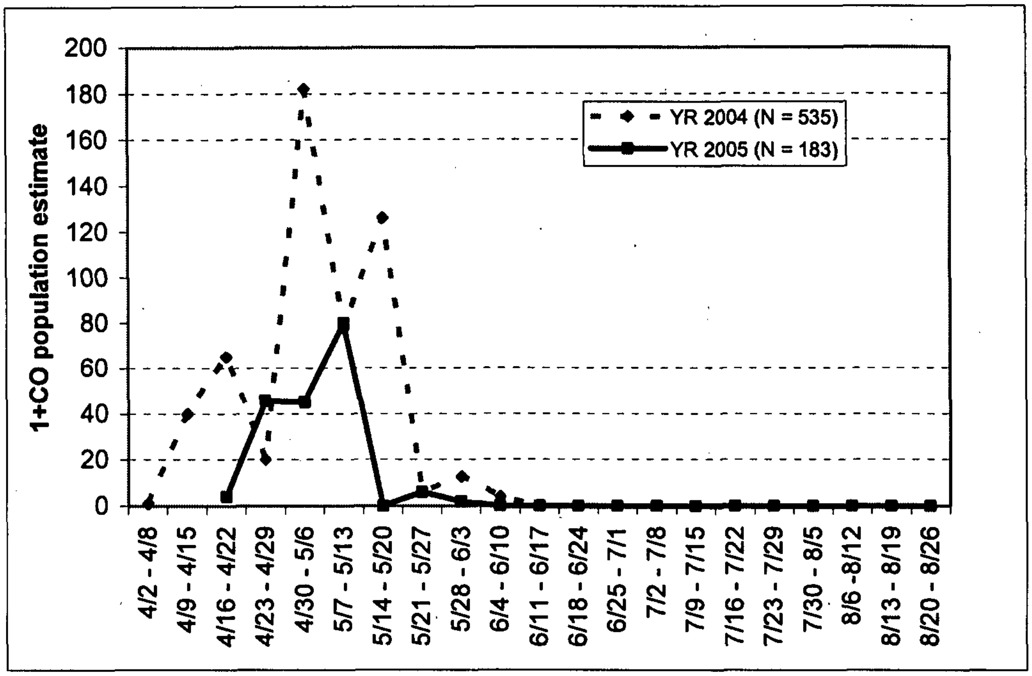

Figure 15. 1+ coho salmon population emigration in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA. Age/species abbreviation is the same as in Figure 2.

Linear Relations of weekly population emigration for 0+ Chinook salmon, 1+ steelhead trout, 2+ steelhead trout and 1+ coho salmon with Stream Gage Height, Stream Discharge, Stream Temperature, and Time (trapping week number)

0+ Chinook salmon weekly population emigration [transformed with log(x+1)] in YR 2005 was not statistically related to the stream gage height, stream discharge, or stream temperature (Regression, $p > 0.05$ for each test); and was also not related to week number (Correlation, $p > 0.05$).

1+ steelhead trout weekly population emigration [transformed with log(x+1)] in YR 2005 was not statistically related to the stream gage height, stream discharge, or stream temperature (Regression, $p > 0.05$ for each test); however, 1+ steelhead trout weekly population emigration (not transformed) was negatively related to the trapping week number (Correlation, $r = 0.52$, $p = 0.023$, slope is negative, power = 0.65). The correlation of week number with emigration showed that 52% of the variation in emigration can be associated with trapping week number.

2+ steelhead trout weekly population emigration [transformed with log(x+1)] in YR 2005 was positively related to the stream gage height (Regression, $R^2 = 0.36$, $p = 0.007$, slope is positive, power = 0.83) and stream discharge (Regression, $R^2 = 0.23$, $p = 0.04$, slope is positive, power = 0.56), and negatively related to stream temperature (Regression, $R^2 = 0.44$, $p = 0.002$, slope is negative, power = 0.93). Weekly population emigration was also negatively related to trapping week number (Correlation, $r = 0.77$, $p = 0.0001$, slope is negative, power = 1.0).

1+ coho salmon weekly population emigration [transformed with log(x+1)] in YR 2005 was positively related to stream gage height (Regression, $R^2 = 0.31$, $p = 0.01$, slope is positive, power = 0.75), and stream discharge (Regression, $R^2 = 0.26$, $p = 0.03$, slope is positive, power = 0.63), and negatively related to stream temperature (Regression, $R^2 = 0.44$, $p = 0.002$, slope is negative, power = 0.93). The weekly population estimates were also negatively related to trapping week number (Correlation, $r = 0.71$, $p = 0.0006$, slope is negative, power = 0.97).

Age Composition of Juvenile Steelhead Trout

The following percentages represent maximum values for 1+ and 2+ steelhead trout because their population estimates were compared to catches of 0+ steelhead trout (ie the actual catches of 0+ steelhead trout are less than expected 0+ steelhead trout population emigration). Far more 1+ steelhead trout migrated downstream than either 0+ or 2+ steelhead trout each study year (Table 14). Using catch and population data, the ratio of 0+ steelhead trout to 1+ steelhead trout to 2+ steelhead trout equaled 0.2:4:1 compared to 1:4:1 in YR 2004. Combining both years, the ratio equaled 0.7:4:1. The ratio of 1+ steelhead trout to 2+ steelhead trout equaled 4:1 for both study years.

Table 14. Comparison of 0+ steelhead trout, 1+ steelhead trout, and 2+ steelhead trout percent composition of total juvenile steelhead trout downstream migration in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

	Percent composition of total juvenile steelhead trout emigration		
Study Year	0+ steelhead*	1+ steelhead	2+ steelhead
2004	16.2	67.0	16.8
2005	3.1	76.5	20.4
Combined	12.6	69.6	17.8

* Uses actual catches instead of population estimate.

Fork Lengths and Weights

0+ Chinook Salmon

We measured (FL mm) 2,723 and weighed (g) 1,284 0+ Chinook salmon in YR 2005 (Table 15). Average FL (74.3 mm) and Wt (5.17 g) in YR 2005 was greater than the average FL (59.8 mm) and Wt (2.55 g) in YR 2004. Standard error of the mean was 0.3 mm and 0.09 g for FL and Wt in YR 2005, and 0.2 mm and 0.04 g for FL and Wt in YR 2004. The average size of fry (FL < 45 mm) was 40.6 mm in YR 2005, and 39.9 mm in YR 2004; average size of fingerlings was 76.4 mm in YR 2005 and 63.5 mm in YR 2004.

Table 15. 0+ Chinook salmon average and median fork length (mm) and weight (g) in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

		0+ Chinook Salmon					
		Fork Length (mm)			Weight (g)		
YR	(N)	n	Ave.	Median	n	Ave.	Median
2004	554,890	3,192	59.8	61.0	1,429	2.55	2.4
2005	131,164	2,723	74.3	80.0	1,284	5.17	5.6

Average weekly FL (mm) significantly increased over time (weeks) in YRS 2004 and 2005 (Correlation, p = 0.000001, r = 0.97, power = 1.0 for each test) (Figure 16). The increases in average FL over time show growth was taking place, and from 4/23 – 8/26 0+ Chinook salmon grew 0.37 mm/d in YR 2005 compared to 0.30 mm/d from 4/9 – 7/29 in YR 2004. The average weekly FL (mm) in both study years was positively related to the percentage of fingerlings each week (Regression, YR 2005, $R^2 = 0.55$, p = 0.0003, power = 0.99; YR 2004, $R^2 = 0.77$, p = 0.000003, power = 1.0). Kruskal-Wallis One-Way ANOVA on Ranks showed that the median weekly FL (79.2 mm) in YR 2005 was significantly greater than the median weekly FL (63.0 mm) in YR 2004 (p = 0.03).

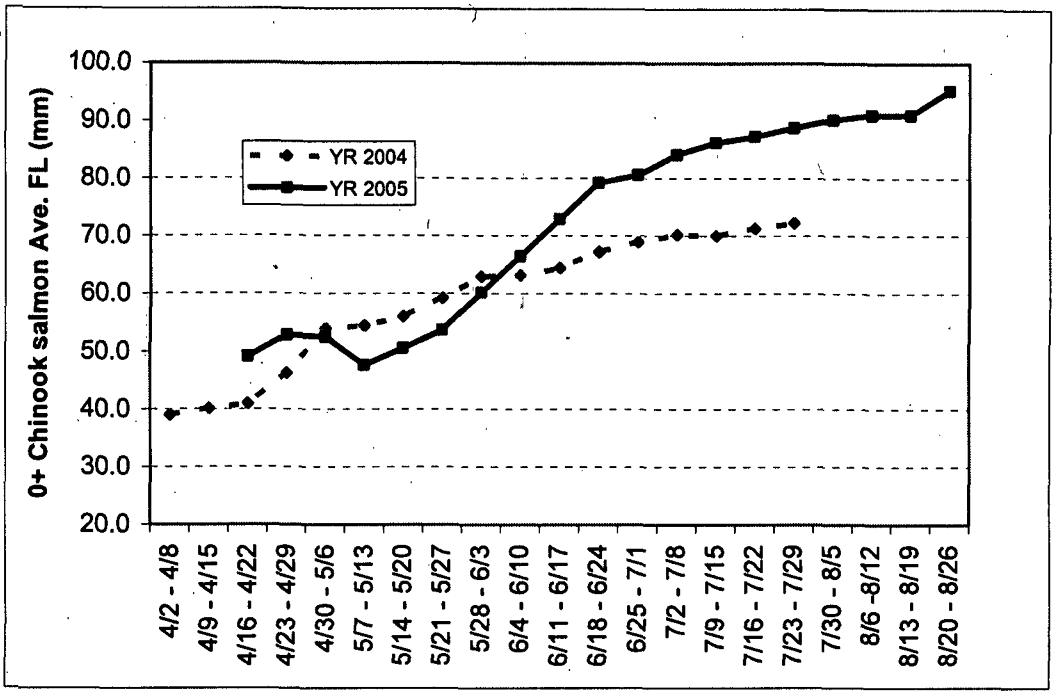

Figure 16. 0+ Chinook salmon average weekly fork length (mm) in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

Average weekly Wt (g) significantly increased over time (weeks) in YRS 2004 and 2005 (Correlation, p = 0.000001, r = 0.97 and 0.98, power = 1.0) (Figure 17). The increases in average Wt over time show growth was taking place, and from 4/30 – 8/26 0+ Chinook salmon grew 0.07 g/d in YR 2005 compared to 0.03 g/d from 4/9 – 7/29 in YR 2004. The average weekly Wt (g) in both study years was positively related to the percentage of fingerlings each week (Regression, YR 2005, $R^2 = 0.55$, p = 0.0003, power = 0.99; YR 2004, $R^2 = 0.63$, p = 0.0001, power = 1.0). The median weekly Wt (g) (5.53 g) in YR 2005 was significantly greater than the median weekly Wt (2.84 g) in YR 2004 (Kruskal-Wallace One-Way ANOVA on Ranks, p = 0.02).

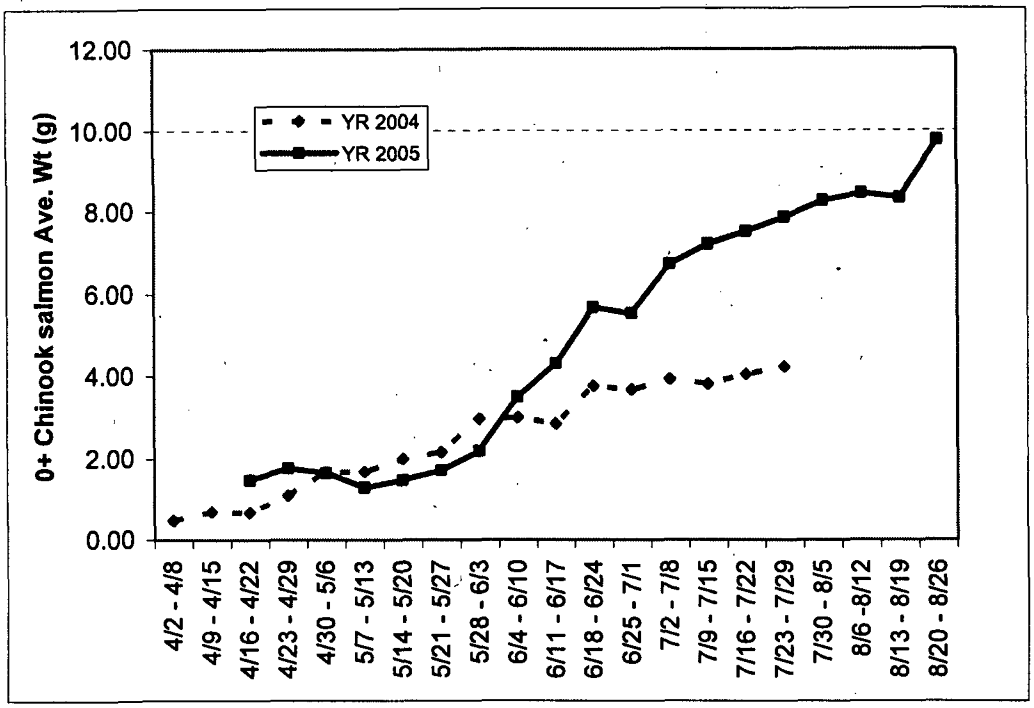

Figure 17. 0+ Chinook salmon average weekly weight (g) in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

1+ Chinook Salmon

We measured (FL mm) and weighed (g) 11 1+ Chinook salmon in YR 2005 (Table 16). Average FL (109 mm) and Wt (13.60 g) in YR 2005 was greater than the average FL and Wt in YR 2004.

Table 16. 1+ Chinook salmon average and median fork length (mm) and weight (g) in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

		0+ Chinook Salmon					
		Fork Length (mm)			Weight (g)		
YR	(N)	n	Ave.	Median	n	Ave.	Median
2004	> 2	2	101.0	101.0	2	11.25	11.25
2005	> 11	11	109.2	111.0	11	13.60	13.50

0+ Steelhead Trout

We measured (FL mm) 1,099 0+ steelhead trout in YR 2005 (Table 17). Average FL (51.1 mm) in YR 2005 was greater than the average fork length (49.6 mm) in YR 2004. Standard error of the mean was 0.6 mm in YR 2005 and 0.2 mm in YR 2004.

Table 17. 0+ steelhead trout average and median fork length (mm) in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

		0+ Steelhead Trout					
		Fork Length (mm)			Weight (g)		
YR	(N)	n	Ave.	Median	n	Ave.	Median
2004	> 18,642	2,939	49.6	52.0	-	-	-
2005	> 1,345	1,099	51.1	53.5	-	-	-

The first three average weekly FL's in YR 2004 were dominated by fry compared to the first five weeks in YR 2005 (Figure 18). Average weekly FL (mm) significantly increased over time (weeks) in YRS 2004 and 2005 (Correlation, $p = 0.000001$, $r = 0.98$, power = 1.0 for each test) (Figure 18). The increases in average FL over time show growth was taking place, and from 4/23 – 8/19 0+ steelhead trout grew 0.34 mm/d in YR 2005 compared to 0.29 mm/d from 4/9 – 7/29 in YR 2004.

Kruskal-Wallis One-Way ANOVA on Ranks showed that the median weekly FL (45.9 mm) in YR 2005 was not significantly different than the median weekly FL (50.3 mm) in YR 2004 ($p > 0.05$).

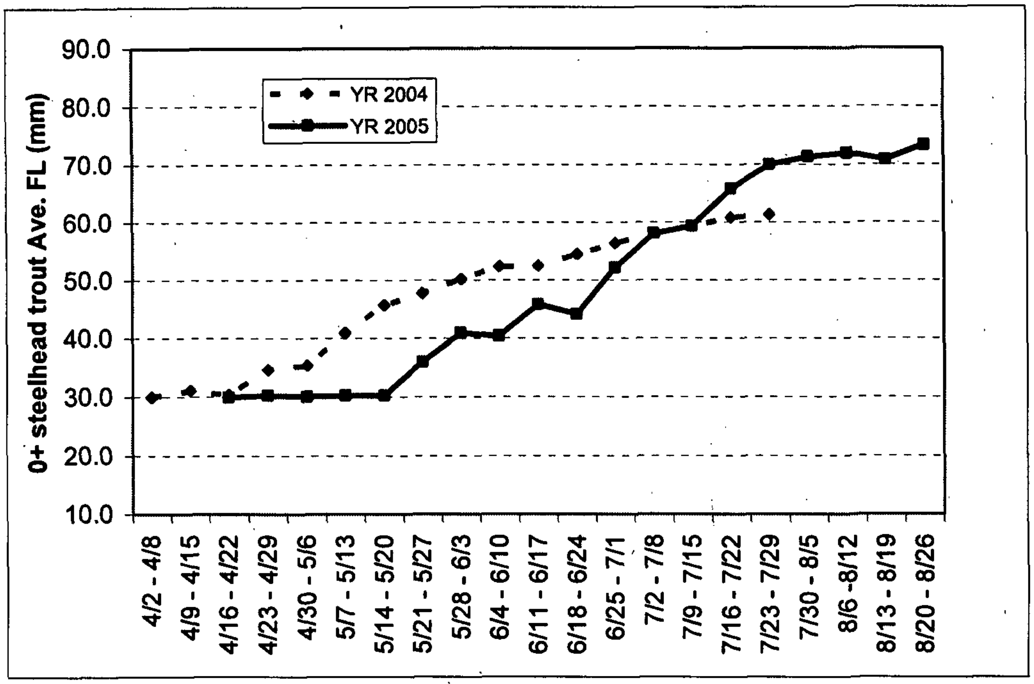

Figure 18. 0+ steelhead trout average weekly fork length (mm) in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

1+ Steelhead Trout

We measured (FL mm) 1,442 and weighed (g) 919 1+ steelhead trout in YR 2005 (Table 18). Average FL (90.8 mm) and Wt (8.31 g) in YR 2005 was greater than the average FL (84.4 mm) and Wt (7.04 g) in YR 2004. Standard error of the mean was 0.3 mm and 0.10 g for FL and Wt in YR 2005, and 0.3 mm and 0.11 g for FL and Wt in YR 2004.

Table 18. 1+ steelhead trout average and median fork length (mm) and weight (g), lower Redwood Creek, Humboldt County, CA.

		1+ Steelhead Trout					
		Fork Length (mm)			Weight (g)		
YR	(N)	n	Ave.	Median	n	Ave.	Median
2004	77,221	2,713	84.4	81.0	1,201	7.04	5.80
2005	32,901	1,442	90.8	89.0	919	8.31	7.40

Average weekly FL (mm) did not significantly change over time (weeks) in YRS 2004 and 2005 (Correlation, $p > 0.05$ for each test) (Figure 19). Average weekly fork length in YR 2005 (91.8 mm) was significantly greater than the average in YR 2004 (84.1 mm) (ANOVA, $p = 0.0007$, power = 0.95).

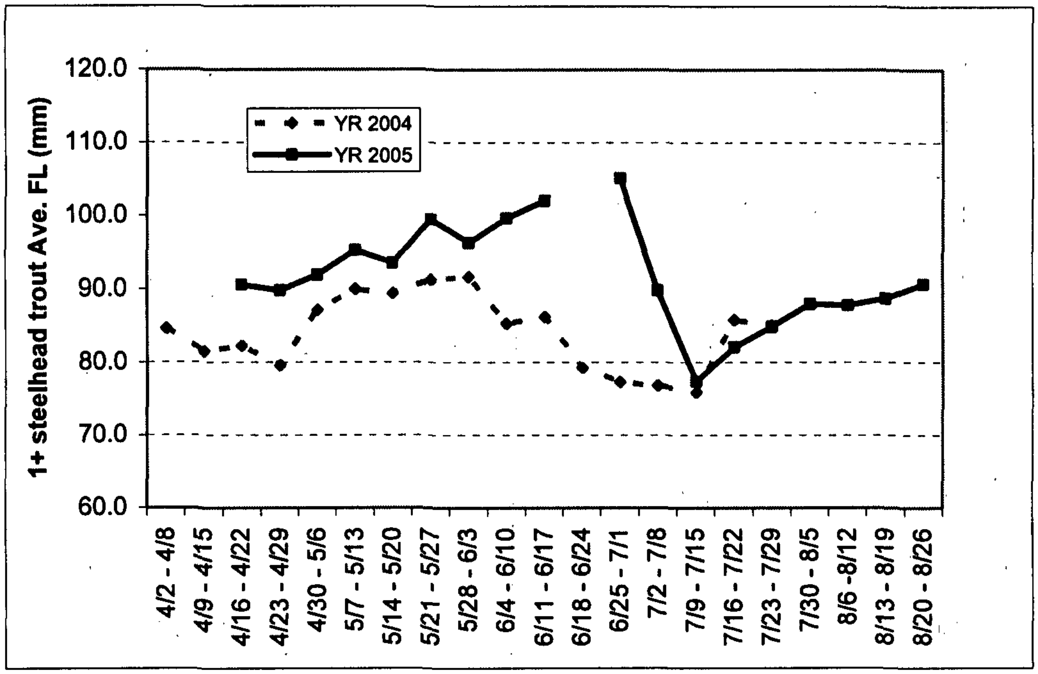

Figure 19. 1+ steelhead trout average weekly fork length (mm) in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

1+ steelhead trout average weekly Wt (g) did not significantly change over time (weeks) in YRS 2004 and 2005 (Correlation, $p > 0.05$ for each test) (Figure 20). Average weekly weight in YR 2005 (8.66 g) was significantly greater than the average in YR 2004 (6.95 g) (ANOVA, $p = 0.005$, power = 0.84).

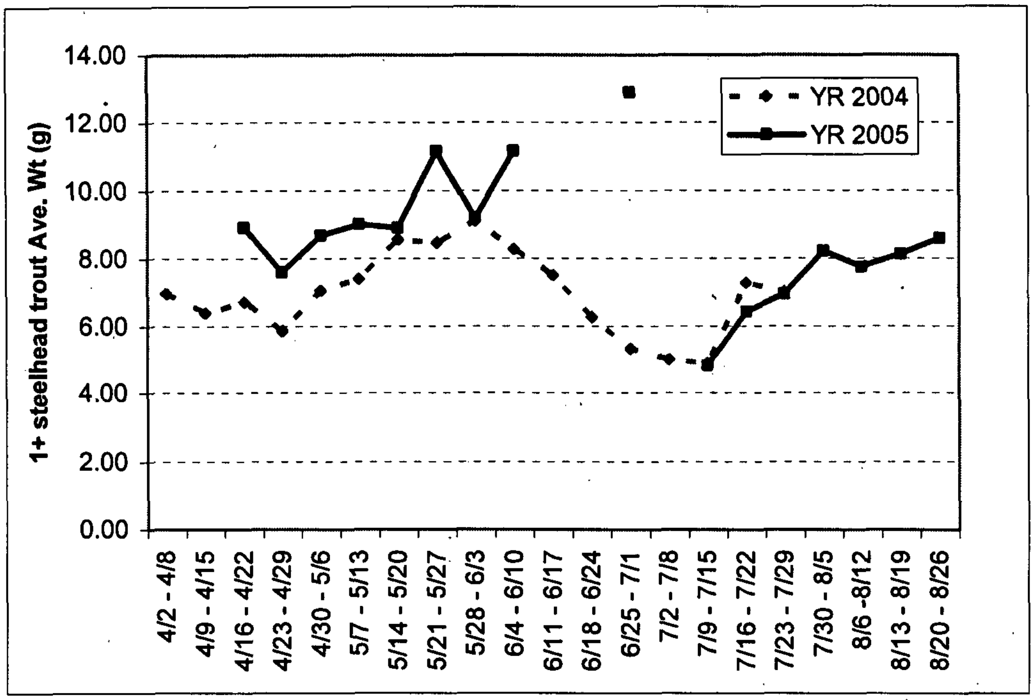

Figure 20. 1+ steelhead trout average weekly weight (g) in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

2+ Steelhead Trout

We measured (FL mm) 413 and weighed (g) 412 2+ steelhead trout in YR 2005 (Table 19). Average FL (143.2 mm) and Wt (31.25 g) in YR 2005 was greater than the average FL (141.9 mm) and Wt (30.69 g) in YR 2004. Standard error of the mean was 1.0 mm and 0.65 g for FL and Wt in YR 2005, and 0.7 mm and 0.44 g for FL and Wt in YR 2004.

Table 19. 2+ steelhead trout average and median fork length (mm) and weight (g) in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

		2+ Steelhead Trout					
		Fork Length (mm)			Weight (g)		
YR	(N)	n	Ave.	Median	n	Ave.	Median
2004	19,353	886	141.9	135.0	864	30.69	26.00
2005	8,754	413	143.2	139.0	412	31.25	27.05

The pattern of 2+ steelhead trout average weekly FL's (mm) over time in YRS 2004 and 2005 were similar (Figure 21). However, average weekly FL's in YR 2004 significantly decreased over time (Correlation, $r = 0.79$, $p = 0.0002$, slope is negative, power = 1.0); and in YR 2005, average weekly FL's did not significantly change over time (Correlation, $p > 0.05$). Average weekly fork length in YR 2005 (140.6 mm) was not significantly different than the average in YR 2004 (142.8 mm) (ANOVA, $p > 0.05$, power = 0.09).

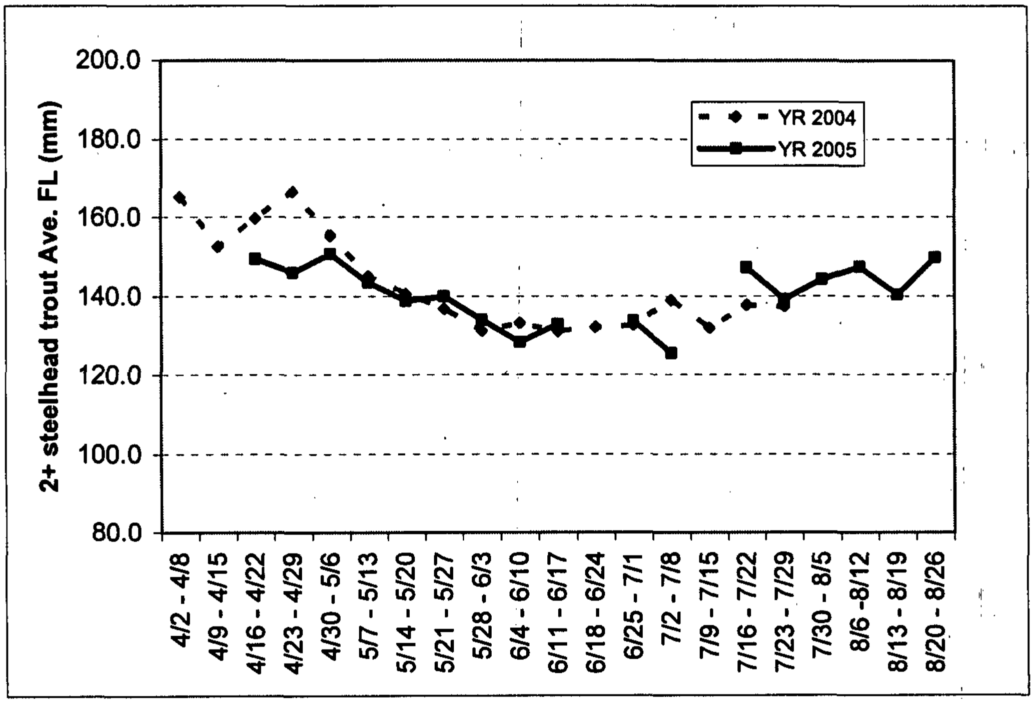

Figure 21. 2+ steelhead trout average weekly fork length (mm) in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

Similar to the FL measurements, 2+ steelhead trout average weekly Wt (g) in YR 2004 significantly decreased over time (Correlation, $r = 0.80$, $p = 0.0001$, slope is negative, power = 1.0); and in YR 2005, average weekly Wt's did not significantly change over time (Correlation, $p > 0.05$). Average weekly Wt (g) in YR 2005 (29.97 g) was not significantly different than the average in YR 2004 (31.51 g) (ANOVA, $p > 0.05$, power = 0.10).

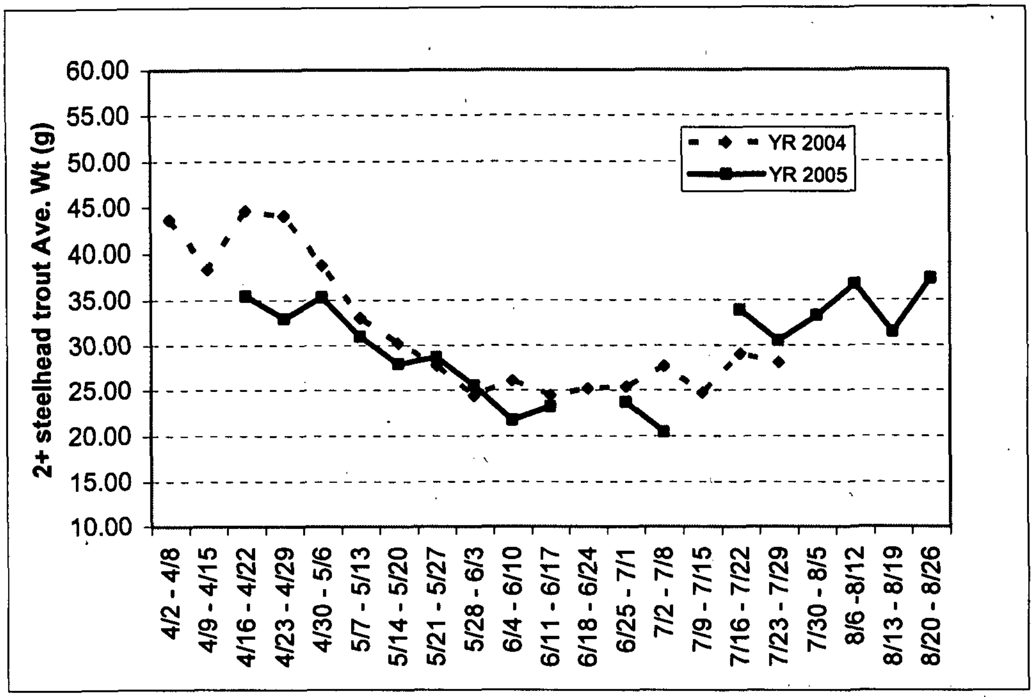

Figure 22. 2+ steelhead trout average weekly weight (g) in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

<u>0+ Coho Salmon</u>

We measured (FL mm) 53 and weighed (g) 50 0+ coho salmon in YR 2005 (Table 20). Average FL (61.8 mm) and Wt (3.38 g) in YR 2005 was less than the average FL (66.2 mm) and Wt (3.76 g) in YR 2004. Standard error of the mean was 2.0 mm and 0.30 g for FL and Wt in YR 2005, and 0.7 mm and 0.11 g for FL and Wt in YR 2004.

Table 20. 0+ coho salmon average and median fork length (mm) and weight (g) in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

		0+ Coho Salmon					
		Fork Length (mm)			Weight (g)		
YR	(N)	n	Ave.	Median	n	Ave.	Median
2004	> 202	202	66.2	66.0	198	3.76	3.50
2005	> 53	53	61.8	63.0	50	3.38	3.15

Data for average weekly FL's in YR 2004 failed correlation assumption tests, and results of the test of FL over time were not valid. However, average weekly FL's in YR 2005 passed assumption tests, and correlation showed a positive increase in FL over time ($r = 0.97$, $p = 0.00006$, slope is positive, power = 1.0) (Figure 23). Average weekly fork length in YR 2005 (60.7 mm) was not significantly different than the average in YR 2004 (63.4 mm) (ANOVA, $p > 0.05$, power = 0.08).

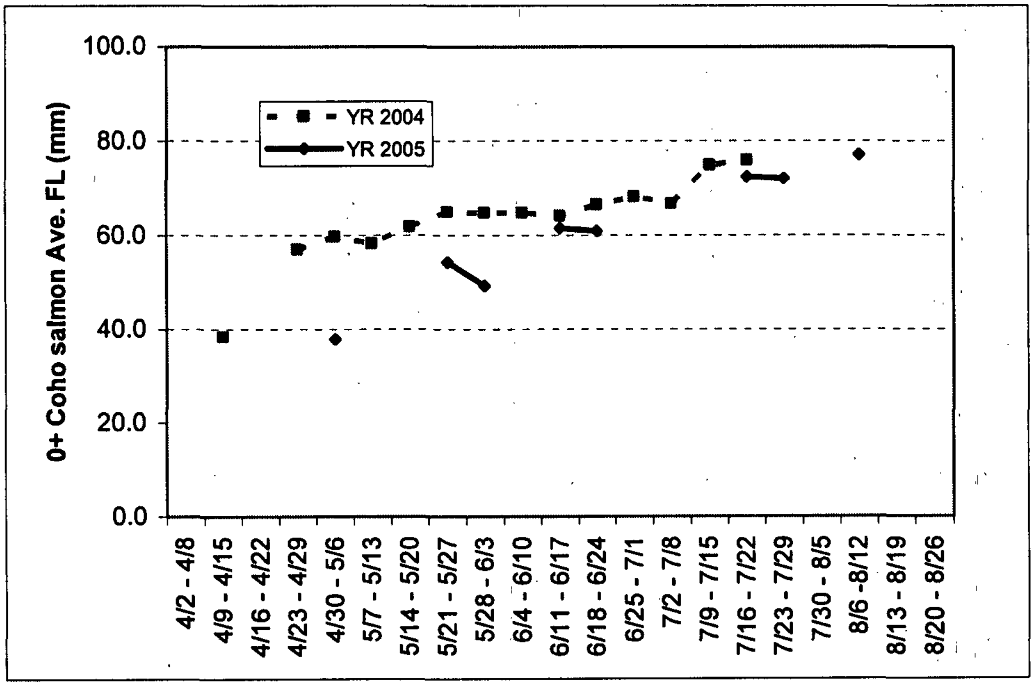

Figure 23. 0+ coho salmon average weekly fork length (mm) in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

0+ coho salmon average weekly Wt (g) in YR 2004 significantly increased over time (Correlation, $r = 0.80$, $p = 0.000003$, slope is positive, power = 1.0) as did the average for YR 2005 (Correlation, $r = 0.98$, $p = 0.000008$, slope is positive, power = 1.0) (Figure 24). Average weekly Wt (g) in YR 2005 (3.06 g) was not significantly different than the average in YR 2004 (3.44 g) (ANOVA, $p > 0.05$, power = 0.09).

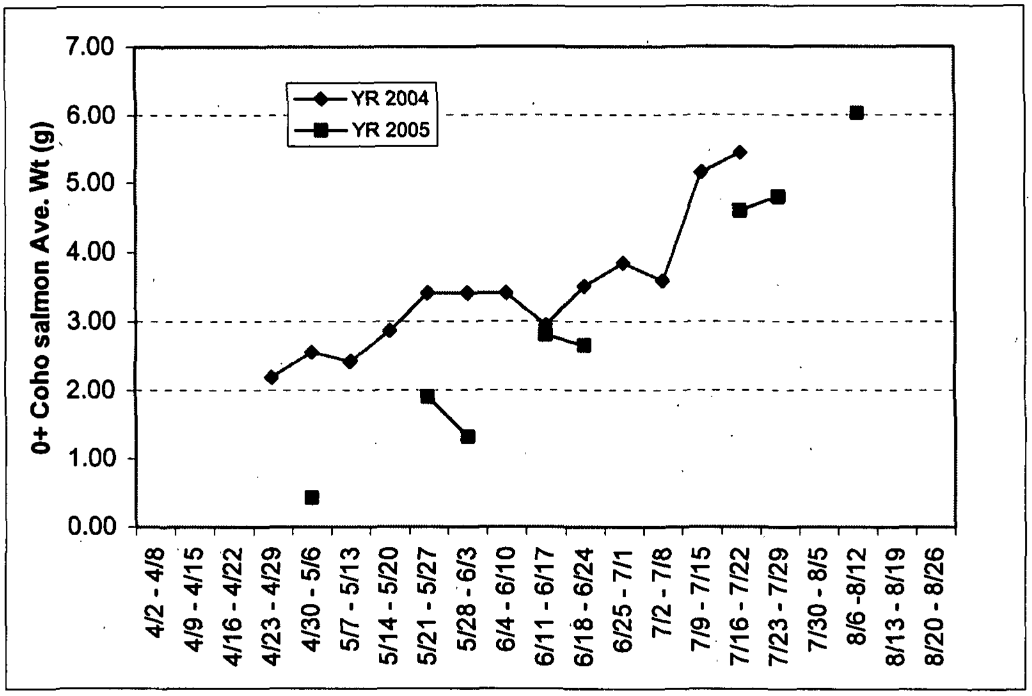

Figure 24. 0+ coho salmon average weekly weight (g) in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

1+ Coho Salmon

We measured (FL mm) 69 and weighed (g) 67 1+ coho salmon in YR 2005 (Table 21). Average FL (109.4 mm) and Wt (13.71 g) in YR 2005 was greater than the average FL (105.3 mm) and Wt (13.09 g) in YR 2004. Standard error of the mean was 1.3 mm and 0.48 g for FL and Wt in YR 2005, and 1.0 mm and 0.37 g for FL and Wt in YR 2004.

Table 21. 1+ coho salmon average and median fork length (mm) and weight (g) in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

		1+ Coho Salmon					
		Fork Length (mm)			Weight (g)		
YR	(N)	n	Ave.	Median	n	Ave.	Median
2004	535	69	105.3	105.0	67	13.09	12.09
2005	183	39	109.4	110.0	39	13.71	13.40

Average weekly fork length in YR 2004 increased over time (Figure 25) and a statistical relationship with time (weeks) was detected (Correlation, r = 0.86, p = 0.006, slope is negative, power = 0.93). Average weekly fork length in YR 2005 (109.1 mm) was not significantly different than the average in YR 2004 (106.0 mm) (ANOVA, p > 0.05, power = 0.18).

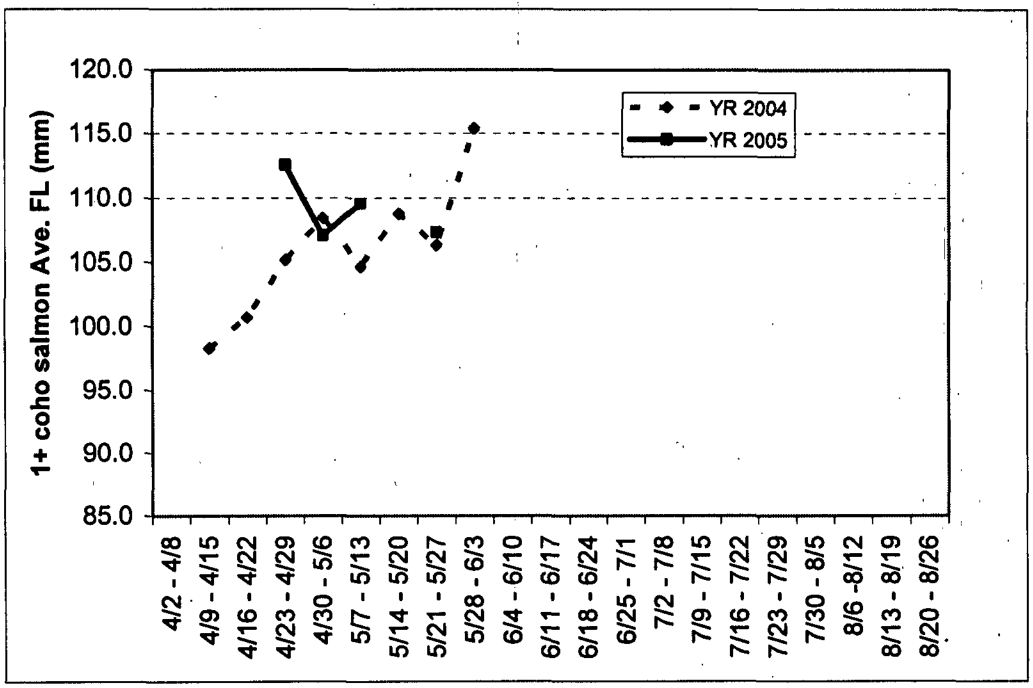

Figure 25. 1+ coho salmon average weekly fork length (mm) in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

Similar to average weekly FL data, 1+ coho salmon average weekly Wt (g) in YR 2004 significantly increased over time (Correlation, r = 0.80, p = 0.017, slope is positive, power = 0.77); and average Wt in YR 2005 did not significantly change over time (Correlation, p > 0.05, power = 0.09) (Figure 26).

Average weekly Wt (g) in YR 2005 (13.8 g) was not significantly different than the average in YR 2004 (13.3 g) (ANOVA, p > 0.05, power = 0.07).

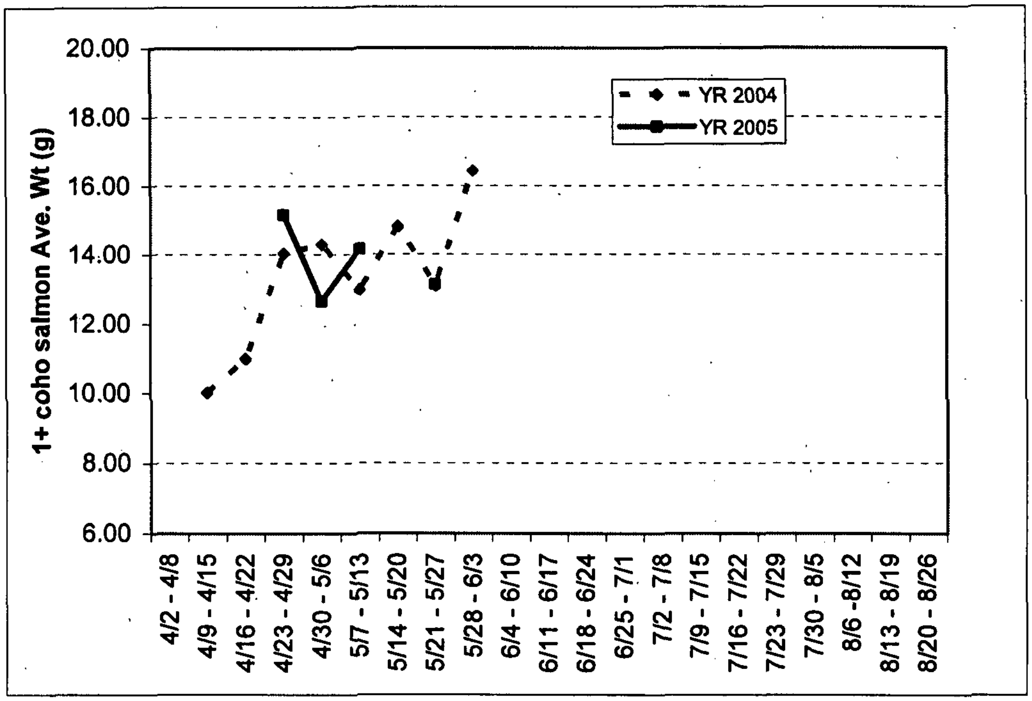

Figure 26. 1+ coho salmon average weekly weight (g) in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

Cutthroat Trout

We measured (FL mm) nine and weighed (g) seven cutthroat trout in YR 2005 (Table 22). Average FL (228.7 mm) and Wt (70.14 g) in YR 2005 was greater than the average FL (171.0 mm) and Wt (61.28 g) in YR 2004. Standard error of the mean was 34.2 mm and 16.2 g for FL and Wt in YR 2005, and 5.4 mm and 7.1 g for FL and Wt in YR 2004.

The FL's of cutthroat trout in YR 2004 ranged from 125 - 249 mm, compared to 144 - 450 mm in YR 2005.

Using FL measurements per day, the median FL in YR 2005 was significantly greater than the median in YR 2004 (Kruskal-Wallis One-Way ANOVA on Ranks, $p = 0.006$). No significant difference in median Wt among study years was detected (Kruskal-Wallis One-Way ANOVA on Ranks, $p > 0.05$).

Table 22. Cutthroat trout average and median fork length (mm) and weight (g) in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

		Cutthroat Trout					
		Fork Length (mm)			Weight (g)		
YR	(N)	n	Ave.	Median	n	Ave.	Median
2004	> 37	36	171.0	161.5	36	61.28	43.15
2005	> 9	9	228.7	185.0	7	70.14	64.80

0+ Pink Salmon

The two 0+ pink salmon captured on 4/29/05 had FL's of 38 and 39 mm.

Developmental Stages

1+ and 2+ Steelhead Trout

There was an obvious non-random distribution of parr, pre-smolt, and smolt designations (developmental stages) for 1+ and 2+ steelhead trout captured in YR 2004 and YR 2005 (Table 23). Contingency tests (2x2) showed significant differences in the proportions of pre-smolt and smolt designations for 1+ steelhead trout and 2+ steelhead trout captured in YR 2005 with captures in YR 2004 (1+ SH, Chi-square, $p < 0.000001$; 2+SH, Chi-square, $p < 0.0009$). For both tests (1+SH and 2+SH) there were comparatively more smolt designations in YR 2005. The combined percentage of pre-smolts and smolts for 1+ steelhead trout and 2+ steelhead trout in YR 2004 and YR 2005 was nearly 100% (Table 23).

Table 23. Developmental stages of captured 1+ and 2+ steelhead trout in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

	Developmental Stage (as percentage of total catch)					
	1+ Steelhead Trout			2+ Steelhead Trout		
Year	Parr	Pre-smolt	Smolt	Parr	Pre-smolt	Smolt
2004	0.2	31.5	68.3	0.0	5.7	94.3
2005	0.2	13.6	86.2	0.0	1.7	98.3

Additional Experiments

Re-migration

We did not recapture any of the 1+ and 2+ steelhead trout marked and released with elastomer (n = 800) at the upper trap in YR 2004 at the lower trap in YR 2005. Thus, we have found no evidence of downstream migrating 1+ and 2+ steelhead trout holding over for another year to migrate downstream. This test also served to show that marked fish which passed the lower trap in YR 2004 did not migrate back upstream to later re-migrate downstream in YR 2005.

Travel Time and Growth

0+ Chinook Salmon

We recaptured 27 pit tagged 0+ Chinook salmon smolts at the lower trap out of 555 released from the upper trap site (Sparkman In progress). The lower trap caught pit tagged individuals from 16 of the 21 (or 76%) tagging groups released. The percentage recaptured per tagging group ranged from 0.0 – 20.0% and averaged 5.3%.

Initial fork lengths of recaptured fish ranged from 70 - 90 mm and averaged 80 mm (Appendix 6). Time to travel the 29 miles between traps ranged from 1.5 - 19.5 d and averaged 7.5 d (median = 5.5 d). Travel time was not significantly related to FL or Wt at time 1 or time 2, stream temperature, or stream discharge (Regression, $p > 0.05$ for all tests, n = 27). Travel rate ranged from 1.5 - 19.3 mi/d (2.4 – 31.1 km/d) and averaged 8.2 mi/d (13.2 km/d) (median = 5.3 mi/d or 8.5 km/d) (Appendix 6). Travel rate was weakly related to FL at time 1 (Regression, $p = 0.01$, $R^2 = 0.24$, slope is positive, power = 0.76, n = 27) and Wt at time 1 (Regression, $p = 0.006$, $R^2 = 0.27$, slope is positive, power = 0.83); no significant relationships were found with stream temperature, stream discharge or fish size at time 2 (Regression, $p > 0.05$ for each test).

Multiple fish released at the same time were occasionally recaptured at the lower trap on the same day (n = 5 recaptures). In contrast, most fish that were released at the same time (as a group) were recaptured on varying dates, and travel time for recaptured individuals (n = 5) for the 7/21/05 release group ranged from 4.5 - 19.5 days (Appendix 6).

The size of recaptured pit tagged 0+ Chinook salmon at time 2 (recapture day) was positively related to initial size at release (Regression, FL: $p = 0.000001$, $R^2 = 0.67$, power = 1.0; Wt: $p = 0.00001$, $R^2 = 0.62$, power = 1.0).

Fourteen (52%) of the 27 recaptured 0+ Chinook salmon showed positive growth in FL and Wt, five (18%) showed a decrease in Wt, and none of the recaptures showed a decrease in FL. Thirteen individuals (48%) showed no change in FL and eight individuals did not experience a change in Wt (30%) (Appendix 7). On average, the 0+ Chinook salmon experienced a positive percent change in size of 3.6% for FL and 9.6% for Wt (Appendix 8). The 0+ Chinook salmon showed, on average, positive growth in FL for absolute growth rate (Ave. = 0.22 mm/d), relative growth rate (Ave. = 0.003

mm/mm/d), and specific growth rate scaled [Ave. = 0.279 %(mm/d)] (Appendix 8). The 0+ Chinook salmon averaged an absolute growth rate in Wt of 0.00 g/d, a relative growth rate of 0.001 g/g/d and a specific growth rate scaled of 0.003 %(g/d) (Appendix 8).

The relationship of travel time on various FL and Wt growth indices was significant and positive (Appendix 9). Travel time explained more of the variation in growth than any other variable tested (Appendix 9 and Figure 27).

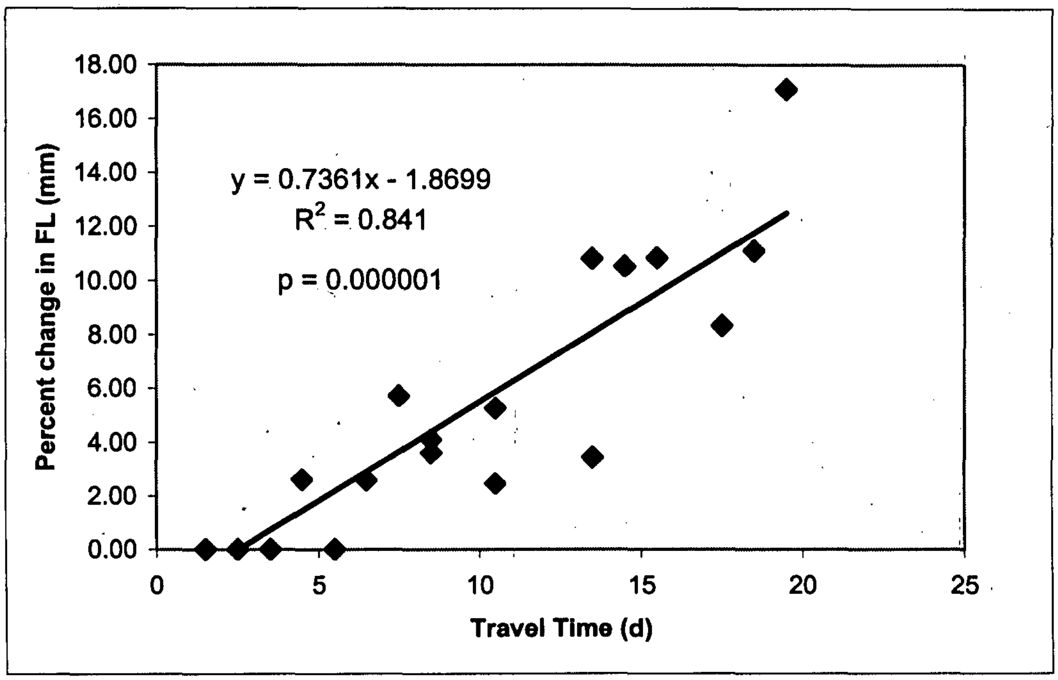

Figure 27. Linear regression of travel time (d) on percent change in FL (mm) for pit tagged 0+ Chinook salmon released at the upper trap site and recaptured at the lower trap (a distance of 29 mi) in Redwood Creek, Humboldt County, CA., 2005. Although 27 data points were used in the regression, only 18 are visible due to symbol overlap.

Separate growth statistics were determined for recaptured pit tagged 0+ Chinook salmon individuals showing either positive (n = 14) or negative growth (n = 5) (Table 22). On average, the pit tagged Chinook salmon absolute growth rate equaled 0.428 mm per day for FL, and 0.094 g per day for Wt (Table 24).

Table 24. Growth statistics for recaptured pit tagged 0+ Chinook salmon that showed positive (n = 14) or negative (n = 5) growth, Redwood Creek, Humboldt County, CA., 2005.

	Positive Growth							
	% Change in:		AGR*		SGRsc*		RGR*	
	FL	WT	FL	WT	FL	WT	FL	WT
Min.	2.47	4.20	0.190	0.020	0.232	0.312	0.002	0.003
Max.	17.11	46.04	0.670	0.270	0.810	3.177	0.009	0.033
Ave.	**7.04**	**20.75**	**0.428**	**0.094**	**0.538**	**1.546**	**0.006**	**0.017**
SD	4.46	16.03	0.142	0.063	0.182	0.744	0.002	0.009
	Negative Growth							
	% Change in:		AGR		SGRsc		RGR	
	FL	WT	FL	WT	FL	WT	FL	WT
Min.	-	-5.09	-	-0.190	-	-3.481	-	-0.034
Max.	-	-7.66	-	-0.390	-	-5.315	-	-0.051
Ave.	**-**	**-6.26**	**-**	**-0.286**	**-**	**-4.312**	**-**	**-0.042**
SD	-	0.95	-	0.076	-	0.677	-	0.006

* AGR = absolute growth rate (FL mm/d; Wt g/d), SGR = specific growth rate scaled [FL %(mm/d); Wt %(g/d)], RGR = relative growth rate (FL mm/mm/d; Wt g/g/d).

1+ and 2+ Steelhead Trout

We recaptured one 2+ steelhead trout marked with elastomer (which also had a partial upper caudal fin clip), and three 1+ steelhead trout marked with elastomer in YR 2005 at the lower trap in YR 2005 (Table 25). The 2+ steelhead trout was not a re-migrating fish (1+SH) from YR 2004 because the partial fin clip was fresh, and showed no signs of regeneration. We also captured two pit tagged 1+ steelhead trout at the lower trap which were released at the upper trap (Table 25). Travel time for the single 2+ steelhead trout was 7 d, as compared to the average travel time for 1+ steelhead trout of 12 d (n = 5, SD = 13.3). Travel time for 1+ steelhead trout ranged from 2 - 35 d, and travel rate ranged from 0.8 - 14.5 miles per day (Table 25).

One of the recaptured pit tagged steelhead trout showed growth during the 29 mile migration (initial size = 71 mm). This fish experienced a percent change in FL and Wt of 7.0 and 39.7%, an absolute growth rate of 0.43 mm/d and 0.11 g/d, a specific growth rate (scaled) of 0.257 %(mm/d) and 1.262 %(g/d), and a relative growth rate of 0.006 mm/mm/d and 0.035 g/g/d.

Table 25. Travel time (d) and travel rate (mi/d) for 2+ steelhead trout and 1+ steelhead trout released at the upper trap site and recaptured at the lower trap (distance of 29 miles) in Redwood Creek, Humboldt County, CA., 2005.

Travel Time Experiments						
Age/species	Initial FL mm	Mark or Tag type	Date Released*	Date Recaptured**	Travel time (d)	Travel rate (mi/d)
2+ SH	-	Elastomer	5/28/05	6/04/05	7.0	4.1
1+ SH	-	Elastomer	4/28/05	4/30/05	2.0	14.5
1+ SH	-	Elastomer	4/28/05	6/02/05	35.0	0.8
1+ SH	-	Elastomer	5/05/05	5/15/05	10.0	2.9
1+ SH	89	Pit Tag	6/02/05	6/06/05	3.5	8.3
1+ SH	71	Pit Tag	7/14/05	7/26/05	11.5	2.5

* Released at upper trap (RM 33). Elastomer fish were released in the morning, pit tag fish were released at night.

** Recapture at lower trap (RM 4).

Trapping Mortality

The mortality of fish that were captured in the trap and subsequently handled was closely monitored over the course of each trapping period. The trap mortality (includes handling mortality) for a given age/species in YR 2005 ranged from 0.00 – 1.56%, and using all data, was 1.00% of the total captured and handled (Table 26). Trapping mortality was probably higher in YR 2005 compared to YR 2004 because in YR 2005 we experienced much higher stream flow and debris loading in the trap's livebox.

Table 26. Trapping mortality for juvenile salmonids captured in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

	Trapping Mortality					
	YR 2004			YR 2005		
Age/spp.*	No. Caught	No. of mortalities	% Mortality	No. Caught	No. of mortalities	% Mortality
0+ KS	61,778	121	0.20	10,827	101	0.93
1+ KS	2	0	0.00	11	0	0.00
0+ SH**	18,642	44	0.24	1,345	21	1.56
1+ SH	6,371	2	0.03	2,033	20	0.84
2+ SH	907	0	0.00	417	4	0.96
0+ CO	202	0	0.00	53	0	0.00
1+ CO	69	0	0.00	39	0	0.00
CT	37	0	0.00	9	0	0.00
Total:	88,088	167	0.19	14,734	146	1.00

* Age/spp abbreviation is the same as in Figure 2.
** Includes a small but unknown percentage of young-of-year cutthroat trout.

Stream Temperatures

The average daily (24 hr period) stream temperature from 4/19/05 – 8/26/05 was 15.58 °C (or 60.4 °F) (95% CI = 15.08 – 16.08 °C), with daily averages ranging from 9.98 – 19.85 °C (50.0 – 67.7 °F). Median stream temperature in YR 2005 was 15.08 °C (59.1 °F). The average daily (24 hr period) stream temperature from 4/04/04 – 7/27/04 was 15.50 °C (or 59.9 °F) (95% CI = 15.02 – 15.98 °C), with daily averages ranging from 10.16 – 19.47 °C (50.3 – 67.0 °F). Median stream temperature in YR 2004 was 15.79 °C (60.4 °F).

The average daily stream temperature in YR 2005 from 4/19/05 – 7/27/05 (truncated to compare with YR 2004) was 14.69 °C (58.4 °F); and the average daily stream temperature from 4/19/04 – 7/27/04 (truncated to compare with the truncated data of YR 2005) was 16.08 °C (60.9 °F). The median daily stream temperature (truncated) in YR 2005 (14.49 °C) was significantly lower than median daily stream temperature (truncated) in YR 2004 (16.19 °C) (Kruskal-Wallis One Way ANOVA on Ranks, $p = 0.0001$).

Average monthly stream temperatures during the majority of the trapping season (April – July) in YR 2005 ranged from 11.5 – 18.5 °C (52.7 – 65.3 °F) (Table 27). In YR 2004, average monthly stream temperatures during trapping ranged from 11.9 – 18.6 °C (53.4 – 65.5 °F) (Table 27). Highest stream temperatures occurred in the later part of the trapping season (July or August) each study year. When comparing the months of April – July or April – August among study years, no significant differences were detected (ANOVA, $p > 0.05$ for each test).

Table 27. Average monthly stream temperatures (°C) during the majority of the trapping periods in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

	Average Stream Temperature (°C)	
Month	YR 2004	YR 2005
April	11.92*	11.49*
May	14.66	12.82
June	16.78	14.55
July	18.62*	18.51
August	-	18.45*
Average:	15.50	15.16

* Measurements do not encompass entire month.

The maximum weekly average temperature (MWAT) and the maximum weekly maximum temperature occurred in July for both study years (Table 28). Truncated and non-truncated data gave similar values which were nearly equal among study years (Table 28).

Table 28. Maximum weekly average temperature (MWAT) and maximum weekly maximum temperature (MWMT) for lower Redwood Creek stream temperatures °C (°F in parentheses) in both study years, Humboldt County, CA.

		MWAT**		MWMT***	
Year	Time period	Date occurred	°C (°F)	Date occurred	°C (°F)
2004	4/07 – 7/24	7/22	19.2 (66.6)	7/18	22.2 (72.0)
2004*	4/22 – 7/24	7/22	19.2 (66.6)	7/18	22.2 (72.0)
2005	4/22 – 8/23	7/17	19.3 (66.7)	7/17	22.1 (71.8)
2005*	4/22 – 7/24	7/17	19.3 (66.7)	7/17	22.1 (71.8)

* Data truncated to same period of measurements for equal comparison among years.
** MWAT is the maximum value of a 7-day moving average of daily average stream temperatures.
*** MWMT is the maximum value of a 7-day moving average of daily maximum stream temperatures.

The average stream temperature (not truncated) in lower Redwood Creek significantly increased over time (Correlation, $r = 0.91$, $p = 0.000001$, slope is positive, power = 1.0) (Figure 28). The minimum stream temperature (not truncated) in YR 2005 equaled 8.99 °C (48.2 °F) and occurred on 4/19/05; the maximum stream temperature equaled 22.6 °C (72.7 °F) and occurred on 7/18/05.

The average stream temperature during the study period in YR 2005 was inversely related to the gage height of the stream at the trapping site (Regression, $R2 = 0.82$, $p = 0.0000001$, slope is negative, power = 1.0).

The average stream temperature in YR 2004 also increased over time [time was transformed with log(x+1)] (Correlation, $r = 0.88$, $p = 0.000001$, power = 1.0) (Figure 29). Average daily stream temperatures in YR 2005 were lower than temperatures in YR 2004 from 4/27 – 6/29 (Figure 29); however, the median daily stream temperature during the study period in YR 2004 (15.8 °C or 60.4 °F) was not significantly different than the median in YR 2005 (15.1 °C or 59.2 °F) (non-truncated data, Kruskal-Wallis One-Way ANOVA on Ranks, $p > 0.05$). When using truncated data (to match measurement dates among years; 4/19 – 7/27) the median daily stream temperature in YR 2004 (16.2 °C or 61.2 °F was significantly greater than the median in YR 2005 (14.5 °C or 58.1 °F) (Kruskal-Wallis One-Way ANOVA on Ranks, $p = 0.0001$).

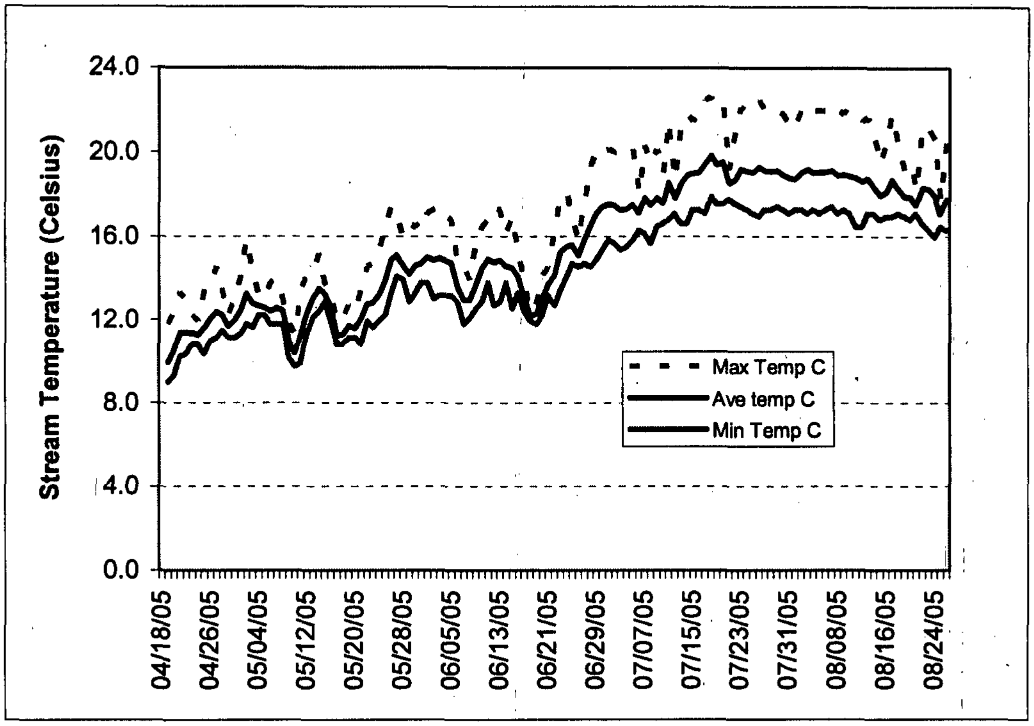

Figure 28. Average, minimum, and maximum stream temperatures (Celsius) at the trap site in lower Redwood Creek, Humboldt County, CA., 2005.

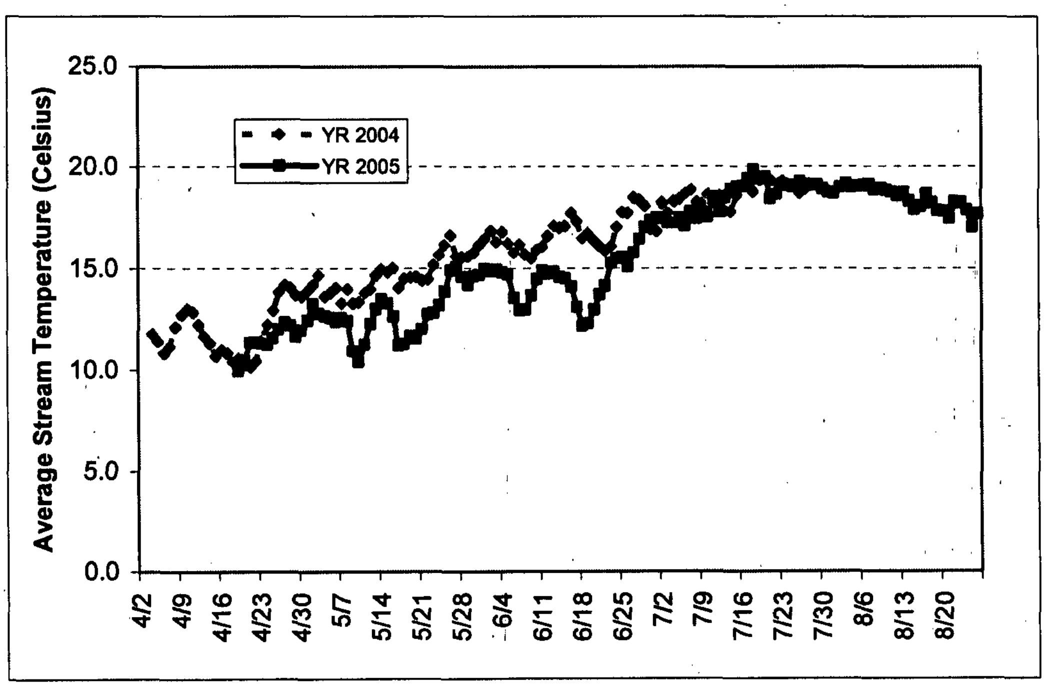

Figure 29. Average daily stream temperatures in YR 2004 and YR 2005, lower Redwood Creek, Humboldt County, CA.

DISCUSSION

The main goal of our downstream migration study in lower Redwood Creek is to estimate and monitor the production of Chinook salmon, steelhead trout, and coho salmon from the majority of the Redwood Creek watershed in a reliable, long-term manner. The long term goal is to monitor trends in smolt abundance and smolt size to detect positive or negative changes due to watershed conditions and restoration activities in the basin. Redwood Creek is a difficult, if not impossible stream to monitor for adult salmon and steelhead populations on a long term basis using traditional techniques (weirs and spawning ground surveys). However, "quantifying juvenile anadromous salmonid populations as they migrate seaward is the most direct assessment of stock performance in freshwater" (Seiler et al. 2004). In addition, studies in various streams have found that smolt numbers can relate to stream habitat quality, watershed condition, restoration activities, the number of parents that produced the cohort, and future adult populations.

The second consecutive year of trapping in lower Redwood Creek was a wet year, with average precipitation and stream flow during the trapping period greater than the historic and recent averages. Precipitation during the trapping period in YR 2005 (39.9 cm) was 1.7 times greater than the historic average, and 3.9 times greater than rainfall during YR 2004. In response, the average stream flow in which we operated the trap was about 2 times greater than the historic average, and 4.2 times greater than the average in YR 2004. Average stream flow from April – July 2005 was the fourth highest in the 54 years of record, and thus, the chance that a higher average flow will occur is about 5.6%. The increase in stream flow in YR 2005 probably led to cooler stream temperatures which in turn lowered the average stream temperature compared to YR 2004. High stream flow in YR 2005 also appeared to increase the summer base flow because we did not observe dry sections in lower Redwood Creek as in YR 2004.

Although conditions for trapping in YR 2005 were difficult, we were able to operate the trap and run multiple efficiency trials over a range of trapping conditions to produce a reliable catch and population estimate for most species at age. The 17 days we originally missed (from April 2nd to April 18th) prior to setting the trap in YR 2005 was estimated to equal 3.4 – 13.0% of a given population estimate based upon data collected in YR 2004. These percentages could be higher than what actually occurred during YR 2005 because at the more extreme flow conditions (unlike YR 2004) it appears that juvenile salmonids substantially decrease emigration as evidenced by trapping efforts in the upper basin. The population estimate least affected by the lack of trapping the initial 17 days (on a percent basis) was for 1+ steelhead trout, and the population estimate most affected was for 1+ coho salmon. The 12 days we missed trapping (after trap deployment) did not appear to greatly influence any total catch or population estimate except for 0+ steelhead trout and 1+ coho salmon. However, the catches during these 12 missed days were estimated using linear regression techniques, and then added to a given stratum for expansion to the population level (Roper and Scarnecchia 1999) to account for the (estimated) number of missed fish. The corrected population estimate for a given species at age fell within the 95% confidence interval for the uncorrected population point estimate; thus, the number of fish missed when the trap was inoperable would not have greatly impacted population estimates.

0+ Chinook Salmon

0+ Chinook salmon (ocean-type) were the most numerous migrant in both study years, however, the population emigrating in YR 2005 was much lower (by 76%) than the population emigrating in YR 2004. The reduction in population size we observed in YR 2005 could be due to: 1) decrease in the total number of spawners upstream of the trap site, 2) high bedload mobilizing flows in early December which scoured or jostled redd gravels, or 3) some combination of factors 1 and 2. Changes in spawner distributions are not likely responsible for the large decrease because Chinook salmon do not generally spawn in mainstem areas below the trap, and the number of spawners in Prairie Creek was not exceptionally large for that year. The large decrease in YR 2005 was probably not due to the lack of trapping from 4/2 – 4/18 because in YR 2004, only 10% of the juvenile Chinook salmon population emigrated during this time period. Additionally, few juveniles were captured from 4/19 – 4/31 in YR 2005.

Currently, we cannot separate effects of lower adult population size during years with high, bedload mobilizing flows on the subsequent production of juveniles because adult counts are not conducted. Several investigators have shown that the scour of redds due to high stream flows or floods can often cause severe decreases in the production of juvenile salmonids (Gangmark and Bakkala 1960, McNeil 1966, Holtby and Healey 1986, Montgomery et al. 1996, Devries 1997, Schuett-Hames et al. 2000, Seiler et al. 2003, Don Chapman pers. comm. 2003, Greene et al. 2005); and that estimates of mortality attributable to high flows and redd scour can reach 90% (Schuett-Hames et al. 2000). Greene et al. (2005) were able to show that the flood recurrence interval (and magnitude of floods) during Chinook salmon intragravel development was the second most important variable in their models used to predict the return rate of adult Chinook salmon. They further report that "large flow events may be a key factor in regulating Chinook salmon populations in the Skagit River basin, Washington" (Greene et al. 2005). High flows during December 8th (15,300 cfs) in Redwood Creek could have mobilized (or jostled) redd gravels (Mary Ann Madej pers. comm. 2006) which would then cause high egg mortality in the redd. This hypothesis is also relevant to populations upstream of the upper trap site (RM 33) because in two of the six study years, high bedload mobilizing flows occurred during the spawning season and subsequent juvenile production was severely reduced (Sparkman 2005). Adult Chinook salmon that spawned upstream of the lower trap after the high flow events in YR 2005 would not be subjected to the redd scour, and thus their progeny are more likely to be the survivors that made up the majority of the juvenile Chinook salmon population estimate for YR 2005.

0+ Chinook salmon population emigration in YR 2005 peaked in July, and lacked a large migration during June as in YR 2004 (N = 292,155). The two months within which the majority of emigration occurred was June and July in YR 2005, and May and June in YR 2004. Population emigration by week clearly showed that emigration in YR 2005 was delayed compared to YR 2004, with the peak in weekly emigration occurring four weeks later than the peak in YR 2004. Weekly population emigration in YR 2004 and YR 2005 closely resembled the catch distribution each year.

The 0+ Chinook salmon (ocean-type) emigrating from Redwood Creek exhibit two different juvenile life histories (fry and fingerling) based on size and time of downstream migration. The fry are migrating shortly after emergence from spawning redds, and therefore are much smaller than the fingerlings which have reared in the stream for a longer period of time. The emigration of 0+ Chinook salmon fry began near the onset of trapping in both study years, peaked during 4/30 – 5/6 in YR 2005 and 4/9 – 4/22 in YR 2004, and decreased to relatively low values by 5/21 in YR 2005, compared to 4/23 in YR 2004. Factors that can influence the temporal component to fry migration are: 1) time of adult spawning, 2) how far upstream of the trap the adults spawned, 3) time from egg deposition to fry emergence from redds, and 4) travel rate.

Post emergent fry migration is not unique to Redwood Creek, and many other streams experience migrations (sometimes in large numbers) of Chinook salmon fry as well (Allen and Hassler 1986, Healey 1991, Taylor and Bradford 1993, Thedinga et al. 1994, Bendock 1995, Roelofs and Klatte 1996, Meyer et al. 1998, Seiler et al. 2004, among others). Myers el al. (1998) summarized that ocean-type Chinook salmon fry can migrate immediately to the ocean in sizes ranging from 30 – 45 mm FL. Healey (1980), Carl and Healey (1984), Allen and Hassler (1986), and Healey (1991) also report that Chinook salmon fry can immediately migrate downstream to the estuary and ocean. The reasons why Chinook salmon fry migrate soon after emergence (or remain in the stream to grow into fingerlings) are elusive, difficult to prove, and generally unknown (Healey 1991). Healey (1991) covers the topic in much detail, and cites findings from authors who attributed (or speculated) fry dispersal to: 1) passive migration, 2) flow increases, 3) social interactions within species, 4) limits to rearing area (carrying capacity), 5) interactions with other species, and 6) genetics. In contrast, Healey (1991) also cites authors who reported no relationship between the number (or percentage) of fry and stream discharge, stream temperature, and rearing capacity. To summarize, Healey (1991) states that: 1) fry migration is a normal dispersal mechanism that helps re-distribute fry within the river, 2) estuaries can provide important rearing areas for fry, 3) fry are not 'lost' or surplus production, and 4) genotype may play an important role in fry migration. I used linear regression and six years of data from smolt trapping in upper Redwood Creek to investigate any relationship between stream flow (surrogate for habitat space), average stream temperature, and seasonal 0+ Chinook salmon population estimate on the percentage of emigrants each year that were fry (Sparkman 2005). None of the regression models were significant, and in fact, the regressions were highly non-significant ($p > 0.70$); therefore, no relationships between measured habitat variables or juvenile Chinook salmon population size on the percentage of fry in any given year were detected (ie no density-dependent relationship existed). Thus, the mechanism for fry dispersal from upper Redwood Creek was hypothesized to be largely genetic, and a normal component of diversity in the juvenile life history of ocean-type Chinook salmon in upper Redwood Creek.

Fingerlings have a much different migration pattern than fry as they migrate downstream through lower Redwood Creek. Fingerlings migrated in low numbers in April, increased in number over the emigration periods, and rather sharply decreased in number near the end of the emigration periods. The pattern of fingerling migration differed each year in that peak emigration in YR 2005 was four weeks later than the peak in YR 2004; and migration in YR 2005 reached low values in early August compared to mid July in YR 2004.

Fry and fingerlings also showed differences in the number and percent composition of total juvenile Chinook salmon emigration, which varied from year to year. For example, the percentage of juvenile Chinook salmon that migrated downstream as fry in YR 2004 (15%) and YR 2005 (1.6%) was much less than the percentage migrating downstream as fingerlings in YR 2004 (85%) and YR 2005 (98.4%). Fingerlings were far more abundant than fry each study year, with population abundance estimated as 427,306 in YR 2004 and 129,113 in YR 2005. Relatively larger numbers of fry were observed in YR 2004 (N = 82,854), compared to YR 2005 (N = 2,052); however, these numbers were still much less than the number of fingerlings.

The average size of 0+ Chinook salmon smolts in YR 2005 was markedly larger (by 14 mm and 2.6 g) than smolts in YR 2004, and may be related to a higher percentage of fingerlings or the smaller population size observed in YR 2005. However, in 2005 I found no statistical relationship between the overall percentage of fry or fingerlings in a given population estimate emigrating from upper Redwood Creek and average size (n = 6), but did detect a significant negative relationship of yearly 0+ Chinook salmon population emigration on average FL or Wt (Sparkman 2005). The negative relationship between population size and size of the emigrant may indicate a density-dependent relationship; with higher abundance and emigration, we see a decrease in the average FL or Wt. The density-dependent relationship may suggest that rearing space or carrying capacity (and food availability) upstream of the upper trap site was limiting the average size of Chinook salmon juveniles at higher population abundances. This same type of relationship could exist for juvenile Chinook salmon migrating through the majority of the Redwood Creek basin as well. Future trapping efforts in the lower basin should be able to detect such a relationship if it exists. If habitat is limiting the size of smolts at high abundances, successful watershed restoration in the basin should allow for the juvenile Chinook salmon to gain a larger size during years of higher abundance.

The larger average size observed in YR 2005 will most likely not compensate (as a compensatory, density-dependent effect) for the severe reduction in population emigration in YR 2005. One explanation for not compensating the low numbers with increased survival due to a larger average size (FL or Wt) for the 2005 cohort is found by examining the percentage of migrants in the fry and fingerling categories each study year. Although the population of smolts in YR 2005 was on a percentage basis mostly fingerlings, the number of fingerlings migrating in YR 2005 (N = 129,113) was much less than in YR 2004 (N = 472,306). Thus, the increase in the average size of fingerlings observed in YR 2005 would have to compensate for 343,193 less fingerlings migrating to the estuary and ocean compared to YR 2004.

Average weekly FL and Wt in YR 2005 and YR 2004 followed a similar pattern over time of starting out low and then increasing through the end of the study periods. The rather sharp increase in FL and Wt by week in YR 2004 and YR 2005 was influenced by the increasing percentage of fingerlings in the catch over time compared to fry. Unwin (1985) reported a similar finding in his trapping studies of ocean-type Chinook salmon juveniles in New Zealand. Average FL and Wt in YR 2005 from 6/10 onward was markedly higher than in YR 2004, and by the end of the emigration period, 0+ Chinook salmon were 23 mm and 5.6 g larger than emigrants at the end of the study in YR 2004. The increase in weekly FL's and Wt's over time indicate growth was taking place within the study periods. The rough or group estimate of growth in YR 2005 (0.37 mm/d and 0.07 g/d) was greater than growth in YR 2004 by about 0.07 mm/d and 0.04 g/d. The growth rate (FL) in both years fell within the range of juvenile Chinook salmon growth rates (range = 0.21 – 0.64 mm/d) measured in other streams (Healey 1991, Bendock 1995). Healey (1991) reported that growth of juvenile Chinook salmon migrants in the Sacramento River, CA equaled 0.33 mm/d during a particular study, and Bendock (1995) determined growth to equal 0.64 mm/d in Deep Creek, Alaska. In accord with Healey (1991), these group growth estimates should be viewed cautiously because we do not know exactly how long fry and fingerlings have been residing in the stream after emerging from redds. Although these growth rate estimates are for groups of fish and do not necessarily represent individual growth rates, they do take into account a variety of fish sizes and should be meaningful.

Both fry and fingerlings from upper Redwood Creek are actively moving downstream to lower Redwood Creek and the estuary. In both study years, the lower trap in Redwood Creek has captured marked efficiency trial fry and fingerlings from upper Redwood Creek. In addition, Dave Anderson (pers. comm. 2005) has consistently captured marked 0+ Chinook salmon juveniles from upper and lower Redwood Creek in the estuary.

The estimates of travel time (in days) for recaptured pit tagged 0+ Chinook salmon smolts (n = 27) released at the upper trap site should be viewed as a maximum because the lower trap caught these fish sometime prior to when the crew checks and empties the livebox at 0900. For example, if a pit tagged fish was captured at 0200 and the crew emptied the trap's livebox at 0900, then travel time would be off by 7 hours. Travel time may also be positively biased if the juveniles resided in the stream during daylight hours and primarily migrated downstream at night (likely scenario). In contrast to travel time, travel rate should be viewed as a minimum for similar reasons; the individual's rate would be higher than what was observed if they were captured prior to checking the trap's livebox, and higher if they primarily migrated at night. Nevertheless, our experiments gave insight into individual juvenile Chinook salmon migration and growth between the two trap sites, which in turn may reflect stream habitat conditions and/or the salmon stock in Redwood Creek.

The travel time for 0+ Chinook salmon smolts to migrate 29 miles downstream ranged from 1.5 - 19.5 d, and averaged 7.5 d. On average, 0+ Chinook salmon moved downstream to the lower trap in fewer days than 2+ steelhead trout (n = 7, range = 2 to 35 d, ave. = 13 d) and 1+ steelhead trout (n = 9, range = 2 to 32 d, ave. = 15 d) in YR 2004

(Sparkman 2004c). The travel time for 0+ Chinook salmon fingerlings (n = 27) to reach the lower trap was not significantly related to: 1) the size of the migrant at time 1 or time 2, 2) stream temperature, or 3) stream discharge. The recapture of pit tagged 0+ Chinook salmon per release group in YR 2005 was variable. For one release group (6/30/05), five individuals were captured on the same day at the lower trap which suggests these fish traveled together as a group. In contrast, for five separate release groups, multiple recaptures from the same release group were captured on different days at the lower trap. For example, five individuals from the 7/21 release group were recaptured at the lower trap anywhere from 4.5 – 19.5 d after release from the upper trap; these fish did not travel as a group.

Travel rate ranged from 1.5 - 19.3 mi/d (2.4 – 31.1 km/d), and averaged 8.2 miles per day (13.2 km/d). Travel rate was weakly related to the size (FL or Wt) at time 1 (initial release), such that with a greater initial size we observed a higher travel rate. Similar to travel time, travel rate was not related to stream discharge, stream temperature, or fish size at time 2 ($p > 0.05$). Healey (1991) gives results from a study in the Rogue River, Oregon in which travel rate of spring Chinook salmon fingerlings was positively related to fish size and stream discharge in one year, and negatively related to stream discharge in the following year. Quinn (2005) reported that the rate at which 0+ Chinook salmon traveled downstream in the Columbia River was positively related to size. The upper range in travel rate (31.1 km/d) for Chinook salmon fingerlings in Redwood Creek was higher than that observed in the upper Rogue River (24.0 km/d) (Healey 1991). The average travel rate from upper Redwood Creek (13.2 km/d) was also higher than the average (1.6 km/d) put forward by Allen and Hassler (1986). Unfortunately, there appears to be a lack of data in the literature to compare individual travel time and travel rate with data collected on juvenile Chinook salmon in Redwood Creek. Many of the studies using pit tags with juvenile Chinook salmon are within the Columbia River system, which for the most part is not comparable to Redwood Creek because Redwood Creek is much smaller in size, does not have impoundments, and the stream flow is unregulated, among other differences.

Individual growth was expressed using a variety of indices and equations to facilitate comparisons with information found in the literature. The majority of studies appear to report growth using one index or another which makes comparisons difficult if that growth index is not used in a given study. Compounding the problem of comparing data is the difficulty in finding studies that determined individual growth rates for 0+ Chinook salmon fingerlings, and in un-regulated river systems (not counting estuarine studies). In YR 2005, 52% of the 27 recaptured 0+ Chinook salmon fingerling smolts showed positive growth in FL and Wt, 18% showed a decrease in Wt, 48% showed no change in FL and 30% did not show a change in Wt. Absolute growth rate (FL) ranged from 0 - 0.67 mm/d, and averaged 0.22 mm/d. The average value (0.22 mm/d) is comparable to the group growth rate for Chinook salmon fingerlings in the Nitinat River (0.21 mm/d), British Columbia and about 2/3 less than the group growth rate determined in the Cowichan River (0.62 mm/d), British Columbia (Healey 1991). The average value for recaptured pit tagged fingerlings (0.22 mm/d) in Redwood Creek in YR 2005 was about 41% less than that calculated for fry and fingerlings in YR 2005 using the average weekly FL data (0.37 mm/d). However, the latter estimate is a group estimate, includes fry (which may have a higher growth rate than fingerlings) and probably is not influenced by zero growth like the average for the individual growth rates were. For example, the absolute growth rate for Chinook salmon juveniles in Redwood Creek showing only positive growth ranged from 0.19 - 0.67 mm/d and averaged 0.43 mm/d, which is fairly close to the group estimate previously calculated (0.37 mm/d).

Eighteen percent (n = 5) of the recaptured pit tagged Chinook salmon lost weight (absolute growth rate in g/d) from time of release to time of recapture (range = -0.19 to -0.39 g/d, average = -0.29 g/d). Closer examination of data for these fish reveal that four out of the five were released as a group on 6/30 and recaptured 1.5 d later; the fifth fish also had a travel time of 1.5 d. With such a short travel time, it is conceivable that these fish might have had more food in their stomachs when released than when recaptured, which could explain the apparent weight loss (loss of 0.3 – 0.6 g per fish). Alternative explanations that could apply are: 1) these fish simply spent more time traveling downstream and less time foraging for food and feeding, thereby losing weight, or 2) crews at the upper or lower trap made measurement errors. The probability that the scale malfunctioned was slight because field crews calibrated the scale each day prior to use.

The growth (positive, negative, and zero) of the 27 recaptured pit tagged 0+ Chinook salmon was successfully modeled using linear regression. The best model for any growth index included travel time as the independent variable (p ranged from 0.002 – 0.000001, R^2 ranged from 0.32 – 0.84, slope was positive for all tests); no significant relationships were detected using stream discharge or stream temperature even though the range in values for each was fairly wide. Percent change in FL was positively related to travel time, and travel time explained 84% of the variation in growth; likewise, absolute growth rate (FL) was positively related to travel time, which explained 69% of the variation in growth. Thus, fish that took longer to reach the lower trap gained more length or weight than fish that traveled the distance in a shorter amount of time. This in turn suggests fish that took a longer amount of time to migrate downstream had more time to forage for food, feed, and convert the food to growth. Beamer et al. (2004) found that the growth of juvenile ocean-type Chinook salmon (in Skagit Bay) was positively related to the amount of time that the juveniles spent in the delta.

The final size of recaptured pit tagged Chinook salmon fingerlings was positively related to the size at initial release (FL; $p < 0.0001$, $R^2 = 0.67$, power =1.0). Sixty-seven percent of the variation in the final FL was explained by the initial FL. Larger fish released at the upper trap site (time 1) were, on average, larger at recapture (time 2) than smaller fish released at the trap site and subsequently recaptured; likewise, smaller fish at time 1 were, on average, usually the smaller fish at time 2. The importance of this relationship is that fish size at the upper trap (initial size) had a large impact on fish size when they reached the lower trap (final size); the larger fish at the lower trap were more likely to have been the larger fish at the upper trap.

1+ Chinook Salmon

1+ juvenile Chinook salmon (stream-type) in Redwood Creek represent the third juvenile Chinook salmon life history, and appear to be in very low abundance as evidenced by trap catches in YR 2005 (n = 11) and YR 2004 (n = 2). Stream-type juvenile Chinook salmon are easily differentiated from ocean-type by size at time of downstream migration. The average juvenile FL in April 2005, for example, was 113 mm for 1+ Chinook salmon and 51 mm for 0+ Chinook salmon.

When present, 1+ Chinook salmon in Redwood Creek are more likely to be progeny of fall/winter-run Chinook salmon adults than from spring-run adults (Stream type) because few if any spring-run Chinook salmon are observed during spring and summer snorkel surveys in Redwood Creek (Dave Anderson, pers. comm. 2004). For example, in 21 years of adult summer steelhead snorkel dives, adult spring Chinook salmon were only observed in one year (1988) and in very low numbers (< 7 individuals) (Dave Anderson, pers. comm. 2005). Additionally, stream flows during late spring/summer months can become so low that adult upstream passage into upper Redwood Creek can become problematic. High average stream temperatures (eg > 20 °C) may also prevent any adult spring-run Chinook salmon migration into upper Redwood Creek, or inhibit their ability to over-summer in pools. Thus, a spring run of Chinook salmon adults was probably not responsible for the production of yearling Chinook salmon juveniles in Redwood Creek. Bendock (1995) also found both stream-type and ocean-type juvenile Chinook salmon in an Alaskan stream which only has one adult Chinook salmon race; and Conner et al. (2005) reported that fall Chinook salmon in the Snake River produced juveniles exhibiting an ocean-type or stream-type juvenile life history.

The 1+ Chinook salmon life history pattern may be important for increased ocean survival of Chinook salmon juveniles, and general species diversity (Don Chapman pers. comm. 2003, Sparkman 2005).

0+ Steelhead Trout

Relatively high catches of young-of-year steelhead trout by downstream migrant traps in small and large streams is not uncommon (USFWS 2001, William Pinnix pers. com. 2003, Rowe 2003, Johnson 2004, Don Chapman pers. comm. 2004, Sparkman 2005). Young-of-year steelhead trout downstream migration in Redwood Creek is considered to be stream redistribution (passive and active) because juvenile steelhead in California normally smolt and enter the ocean at one to two years old, with lesser numbers out-migrating at an age of 3^+ years (Busby et al. 1996).

The capture of 0+ steelhead trout in YR 2005 was 93% less than catches in YR 2004 and may reflect a change in the total number of adult spawners upstream of the trap site and/or a simple change in the percentage of the total 0+ juveniles (each year) that migrated downstream. The potential variable of trapping efficiency (not measured) among study years would not account for the large decrease we observed in YR 2005 because the trap was operated in the same manner as in YR 2004 (trap positioning, use of weir panels, etc).

The number of 0+ steelhead trout that can remain upstream of the trap site is considered to be some function of a fish's disposition to out-migrate (or not out-migrate) and habitat carrying capacity. Meehan and Bjornn (1991) comment that juvenile steelhead trout have a variety of migration patterns that can vary with local conditions, and that the trigger for out-migration can be genetic or environmental. They further state that some steelhead populations normally out-migrate soon after emergence from redds to occupy other rearing areas (we observe this as well in upper Redwood Creek). Habitat carrying capacity is generally thought to be related to environmental (hydrology, geomorphology, stream depth and discharge, stream temperatures, cover, sedimentation, etc) and biological variables (food availability, predation, salmonid behavior), and any interactions between the two (Murphy and Meehan 1991). The general idea is that when habitat carrying capacity is exceeded (over-seeding), the juvenile fish emigrate to find other areas to rear. A problem with the view of habitat carrying capacity's affect on migration is that it fails to explain why juvenile fish emigrate at low densities or low population levels.

0+ steelhead trout migration in YR 2005 was markedly different than migration in YR 2004. The peak in migration in YR 2005 occurred during May and the peak in YR 2004 occurred in June. In addition, weekly migration during 5/20 – 7/22, 2005 was considerably less than migration during this same time period in YR 2004.

The average FL in YR 2005 was about 1.5 mm greater than the average FL in YR 2004. The increase in size of migrants in YR 2005 was substantiated by a growth rate (0.34 mm/d) that was about 0.05 mm/d greater than the growth rate in YR 2004. However, these differences among years are un-likely to be biologically meaningful because of being so small. Average weekly FL increased over time each study year and indicate growth was taking place, which in turn suggests habitat conditions and the availability of prey items were sufficient for growth. Average weekly FL's during the first five weeks of trapping in YR 2005 were dominated by emergent fry, compared to the first 3 weeks in YR 2004. The rather sharp increase in weekly FL starting 5/21/2005 and 4/23/2004 was probably influenced by the increasing percentage of parr in the catch compared to fry.

The 0+ steelhead trout captured by the lower trap indicate these fish are going to rear for some time period in lower Redwood Creek, including the estuary. Dave Anderson (pers. comm. 2005), for example, routinely captures young-of-year steelhead trout (and coho salmon) in the estuary during summer and early fall sampling; thus, the condition of lower Redwood Creek and the estuary can impact 0+ steelhead trout.

1+ Steelhead Trout

One-year old steelhead trout were the most numerous juvenile steelhead migrating downstream in both study years. The ratio of 1+ steelhead trout to 0+ steelhead trout to

2+ steelhead trout was 4:1:1 in YR 2004 and 4:0.2:1 in YR 2005. On a percentage basis, 1+ steelhead trout comprised 67 and 76% of total juvenile steelhead downstream migration each study year. Population emigration in YR 2005 was 57% lower than emigration in YR 2004. The apparent decrease in numbers in YR 2005 was not due to the lack of trapping because only 3.4% of the population was estimated to emigrate from 4/2 – 4/18; and for the 12 days missed trapping, an estimated 3.9% (or 1,222 individuals) of the total population size was missed due to trap non-deployment. The estimated number of 1+ steelhead trout emigrating during the 12 days we missed trapping was included in the population estimate, thus the remaining 3.4% emigrating from 4/2 – 4/18 would have had a negligible effect on the total population estimate for 1+ steelhead trout in YR 2005.

In addition to a decrease in population abundance in YR 2005, there were temporal differences in migration. In YR 2005, slightly higher numbers of 1+ steelhead trout emigrated in April; and in YR 2004, more 1+ steelhead trout emigrated during May than other months. The two most important months in YR 2005 were April and May, compared to May and June for YR 2004. The pattern of emigration by week among the two study years was strikingly different. In YR 2005, migration was highest in the beginning of trapping, reached very low values during June to mid July, and then showed a small increase in numbers followed by a decrease to the end of the study period (late August). Weekly migration in YR 2004 showed a bell curve shaped pattern, such that migration was low in the beginning of trapping, peaked near the middle of the trapping period, and then decreased to the end of the study period with the exception of a few small increases on the descending limb of the curve. The peak in weekly population emigration was also different each study year, such that the peak in YR 2005 was two weeks earlier than the peak in YR 2004. Weekly population emigration in YR 2004 and YR 2005 closely resembled the catch distribution each year.

The large decline in 1+ steelhead trout emigrating from 5/7 – 7/15 in YR 2005 caused the population estimate to be much lower than the estimate for YR 2004; migration during this time period in YR 2005 equaled 6,680 individuals (or 21% of total) compared to 61,229 (or 79% of total) in YR 2004. The variation in trapping efficiencies among years during this time period cannot reasonably explain the large difference in numbers because there was only a 3% difference in efficiency. Thus, the large decrease observed in YR 2005 was not due to trap operation, and more likely represented an actual difference among years. This rationale also applies to the difference in total population emigration between YR 2004 and YR 2005.

The average size of 1+ steelhead trout migrants in YR 2005 (90.8 mm, 8.31 g) was about 6 mm and 1.3 g greater than the average for 1+ steelhead trout in YR 2004. The average weekly FL and Wt in YR 2005 was significantly greater than weekly FL and Wt in YR 2004. The larger size of 1+ steelhead trout could be attributable to a lower population size, assuming a negative influence of population size on average FL and Wt (density-dependence). However, for the past six consecutive years of trapping in the upper basin, I found that the average size of 1+ steelhead trout increased with increasing population size; and then speculated that if stream conditions were favorable for survival, they could also be favorable for growth (Sparkman 2005). Whether this will be true for 1+ steelhead migrating through lower Redwood Creek remains to be tested with more years of data collection.

The average FL and Wt over time (weeks) in both study years did not statistically change over the study period. This is not too surprising when viewing graphical representations of the data because in both years the size of 1+ steelhead trout started out relatively low, increased to reach a maximum, and then decreased to values nearly equal to the starting size. The increase in size near the middle of the trapping period warrants further investigation, such as an evaluation of diet and stomach contents. There may also be a relationship of increased food abundance (insects, Chinook salmon and steelhead trout fry, etc) for migrants during this time period. Warmer stream temperatures, within the normal range for growth, may also play a role.

Information in the literature indicates that steelhead smolting at age 1 is not uncommon, particularly in streams that are south of British Columbia (Quinn 2005, Busby et al. 1996). The percentage of 1+ steelhead trout showing parr characteristics in Redwood Creek was very low each study year (0.2%), and indicates that few 1+ steelhead trout migrated downstream in a stream-residence form (parr). In contrast, the majority of 1+ steelhead trout were emigrating in a smolt stage. The percentage of 1+ steelhead trout showing smolt characteristics in YR 2005 (86%) was greater than the percentage in YR 2004 (68%). This difference is likely to be real because between-observer variation was minimized in three different ways: 1) each crew member used the same protocol, 2) each crew member was thoroughly trained and tested, and 3) most of the crew members had worked on this study the previous year. In my report on trapping in upper Redwood Creek in YR 2005 (Sparkman 2005), I was able to statistically show that the percentage of 1+ steelhead trout showing smolt characteristics each year (n = 6) was negatively related to average stream temperature and positively related to average stream discharge during the trapping periods. Thus, more 1+ steelhead trout were in a smolt stage during years with colder temperatures and higher stream discharge. Whether this will be true for 1+ steelhead trout migrating through lower Redwood Creek remains to be seen. Quinn (2005) reported that both photo period and steam temperature play important roles in smoltification by providing an external stimulus for the endocrine system, which in turn drives the internal physiological changes necessary for smoltification.

1+ steelhead trout are actively migrating from the upper basin to the lower basin and estuary, as evidenced by trap catches in lower Redwood Creek of efficiency trial fish, elastomer marked fish, and pit tagged fish released from the upper trap. The marked 1+ steelhead trout emigrating from upper Redwood Creek and through lower Redwood Creek have also been captured in the estuary (Dave Anderson, pers. comm. 2005) since the beginning of our smolt trapping studies. The time required for 1+ steelhead trout to travel the 29 miles from the upper trap to the lower trap (n = 5) in YR 2005 ranged from 2 – 35 d, and averaged 12.4 d. These values were close to the 1+ steelhead trout travel time determined in YR 2004 (n = 9, ranged from 2 – 32 d, average = 14.9 d). Travel rate (mi/d) in YR 2005 ranged from 0.8 – 14.5 mi/d and averaged 5.8 mi/d; in YR 2004 travel

rate ranged from 0.9 – 14.9 mi/d, and averaged 4.3 mi/d. Thus, 1+ steelhead trout, on average, traveled at a higher rate in YR 2005 compared to YR 2004.
As previously mentioned, far more 1+ steelhead trout emigrated past the lower trap than other juvenile steelhead age-classes (0+, 2+). 1+ steelhead trout downstream migration is not unique to Redwood Creek, and other downstream migration studies have routinely documented 1+ steelhead trout emigration (USWFW 2001, Ward et al. 2002, Johnson 2004; among many others). However, the ratio of 1+ steelhead trout to 2+ steelhead trout (4:1 in both years) in Redwood Creek was much different than that determined in a nearby river (Mad River). In 2002, I reported that for two years of smolt trapping in the Mad River, the ratio of 1+ steelhead trout to 2+ steelhead trout equaled 1:6 (YR 2001) and 1:3 (YR 2002) (Sparkman 2002). The variability in trap locations among streams (Redwood Cr RM 4, Mad River RM 12.5) would probably not account for these differences.

Based upon studies in other streams, the number of returning adult steelhead trout that migrated to the ocean as one-year-old smolts is relatively low, and usually less than 29% (Pautzke and Meigs 1941, Maher and Larkin 1955, Busby et al. 1996, McCubbing 2002). Based upon a limited number of scale samples from adult steelhead trout (n = 10) collected in Redwood Creek, 30% of the adults entered the ocean as one-year-old juveniles. The most successful juvenile steelhead migrants to reach adulthood were 2+ steelhead trout. Therefore, the reason(s) for the large number of 1+ steelhead trout emigrating from the basin of Redwood Creek warrants further investigation. Pit tagging 1+ steelhead smolts should provide useful insights when conducted over multiple, consecutive years because if most of the 1+ steelhead trout are not actually entering the ocean, we should then be able to recapture a given percentage of those fish the following year with the rotary screw trap in lower Redwood Creek and seine nets in the estuary; if we fail to recapture any of the marked 1+ steelhead trout the following year, then a logical conclusion would be that the fish either stayed in the stream and suffered severe mortality during winter, actually entered the ocean, or some combination of the two factors.

2+ Steelhead Trout

In several studies investigating steelhead life histories, the majority of the returning adult steelhead spent two or more years as juveniles in freshwater prior to ocean entry (Pautzke and Meigs 1941, Maher and Larkin 1955, Busby et al. 1996, Smith and Ward 2000, McCubbing 2002). Pautzke and Meigs (1941), for example, reported that 84% of returning adult steelhead in the Green River had spent two or more years as juveniles in freshwater. Maher and Larkin (1955) found that 98% of the adult steelhead they examined had spent two or more years in freshwater prior to entering the ocean, and McCubbing (2002) reported 92% of steelhead adults in a British Columbia stream had spent two or more years as juveniles in freshwater. If this applies to steelhead trout in Redwood Creek, then 2+ steelhead trout are the most important (and most direct) group of juvenile steelhead trout that contribute to future adult steelhead trout populations. The paradox for the 2+ steelhead trout smolt in Redwood Creek is that it was far less abundant than 1+ steelhead trout smolts in both study years.

The population of 2+ steelhead trout smolts in YR 2005 was about 55% lower than the estimate in YR 2004. Similar to 0+ Chinook salmon and 1+ steelhead trout, the large decrease in numbers observed in YR 2005 was not due to the lack of trapping because 11% of the population was estimated to emigrate from 4/2 – 4/18. Eleven percent of the population expected to be missed would equal about 963 fish. The estimated number of 2+ steelhead trout emigrating during the 12 days we missed trapping was included in the population estimate, thus the remaining 11% emigrating prior to trap placement would have a negligible influence on population size. In addition, the 95% confidence interval for the YR 2005 estimate would encompass the 11% if added to the population estimate. Confidence intervals (and percent error) for 2+ steelhead trout population estimates were larger than the 95% confidence intervals for 1+ steelhead trout because: 1) 2+ steelhead trout are typically harder to catch than younger age-classes of steelhead trout, and 2) sample size for marking and subsequent recapture was low. During the trapping period we routinely adjust trap configuration and install weir panels to increase the capture efficiency of 2+ steelhead trout. Additionally, we perform numerous mark/recapture trials, and when combined with altering trap configuration and paneling, are able to produce a fairly reliable population estimate.

2+ steelhead trout migrated through lower Redwood Creek in higher numbers in May during both study years. However, the two most important months for emigration were April and May for YR 2005, and May and June for YR 2004. Migration in both study years dropped to very low values after mid June, with the exception of a few small peaks.

The weekly migration of 2+ steelhead trout at the population level in YR 2005 was positively influenced by stream discharge and stream gage height, and negatively related to trapping week number. Thus, more 2+ steelhead trout migrated during times when the stream flow was moderately high and stream temperatures were relatively cool. However, like other juvenile salmonids in Redwood Creek, they seem to substantially decrease migration during periods of high and turbid stream flow. A likely explanation is that the juvenile salmonids simply find refuge during high stream flow events. 2+ steelhead trout emigrating from the upper basin in YR 2005 also showed this migration pattern with respect to stream flow, gage height, and trapping week number (Sparkman 2005). The pattern of emigration by week among the study years was obviously different. In YR 2005, migration was highest during the first half of the study period, and from June 11th onward, was relatively low. In YR 2004, the pattern of migration approximated a bell curve shaped pattern, with the exception that emigration during the first three weeks was higher than the fourth week. Similar to YR 2005, migration from mid June onward in YR 2004 was much less than emigration during the first half of the study period. Weekly peaks in emigration occurred during the same time period each study year (4/30 – 5/6). Weekly population emigration in YR 2004 and YR 2005 also closely resembled the catch distribution each year.

Weekly migration through lower Redwood Creek in YR 2005 lacked a large number of migrants from 5/7 – 5/27 compared to migration in YR 2004. For example, the 2+ steelhead trout smolt population that emigrated during this time period equaled 7,365 (or 38% of total) in YR 2004 compared to 985 (or 11% of total) in YR 2005. The variation in trapping efficiencies among years during this time period cannot reasonably explain the large difference in numbers because there was only a 1% difference in trapping efficiency. Thus, the large decrease observed in YR 2005 was not due to trap operation, and more likely represented an actual difference in population emigration among years. The pattern of 2+ steelhead trout migration by week in YR 2005 was markedly similar to the pattern for 1+ steelhead trout in YR 2005, and may indicate that these fish travel together in schools. Data collected at the upper trap also shows that the two age classes appear to have very similar weekly migration patterns (Sparkman 2005).

The average fork length of 2+ steelhead smolts in YR 2005 (143.2 mm) was about 1 mm less than the average in YR 2004, and average weight in YR 2005 (31.25 g) was about 0.6 g less than the average in YR 2004. The average weekly FL and Wt in YR 2005 was not significantly different than the averages in YR 2004. The pattern of average weekly FL and Wt in YR 2005 was similar to YR 2004 in that values were relatively high in the beginning of trapping, decreased in value to the middle of trapping, and then increased in value to the end of the study period. However, average weekly FL and Wt significantly changed over time in YR 2004 but not in YR 2005. These results are not surprising when examining graphical representations of the data because the starting values in YR 2004 were greater than the ending values; and in YR 2005, the starting values were about the same as the ending values. 2+ steelhead trout smolts emigrating from upper Redwood Creek in YR 2005 showed the same pattern in FL and Wt over time as 2+ steelhead trout emigrating through lower Redwood Creek in YR 2005 (Sparkman 2005).

The percentage of 2+ steelhead trout emigrants showing smolt characteristics in YR 2005 (98%) was greater than YR 2004 (94% were smolts). The number of parr designations was zero each year, and indicated that 2+ steelhead trout did not emigrate through lower Redwood Creek in a stream-resident form (parr). My analysis of trapping data in upper Redwood Creek showed that the 2+ steelhead trout smolt index was negatively related to 2+ steelhead trout population size, and negatively related to average stream temperature during the study period (Sparkman 2005). Whether this will be true for 2+ steelhead trout populations emigrating through lower Redwood Creek remains to be tested.

2+ steelhead trout are actively emigrating from upper Redwood Creek because the lower trap in Redwood Creek (RM 4) has consistently captured efficiency trial fish and elastomer marked fish released from the upper trap site in both years of operation. Additionally, 2+ steelhead trout from upper Redwood Creek have been observed in the estuary of Redwood Creek every year since the beginning of our smolt trapping studies (Dave Anderson, pers. comm. 2005). The time required for one 2+ steelhead trout released from upper Redwood Creek to travel to the trap in lower Redwood Creek equaled 7 d in YR 2005. In YR 2004, the time required to travel from the upper trap to the lower trap ranged from 2 – 35 d, and averaged 13 d. Future trapping efforts will try to increase the sample size of recaptured 2+ steelhead trout for travel time experiments by increasing the sample size of releases from the upper trapping site.

Although there seems to be few studies that specifically look at steelhead smolt to adult survival, steelhead life history studies in a British Columbia stream (Keogh River) show there is a positive linear relationship between out-migrating 2+ smolts and returning adult steelhead (Ward and Slaney 1988, Ward 2000, Ward et al. 2002). Ward (2000) cites other authors who report similar positive linear relationships between smolts and adults along the British Columbia coast as well (eg Smith and Ward 2000). Survival from smolt to adult can be variable, and may range from an average of 15% (during 1976-1989) to an average of 3.5% (during 1990-1995) (Ward 2000). Ward and Slaney (1988), reporting on data from the Keogh River for 1978 – 1982 cohorts, determined survival from smolt to adult ranged from 7% to 26%, and averaged 16%. Meehan and Bjornn (1991) reported steelhead smolt to returning adult survival can be a relative high ranging from 10 – 20% in streams that are coastal to a low survival of 2% in streams where steelhead must overcome dams and travel long distances to reach spawning grounds. It is difficult to make specific inferences about 2+ steelhead smolt to adult survival for Redwood Creek steelhead based upon successful studies in the literature because of differences in latitude/longitude, geography, ocean conditions (physical and biological), estuaries, and trap locations in the watershed. However, the belief that the number of 2+ smolts relate to future adults (and watershed conditions) is hard to dismiss or invalidate.

With respect to younger juvenile stages (0+ and 1+), the 2+ steelhead smolt is the best candidate for assessing steelhead status, trends, and abundance when information on adult steelhead is unavailable or un-attainable. 2+ steelhead trout have overcome the numerous components of stream survival that younger steelhead (0+ and 1+) have not yet completely faced (over-summer, over-winter, etc), and 2+ steelhead smolts are also the most direct recruit to adult steelhead populations. Along these same lines, Ward et al. (2003) reported that the 2+ steelhead smolt was a more reliable response variable with respect to stream restoration than late summer juvenile densities because of being less variable.

Cutthroat Trout

A low number of cutthroat trout were captured in both study years relative to other juvenile salmonid species. Catches in YR 2004, for example, equaled 37 and catches in YR 2005 equaled 9. Cutthroat trout were caught in six of 19 total weeks of trap operation in YR 2005, with no discernable peak in weekly catches. In contrast, cutthroat trout catches in YR 2004 peaked during 5/14 – 5/20.

All cutthroat trout that were captured were in a smolt stage. An unknown number or percentage of cutthroat trout will residualize in the stream for varying years, and not out-migrate to the estuary and ocean; thus the low trap catches may not necessarily reflect a low population size in Redwood Creek. However, if there were large numbers present, we would probably catch much more than we do, as they re-distribute or migrate downstream. For example, juvenile salmonid trapping efforts in Prairie Creek consistently capture hundreds of cutthroat trout during spring/early summer as they migrate downstream (Roelofs and Klatte 1996, Roelofs and Sparkman 1999, Walt Duffy, pers. comm. 2003).

We did not consider any of the young-of-year steelhead trout to be progeny of cutthroat trout because few aged 1 and older cutthroat trout were captured in any given year. Far more older juvenile steelhead trout (1+ and 2+) migrated through lower Redwood Creek than cutthroat trout as evidenced by trap catches. In the two study years, for example, the ratio of 1+ and 2+ steelhead trout combined catches to cutthroat trout catches each year equaled 197:1 and 272:1, and using all data equaled 211:1. Ratios would be even higher if juvenile steelhead trout population data were used instead of catch data, and it seems very unlikely that low numbers of cutthroat trout could produce a significant portion of the juvenile trout captures. Therefore, we considered the percentage of 0+ cutthroat trout included in the 0+ steelhead trout catch to be low and negligible.

We used three characteristics to identify coastal cutthroat trout: upper maxillary that extends past the posterior portion of the eye, slash marks on the lower jaws, and hyoid teeth; spotting is also usually more abundant on cutthroat trout. Hybrid juveniles, the product of mating between steelhead trout and cutthroat trout, are commonly noted to be missing one or two of these characters. We have not observed any hybrids in the two years of study, and based upon visual identification, the number of potential hybrids (age 1 and greater) is extremely rare in Redwood Creek.

0+ Pink Salmon

Pink salmon in California are recognized as a "Species of Special Concern", and California is recognized as the most southern border for the species (CDFG 1995). Although not in large numbers, pink salmon have been historically observed in the San Lorenzo River, Sacramento River and tributaries, Klamath River, Garcia River, Ten Mile River, Lagunitas River, Russian River, American River, Mad River, and once in Prairie Creek, which is tributary to Redwood Creek at RM 3.7. Pink salmon were observed spawning in the Garcia River in 1937, and the Russian River in 1955 (CDFG 1995). More recently, adult pink salmon were seen spawning in the Garcia River in 2003 (Scott Monday pers. comm. 2004) and in Lost Man Creek (tributary to Prairie Creek) in 2004 (Baker Holden, pers. comm. 2005).

I know of no historic records or anecdotal information documenting pink salmon presence in the mainstem of Redwood Creek prior to our downstream migration trapping efforts. The pink salmon in Redwood Creek are in very low numbers, and prior to study year 2005, were only caught in even numbered years (e.g. YR 2000, YR 2002, and YR 2004) at the upper trap site. The two individuals caught in lower Redwood Creek in YR 2005 may indicate that pink salmon are now spawning upstream of the trap site in even and odd numbered years.

It is hard to say if the parents of the pink salmon were stays or remnants of a historic run because so little information exists about adult salmon in Redwood Creek. According to the Habitat Conservation Planning Branch (HCPB) of CDFG, pink salmon are considered to be "probably extinct" in California (CDFG 1995). However, the HCPB does state that "more efforts need to be conducted to prove (or disprove) that reproducing populations exist anywhere in California" (CDFG 1995). Based upon our trapping data, it appears that pink salmon are present in Redwood Creek and reproducing, albeit in low numbers.

Coho Salmon

0+ Coho Salmon

Few 0+ coho salmon were captured by the lower trap in either study year (YR 2004, n = 202; YR 2005, n = 53). 0+ coho salmon catches at the lower trap occurred in every month of trap operation, and for both study years, more were captured in July than other months. The two most important months for emigration was May and July for YR 2004 and June and July for YR 2005. The low catches of 0+ coho salmon in lower Redwood Creek is contrasted by often high catches in Prairie Creek. For example, trap catches of 0+ coho salmon in Prairie Creek from 1996 – 1998 ranged from a low of 372 to a high of 25,492, and averaged 9,659 per trapping season (Roelofs and Sparkman 1999). 0+ coho salmon catches at the lower trap indicate that these fish were moving downstream to rear. If the young-of-year coho do not move into Prairie Creek, then they must be moving downstream to the estuary. Thus, lower Redwood Creek and the estuary may serve as an important place for young-of-year coho salmon to rear.

1+ Coho Salmon

Low numbers of one plus-year-old coho salmon were caught at the lower trap in both study years (YR 2004, n = 69; YR 2005, n = 39) prior to mid June; no catches occurred after June 17th. Similar to 0+ coho salmon, the low catches of 1+ coho salmon in lower Redwood Creek is contrasted by much higher catches in Prairie Creek. For example, trap catches of 1+ coho salmon in Prairie Creek from 1996 – 1999 ranged from 1,475 – 2,302, and averaged 1,965 per trapping season (Roelofs and Sparkman 1999).

I did not calculate a 1+ coho salmon population estimate using 1+ coho salmon mark/recapture data in YR 2004 because I originally expected a very poor estimate based upon a low number of marked releases and subsequent recaptures. However, I re-calculated the estimate for YR 2004 in YR 2005 to compare with the mark/recapture based estimate determined in YR 2005, and discovered that the population estimate wasn't as bad as originally thought. However, the estimated error for population estimates in both study years was high (63% for YR 2004, 69% for YR 2005), which is most likely due to small sample sizes for mark/recapture experiments. The lack of trapping the initial 19 days in YR 2005 was estimated to affect the 1+ coho salmon population estimate (26% of total) more than other species at age, however, it is unlikely that enough fish were missed to allow the point estimate to fall outside of the rather wide

95% CI. The population estimates I determined for 1+ coho salmon should be viewed cautiously, and the proper context could be that we are 95% sure that the population during either study year was less than 900 individuals (upper 95%CI for YR 2004 estimate). Population emigration of less than 900 individuals can be considered very low (alarmingly so), particularly for a stream the size of Redwood Creek.

1+ coho salmon emigrated in higher numbers in May during both study periods compared to other months. In YR 2004, for example, an estimated 70% of the total migrated in May, and in YR 2005, an estimated 69% of the total migrated in May; population emigration was basically over by the end of May. The two most important months for migration occurred in April and May for both study years, and the peak in weekly emigration in YR 2005 was one week later than the peak in YR 2004. Weekly population emigration in YR 2004 and YR 2005 closely resembled the catch distribution each year.

The reason(s) for the lack of sufficient numbers of 1+ coho salmon emigrating from Redwood Creek warrants further study.

CONCLUSIONS

The migration of juvenile salmonids from the majority of the Redwood Creek basin in YR 2005 was much lower than emigration in YR 2004 for all species at age. 0+ Chinook salmon experienced the greatest reduction (76%) in population size. The reduction could be attributable to high winter flows which either scoured or jostled redd gravels in early December, a simple decrease in the number of adult spawners upstream of the trap site, or a combination of the two factors. Higher numbers of 0+ Chinook salmon migrated through lower Redwood Creek in June in YR 2004, compared to July in YR 2005. The population of 0+ Chinook salmon emigrants in YRS 2004 and 2005 consisted of both fry and fingerlings, with fingerlings comprising the majority of the migrants. The average size of 0+ Chinook salmon migrants in YR 2005 was considerably larger than the average size in YR 2004, and could be a function of decreased population size or higher average size of fingerlings observed in YR 2005. The average size by week in both study years increased over the duration of the study period, and indicates that growth occurred. Both 0+ Chinook salmon fry and fingerlings from upper Redwood Creek are migrating downstream to lower Redwood Creek and the estuary. Travel time and growth experiments of pit tagged 0+ Chinook salmon released in upper Redwood Creek and recaptured in lower Redwood Creek were successful. Travel time ranged from 1.5 – 19.5 d, and averaged 7.5 d. Travel rate ranged from 1.5 – 19.3 mi/d, and averaged 8.2 mi/d. Travel rate was positively related, albeit weakly, to fish size at Time 1, whereas no statistical relationships of independent variables could be found with travel time (except the positive relationship with growth). 0+ Chinook salmon fingerlings, on average, traveled from upper Redwood Creek to lower Redwood Creek in less days than 1+ or 2+ steelhead trout in YR 2004 and YR 2005. Fifty-two percent of the downstream migrating pit tagged 0+ Chinook salmon showed growth (FL, Wt), 18% showed a decrease in Wt, 48% showed no change in FL, and 30% showed no change in Wt. Growth was positively related to travel time and negatively related to travel rate. Thus, fish that took longer to reach the lower trap gained more FL and Wt than fish that traveled the distance in less amount of time. The final size of recaptured pit tagged 0+ Chinook salmon was positively related to the initial size at tagging. The importance of this relationship is that fish size at the upper trap (initial size) had a large impact on fish size at the lower trap (final size); larger fish recaptured at the lower trap were more likely to have been the larger fish released at the upper trap.

0+ steelhead trout were captured in each week of the trapping period in both study years; however, very few 0+ steelhead trout were captured in YR 2005 compared with YR 2004. The difference in catch between years was an order of magnitude. Most of the 0+ steelhead trout were captured in June and July in YR 2004, compared to May and July in YR 2005. Migration during 5/20 – 7/22 was considerably less in YR 2005 compared to YR 2004. Average weekly FL's during the first three weeks of trapping in YR 2004 were dominated by emergent fry, compared to the first five weeks in YR 2005. Average weekly FL increased over the study period each year, and indicated that growth occurred. Sharp increases in FL over time in both years were probably influenced by the increasing percentage of parr in the catch compared to fry. Catches of 0+ steelhead trout in lower Redwood Creek indicate that these fish are going to rear for some time period in lower Redwood Creek and the estuary; thus, the condition of these habitats can impact 0+ steelhead trout.

1+ steelhead trout were the most numerous juvenile steelhead trout migrating downstream in both study years. Population emigration in YR 2005 was 57% lower than emigration in YR 2004. The large decline observed in YR 2005 was attributable to very low emigration (N = 6,680) during 5/7 – 7/15 which accounted for only 21% of total emigration. Emigration during this time period in YR 2004 equaled 61,229 individuals or 79% of the total for that year. The average size of 1+ steelhead migrants in YR 2005 was significantly greater than in YR 2004, and the pattern in average FL and Wt over time was fairly similar between study years. The percentage of 1+ steelhead trout showing smolt characteristics was higher in YR 2005 (86%) than YR 2004 (68%), and could be related to differences in stream discharge and water temperature among years. 1+ steelhead trout are actively migrating from upper Redwood Creek to lower Redwood Creek and the estuary based upon various recaptures of marked fish released from upper Redwood Creek. The time required for 1+ steelhead trout to travel the 29 miles between traps in YR 2005 averaged 12.4 d, which was close to the average value (14.9 d) determined in YR 2004. Travel rate averaged 5.8 mi/d in YR 2005, compared to 4.3 mi/d in YR 2004; thus, 1+ steelhead trout, on average, traveled the distance in a shorter amount of time in YR 2005 compared to YR 2004. The large number of 1+ steelhead trout emigrants compared to 2+ steelhead trout emigrants warrants further study, particularly if the majority of returning adult steelhead spend two years in freshwater prior to ocean entry.

2+ steelhead trout are probably the most important group of juvenile steelhead trout that contribute to adult steelhead trout populations in Redwood Creek. However, as previously mentioned, the paradox is that 2+ steelhead trout are much less numerous than 1+ steelhead trout. The ratio, for example, of 2+ steelhead trout to 1+ steelhead trout equaled 1:4 in both study years. The population of 2+ steelhead trout smolts in YR 2005 was 55% lower than emigration in YR 2004. The large decrease in numbers observed in YR 2005 could be attributed to very low emigration during 5/7 – 5/27, which in YR 2004 was a period of considerable migration (7,365 smolts, or 38% of the population). The most important month for emigration in both study years occurred in May, and migration beyond mid June was low in each study year. The pattern of 2+ steelhead trout weekly migration was strikingly similar to 1+ steelhead trout migration, and may indicate that both age classes traveled together as a group. The average size of 2+ steelhead trout in YR 2005 was slightly lower than the average size in YR 2004. Patterns of average FL and Wt over time (week) were similar among study years. Experiments of travel time and growth of 2+ steelhead trout marked and released in upper Redwood Creek and recaptured in lower Redwood Creek were unsuccessful, mainly due to low sample size and low recapture probability for marked releases. Future trapping efforts will try to increase the sample size of recaptured 2+ steelhead trout for travel time and growth experiments by increasing the sample size of marked releases from the upper trapping site.

Few cutthroat trout were captured in either study year relative to other juvenile salmonids, and therefore are considered to be in low abundance in Redwood Creek. However, additional sampling methods are warranted to further investigate cutthroat trout population size, status, and distribution in Redwood Creek.

Juvenile pink salmon were captured in lower Redwood Creek in YR 2005 in very low numbers (n = 2). However, prior to our work in Redwood Creek, no known or recorded observation(s) existed. Thus, downstream migrant trapping proved useful for showing that pink salmon, albeit in low numbers, are present in Redwood Creek.

Both 0+ and 1+ coho salmon migrants were in very low abundance in both study years. 0+ coho salmon were mostly captured towards the end of the study period, and contrasts the capture of 1+ coho salmon which occurred during the first two months of the study period. The migration of 1+ coho salmon ceased after June 10th in YR 2004 and May 27th in YR 2005. 1+ coho salmon smolts, at the population level, equaled 535 in YR 2004 compared to 183 in YR 2005. Although the point estimates had considerable error, the fact that few 1+ coho salmon smolts emigrated from the majority of the Redwood Creek basin upstream of Prairie Creek was apparent. Prairie Creek appears to be a very important stronghold for coho salmon populations in the Redwood Creek basin.

RECOMMENDATIONS

This study is one of the few studies that is designed to document smolt abundance and population trends of the California Coastal Chinook salmon ESU, Southern Oregon/Northern California Coasts Coho salmon ESU, and Northern California

Steelhead Trout ESU over a relatively, long time period. With respect to the Chinook salmon ESU, this study might be the only one that provides population data for a relatively large stream.

The most important recommendation to make is to continue the study over multiple consecutive years (10+) in order to:

1. Collect base line data for future comparisons.

2. Detect changes in population abundance which can be used to assess the status and trends of Chinook salmon, steelhead trout, and coho salmon in Redwood Creek.

3. Detect any fish response (population, smolt size, etc) to stream and watershed restoration.

4. Help focus habitat restoration efforts and needs in the basin.

5. Offer data for comparison with other downstream migration smolt studies.

This study, when combined with juvenile salmonid smolt monitoring in the upper basin and the estuary will also help determine potential bottlenecks to anadromous salmonid production in Redwood Creek.

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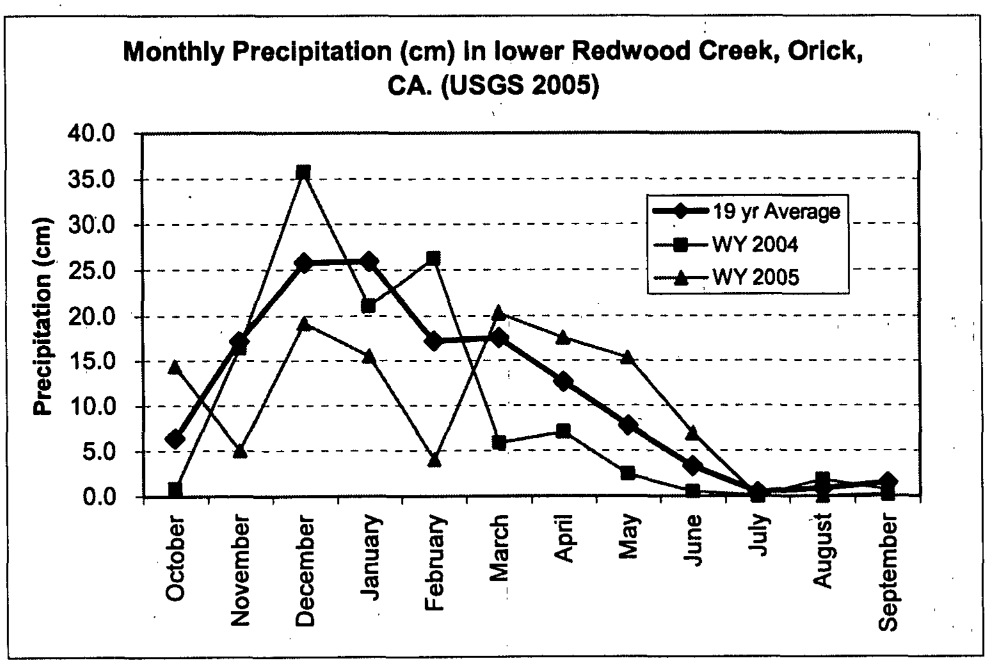
APPENDICES

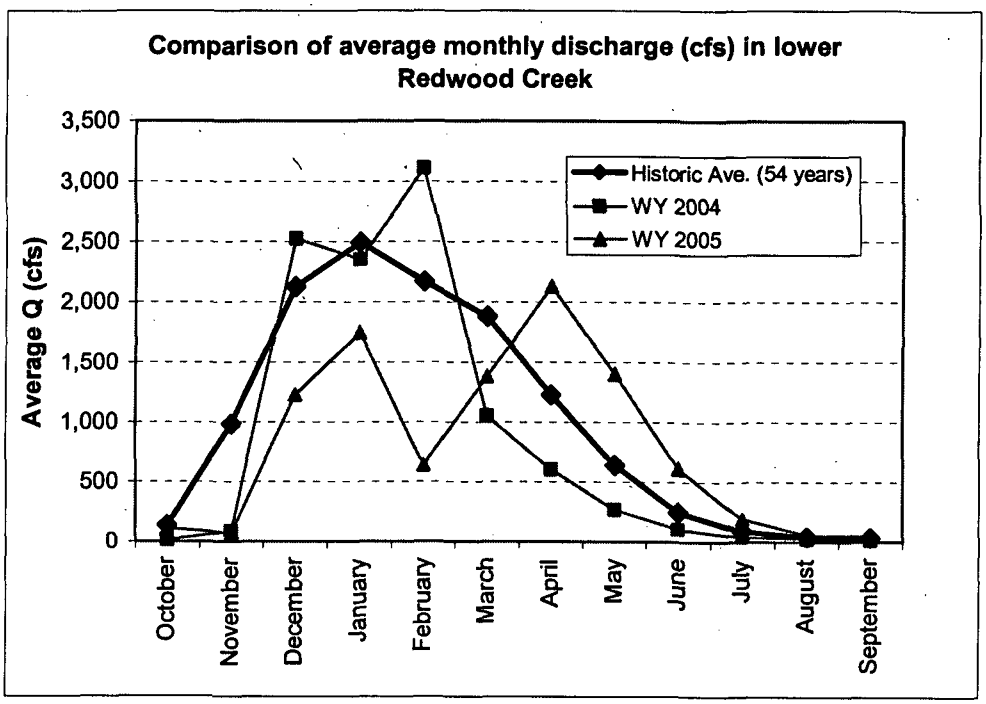
Appendix 1. Comparison of 19 year average monthly precipitation with monthly precipitation in WY 2004 and WY 2005, lower Redwood Creek, Orick, CA. (USGS 2005).

	Monthly Precipitation (cm)		
Month	Historic	WY 2004	WY 2005
October	6.5	0.8	14.4
November	17.2	16.5	5.1
December	25.8	35.8	19.2
January	25.9	21.0	15.5
February	17.3	26.3	4.1
March	17.6	5.9	20.3
April	12.6	7.1	17.6
May	7.8	2.4	15.3
June	3.3	0.5	7.0
July	0.4	0.1	0.0
August	0.9	1.8	0.0
September	1.5	0.7	0.2
Total:	136.8	119.0	118.8
Average:	11.4	9.9	9.9

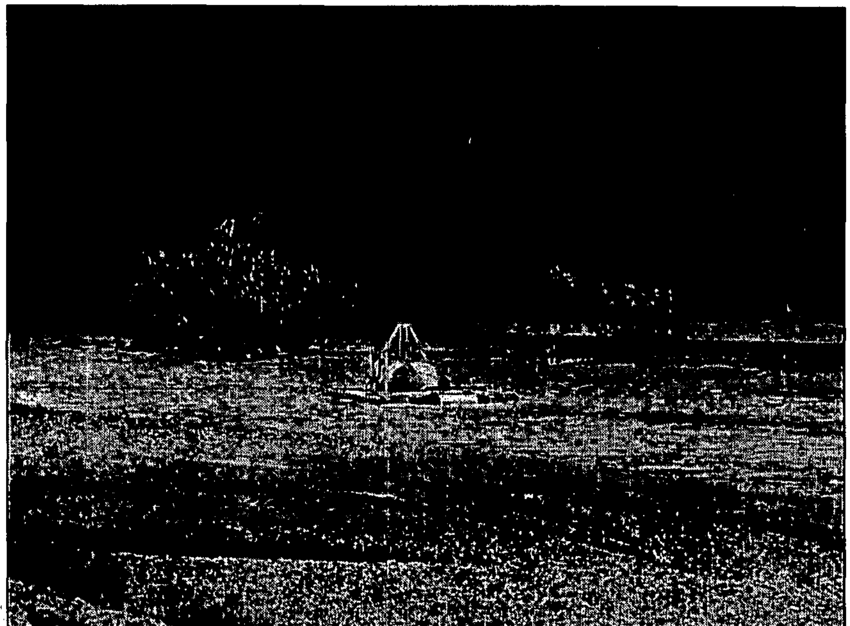


Appendix 2. Comparison of 54 year average monthly discharge (cfs) with average monthly discharge in WY 2004 and WY 2005, Orick gaging station (#11482500), lower Redwood Creek (USGS 2005).

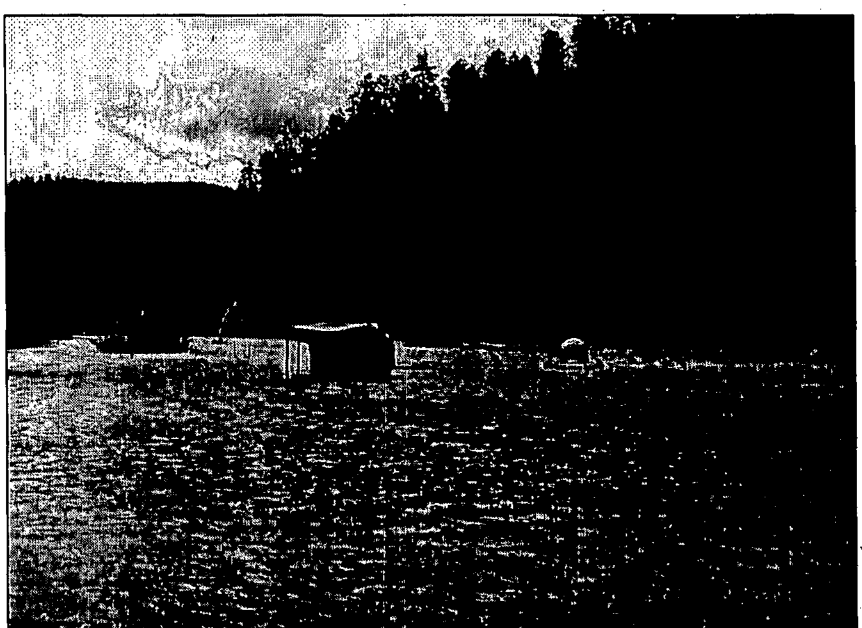
	Monthly Stream Discharge (cfs)		
Month	Historic	WY 2004	WY 2005
October	141	8	111
November	982	90	74
December	2,131	2,526	1,223
January	2,496	2,356	1,749
February	2,170	3,113	638
March	1,885	1,050	1,379
April	1,223	602	2,138
May	636	271	1,400
June	254	109	613
July	86	41	195
August	40	19	56
September	36	9	25
Average:	1,007	850	800



Appendix 3. Picture of rotary screw trap in lower Redwood Creek prior to storm event (top) and picture of rotary screw trap during storm event (bottom), Orick, CA., 2005.

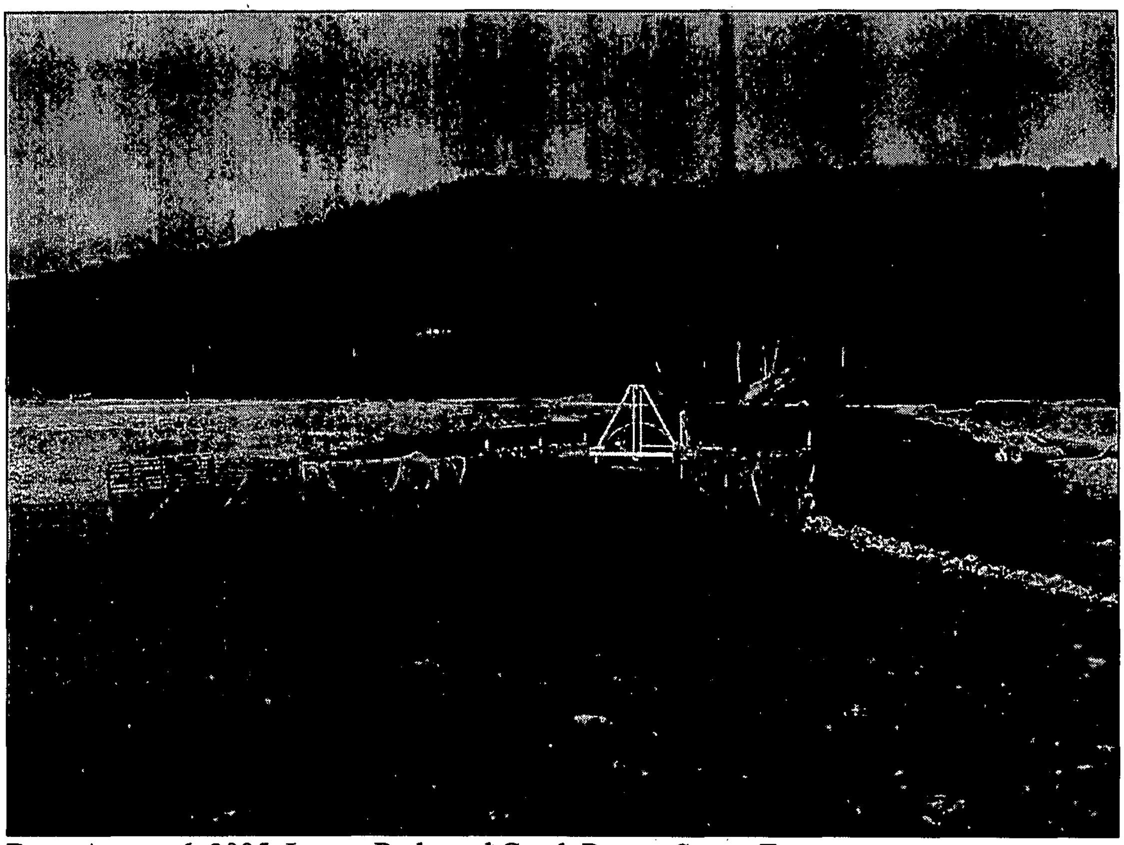


Date: May 13th, 2005, Lower Redwood Creek Rotary Screw Trap.



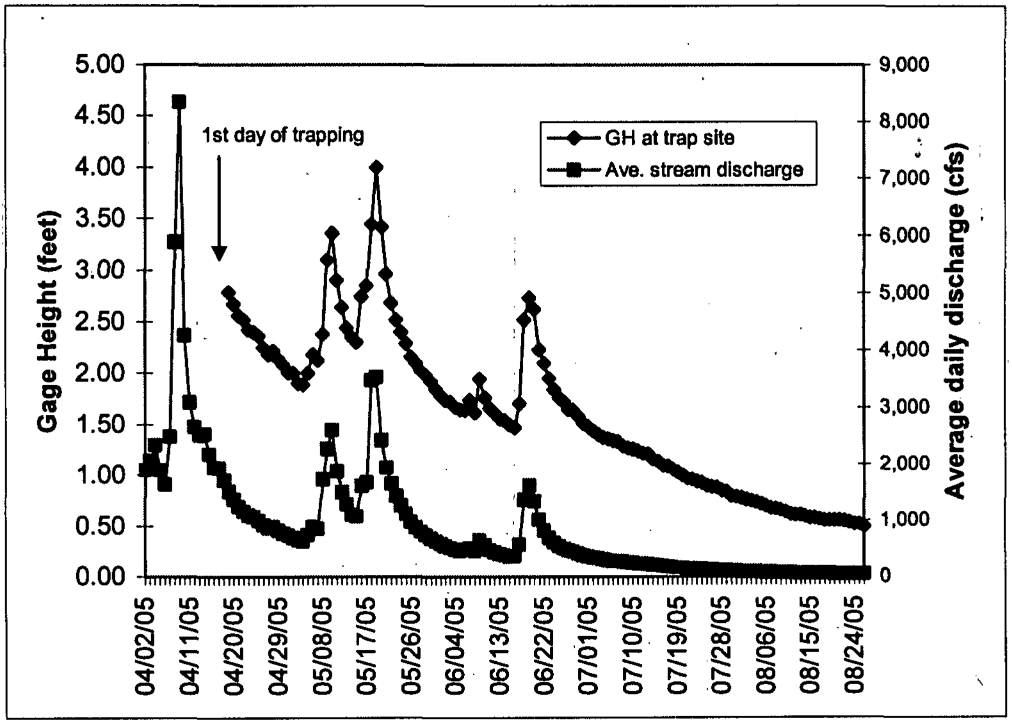
Date: May 19th, 2005, Lower Redwood Creek Rotary Screw Trap.

Appendix 4. Picture of rotary screw trap in lower Redwood Creek (RM 4) during low flow period in August, 2005.



Date: August 6, 2005, Lower Redwood Creek Rotary Screw Trap.

Appendix 5. Graphical representation of daily stream gage height (feet) at trap site and average daily streamflow (cfs) at Orick gaging station (USGS 2005), lower Redwood Creek, Humboldt County, CA.



Appendix 6. Travel time (d) and travel rate (mi/d) for 0+ Chinook salmon released at upper trap site and recaptured at lower trap (distance of 29 miles) in Redwood Creek, Humboldt County, CA., 2005.

Travel Time Experiments						
Age/species	Initial FL mm	Mark or Tag type	Date Released*	Date Recaptured**	Travel time (d)	Travel rate (mi d^{-1})
0+ KS	76	Pit Tag	6/03/05	6/14/05	10.5	2.8
0+ KS	77	Pit Tag	6/08/05	6/15/05	6.5	4.5
0+ KS	87	Pit Tag	6/09/05	6/12/05	2.5	11.6
0+ KS	79	Pit Tag	6/09/05	6/15/05	5.5	5.3
0+ KS	70	Pit Tag	6/09/05	6/17/05	7.5	3.9
0+ KS	83	Pit Tag	6/15/05	6/24/05	8.5	3.4
0+ KS	84	Pit Tag	6/15/05	7/03/05	17.5	1.7
0+ KS	83	Pit Tag	6/16/05	7/02/05	15.5	1.9
0+ KS	81	Pit Tag	6/24/05	6/26/05	1.5	19.3
0+ KS	85	Pit Tag	6/24/05	6/27/05	2.5	11.6
0+ KS	87	Pit Tag	6/30/05	7/02/05	1.5	19.3
0+ KS	85	Pit Tag	6/30/05	7/02/05	1.5	19.3
0+ KS	87	Pit Tag	6/30/05	7/02/05	1.5	19.3
0+ KS	90	Pit Tag	6/30/05	7/02/05	1.5	19.3
0+ KS	84	Pit Tag	6/30/05	7/02/05	1.5	19.3
0+ KS	72	Pit Tag	7/01/05	7/04/05	2.5	11.6
0+ KS	74	Pit Tag	7/07/05	7/10/05	2.5	11.6
0+ KS	76	Pit Tag	7/08/05	7/23/05	14.5	2.0
0+ KS	73	Pit Tag	7/14/05	7/18/05	3.5	8.3
0+ KS	72	Pit Tag	7/15/05	8/03/05	18.5	1.6
0+ KS	76	Pit Tag	7/21/05	7/26/05	4.5	6.4
0+ KS	73	Pit Tag	7/21/05	7/30/05	8.5	3.4
0+ KS	81	Pit Tag	7/21/05	8/01/05	10.5	2.8
0+ KS	74	Pit Tag	7/21/05	8/04/05	13.5	2.1
0+ KS	76	Pit Tag	7/21/05	8/10/05	19.5	1.5
0+ KS	85	Pit Tag	7/28/05	8/03/05	5.5	5.3
0+ KS	87	Pit Tag	7/28/05	8/10/05	13.5	2.1
Ave:	80 (SD =5.9)				7.5 (SD = 5.9)	8.2 (SD = 6.9)

* Released at upper trap site (RM33) at night (2100).

** Recaptured at lower trap (RM4).

Appendix 7. Growth of recaptured pit tagged 0+ Chinook salmon (n = 27) migrating from upper trap to the lower trap (distance of 29 mi.) in Redwood Creek, Humboldt County, CA., 2005.

	Initial Size		Size at Recapture		Period of	% Change in:		AGR**		SGRsc**		RGR**	
Age/spp	FL (mm)	Wt (g)	FL (mm)	Wt (g)*	growth (d)	FL (mm)	Wt (g)	mm/d	g/d	% (mm/d)	% (g/d)	mm/mm/d	mm/mm/d
0+ KS	87	7.6	88	7.51	2.5	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000
0+ KS	76	4.8	80	5.41	10.5	5.26	12.71	0.38	0.06	0.489	1.139	0.005	0.012
0+ KS	77	5.1	79	5.41	6.5	2.60	6.08	0.31	0.05	0.394	0.908	0.004	0.009
0+ KS	79	5.0	79	5.21	5.5	0.00	4.20	0.00	0.04	0.000	0.748	0.000	0.008
0+ KS	70	4.1	74	4.41	7.5	5.71	7.56	0.53	0.04	0.741	0.972	0.008	0.010
0+ KS	83	6.4	86	7.01	8.5	3.61	9.53	0.35	0.07	0.418	1.071	0.004	0.011
0+ KS	81	5.7	82	5.41	1.5	0.00	-5.09	0.00	-0.19	0.000	-3.481	0.000	-0.034
0+ KS	85	6.8	86	6.71	2.5	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000
0+ KS	87	7.5	87	7.01	1.5	0.00	-6.53	0.00	-0.33	0.000	-4.504	0.000	-0.044
0+ KS	83	6.2	92	8.61	15.5	10.84	38.87	0.58	0.16	0.664	2.119	0.007	0.025
0+ KS	85	6.7	86	6.31	1.5	0.00	-5.82	0.00	-0.26	0.000	-3.998	0.000	-0.039
0+ KS	87	7.7	87	7.11	1.5	0.00	-7.66	0.00	-0.39	0.000	-5.315	0.000	-0.051
0+ KS	90	8.4	90	8.81	1.5	0.00	4.88	0.00	0.27	0.000	3.177	0.000	0.033
0+ KS	84	6.3	84	5.91	1.5	0.00	-6.19	0.00	-0.26	0.000	-4.260	0.000	-0.041
0+ KS	84	6.4	91	8.31	17.5	8.33	29.84	0.40	0.11	0.457	1.492	0.005	0.017
0+ KS	72	4.0	73	4.01	2.5	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000
0+ KS	74	4.4	74	4.41	2.5	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000
0+ KS	73	4.0	74	3.91	3.5	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000
0+ KS	76	4.9	84	6.61	14.5	10.53	34.90	0.55	0.12	0.690	2.064	0.007	0.024
0+ KS	76	5.0	78	4.91	4.5	2.63	0.00	0.44	0.00	0.577	0.000	0.006	0.000
0+ KS	73	4.1	76	4.71	8.5	4.11	14.88	0.35	0.07	0.474	1.632	0.005	0.018
0+ KS	81	5.8	83	5.91	10.5	2.47	0.00	0.19	0.00	0.232	0.000	0.002	0.000
0+ KS	85	6.3	85	6.21	5.5	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000
0+ KS	72	3.9	80	5.61	18.5	11.11	43.85	0.43	0.09	0.570	1.965	0.006	0.024
0+ KS	74	4.6	82	6.11	13.5	10.81	32.83	0.59	0.11	0.760	2.103	0.008	0.024
0+ KS	87	7.2	90	7.51	13.5	3.45	4.31	0.22	0.02	0.251	0.312	0.003	0.003
0+ KS	76	4.8	89	7.01	19.5	17.11	46.04	0.67	0.11	0.810	1.942	0.009	0.024
Ave.	**80**	**5.7**	**83**	**6.15**	**7.5**	**3.65**	**9.60**	**0.22**	**0.00**	**0.279**	**0.003**	**0.003**	**0.001**

* Final weight equals weight of fish at recapture minus pit tag weight (0.09g).

** AGR = absolute growth rate, SGRsc = specific growth rate scaled, RGR = relative growth rate.

Appendix 8. Descriptive statistics of size at time 1 (T1) and time 2 (T2), percent change in size (FL, Wt), absolute growth rate (FL, Wt), relative growth rate (FL, Wt) and specific growth rate scaled (FL, Wt) for pit tagged 0+ Chinook salmon recaptured (n = 27) at the lower trap in Redwood Creek, Humboldt County, CA., 2005.

	Descriptive Statistics			
Variable	Min.	Max.	Ave. (median)	SD**
Size at T1				
FL mm	70	90	79.9 (81.0)	5.9
Wt g	3.9	8.4	5.69 (5.70)	1.32
Size at T2				
FL mm	73	92	82.9 (84.0)	5.7
Wt g	3.9	8.8	6.15 (6.11)	1.35
% change in				
FL mm	0.00	17.11	3.65 (2.47)	4.77
Wt g	- 7.66	46.04	9.60 (4.20)	16.50
AGR*				
FL mm	0.00	0.67	0.22 (0.19)	0.240
Wt g	- 0.39	0.27	0.00 (0.02)	0.153
RGR*				
FL mm	0.000	0.009	0.003 (0.002)	0.003
Wt g	- 0.051	0.033	0.001 (0.003)	0.023
SGR*				
FL mm	0.000	0.810	0.279 (0.232)	0.302
Wt g	- 5.315	3.177	0.003 (0.312)	2.282

* AGR = absolute growth rate (FL, mm/d; Wt g/d), RGR = relative growth rate (FL, mm/mm/d; Wt, g/g/d), SGR = specific growth rate scaled, [FL, %(mm/d); Wt %(g/d)].

** SD = standard deviation of mean.

Appendix 9. Results of linear regressions using travel time (d), travel rate (mi/d), average water temperature (^oC), and average stream discharge (cfs) on various growth indices for pit tagged 0+ Chinook salmon recaptured at the lower trap in Redwood Creek, Humboldt County, CA., YR 2005.

Variables		Regression Output (Results)			
Dependent (Y)	Independent (X)	p value	R2	Slope Sign	Power of test
% Change FL	Travel Time	0.000001	0.84	Positive	1.00
% Change FL	Travel Rate*	0.000001	0.64	Negative	1.00
% Change FL	Water Temp	0.32	0.04	Positive	0.16
% Change FL	Stream discharge	0.44	0.02	Negative	0.12
% Change Wt	Travel Time	0.000001	0.82	Positive	1.00
% Change Wt	Travel Rate	0.00007	0.47	Negative	1.00
% Change Wt	Water Temperature	0.41	0.03	Positive	0.12
% Change Wt	Stream discharge	0.62	0.01	Negative	0.08
AGR** FL	Travel Time	0.000001	0.69	Positive	1.00
AGR** FL	Travel Rate	0.000004	0.58	Negative	1.00
AGR** FL	Water Temperature	0.67	0.01	Positive	0.07
AGR** FL	Stream discharge	0.70	0.01	Negative	0.07
AGR** Wt	Travel Time	0.002	0.32	Positive	0.91
AGR** Wt	Travel Rate	Test assumptions not met, test not reliable.			
AGR** Wt	Water Temperature	Test assumptions not met, test not reliable.			
AGR** Wt	Stream discharge	Test assumptions not met, test not reliable.			
SGRsc** FL	Travel Time*	0.000001	0.68	Positive	1.00
SGRsc** FL	Travel Rate	0.000006	0.56	Negative	1.00
SGRsc** FL	Water Temperature	Test assumptions not met, test not reliable.			
SGRsc** FL	Stream discharge	Test assumptions not met, test not reliable.			
SGRsc** Wt	Travel Time	0.005	0.39	Positive	0.97
SGRsc** Wt	Travel Rate	Test assumptions not met, test not reliable.			
SGRsc** Wt	Water Temperature	Test assumptions not met, test not reliable.			
SGRsc** Wt	Stream discharge*	0.37	0.03	Negative	0.14
RGR** FL	Travel Time*	0.000001	0.68	Positive	1.00
RGR** FL	Travel Rate	0.000008	0.56	Negative	1.00
RGR** FL	Water Temperature	Test assumptions not met, test not reliable.			
RGR** FL	Stream discharge	Test assumptions not met, test not reliable.			
RGR** Wt	Travel Time	0.002	0.43	Positive	0.99
RGR** Wt	Travel Rate	Test assumptions not met, test not reliable.			
RGR** Wt	Water Temp	0.83	0.00	Positive	0.05
RGR** Wt	Stream discharge	0.72	0.00	Negative	0.06

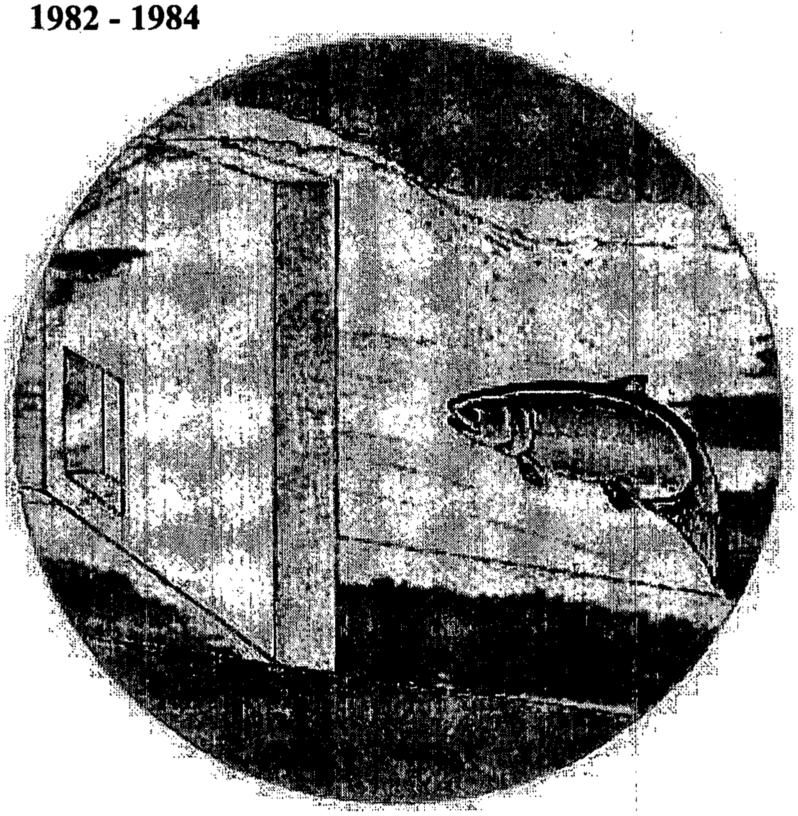
* Denotes Log (x+1) transformation to approximate linearity.

** AGR = absolute growth rate (FL mm/d; Wt g/d), RGR = relative growth rate (FL mm/mm/d; Wt g/g/d), SGR = specific growth rate scaled, [FL %(mm/d); Wt %(g/d)

New Concepts in Fish Ladder Design: Analysis of Barriers to Upstream Fish Migration, Volume IV of IV

Investigation of the Physical and Biological Conditions Affecting Fish Passage Success at Culverts and Waterfalls

Final Report
1982 - 1984



DOE/BP-36523-1

August 1985

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Bonneville Power Administration
P.O. Box 3621
Portland, OR 97208

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FINAL PROJECT REPORT

Part 4 of 4

Analysis of Barriers to Upstream Fish Migration

An Investigation of the Physical and Biological Conditions Affecting Fish Passage Success at Culverts and Waterfalls

Prepared by

Patrick D. Powers
and
John F. Orsborn

Albrook Hydraulics Laboratory
Department of Civil and Environmental Enqineerinq
Washinqton State University
Pullman, Washinqton 99164-3001

Submitted to

Bonneville Power Administration

Part of a BPA Fisheries Project on the

DEVELOPMENT OF NEW CONCEPTS IN FISHLADDER DESIGN

Contract DE-A179-82BP36523

Project No. 82-14

Auqust, 1985

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SUMMARY OF RESEARCH PROJECT REPORTS

Bonneville Power Administration
BPA Fisheries Project 82-14

DEVELOPMENT OF NEW CONCEPTS IN FISH LADDER DESIGN

Conducted at the
Albrook Hydraulics Laboratory
Department of Civil and Environmental Engineering
Washington State University
Pullman, Washington 99164-3001

Project Period: June, 1982-October, 1984

1. Orsborn, John F. 1985. **SUMMARY REPORT**

A synopsis of the project components was prepared to provide an overview for persons who are not fisheries scientists or engineers. This short report can be used also by technical persons who are interested in the scope of the project, and as a summary of the three main reports. The contents includes an historical perspective on fishway design which provides the basis for this project. The major project accomplishments and significant additions to the body of knowledge about the analysis and design of fi shways are discussed. In the next section the research project organization, objectives and components are presented to familiarize the reader with the scope of this project.

The summary report concludes with recommendations for assistinq in the enhancement and restoration of fisheries resources from the perspective of fish passage problems and their solution. Promisinq research topics are included.

2. Aaserude, Robert G. and John F. Orsborn. 1985. **NEW CONCEPTS IN FISHLADDER DESIGN**.--Results of Laboratory and Field Research on New Concepts in Weir and Pool Fishways. (With contributions by Diane Hilliard and Valerie Monsey).

The drivinq force behind this project, and the nucleus from which other project components evolved, was the desire to utilize fish leaping capabilities more efficiently in fishway desiqn. This report focuses on the elements which were central to testing the premise that significant improvements could be made in water use, costs and fish passage efficiencies by developinq a new weir and pool fishway. These elements include: historical review of available information; optimization of weir geometry; fluid jet mechanics; air entrainment; energy dissipation in the pool chamber; and fish capabilities. The new weir and pool chambers were tested in the field with coho and chum salmon.

3. Orsborn, John F. and Patrick D. Powers. 1985. FISHWAYS--AN ASSESSMENT OF THEIR DEVELOPMENT AND DESIGN. (With contributions by Thomas W. Bumstead, Sharon A. Klinqer, and Walter C. Mih.)

This volume covers the broad, though relatively short, historical basis for this project. The historical developments of certain desiqn features, criteria and research activities are traced. Current design practices are summarized based on the results of an international survey and interviews with agency personnel and consultants. The fluid mechanics and hydraulics of fishway systems are discussed.

Fishways (or fishpasses) can be classified in two ways: (1) on the basis of the method of water control (chutes, steps [ladders], or slots); and (2) on the basis of the degree and type of water control. This degree of control ranges from a natural waterfall to a totally artificial environment at a hatchery. Systematic procedures for analyzing fishways based on their- confiquration, species, and hydraulics are presented. Discussions of fish capabilities, energy expenditure, attraction flow, stress and other factors are included.

4. Powers, Patrick D. and John F. Orsborn. 1985. ANALYSIS OF BARRIERS TO UPSTREAM MIGRATION. --An Investigation into the Physical and Biological Conditions Affecting Fish Passage Success at Culverts and Waterfalls.

Fish passage problems at natural barriers (waterfalls) and artificial barriers (culverts) are caused by excessive velocity and/or excessive height. By determining which geometric or hydraulic condition exceeds the capabilities of the fish, the most promising correction can be made to the barrier.

No waterfall classification system was found in the literature which could be applied to fish passage problems. Therefore a classification system was designed which describes: (1) downstream approach conditions at the base of the barrier; (2) central passage conditions as in a high velocity chute or the leap over a falls; and (3) upstream conditions where the fish exits the high velocity chute or lands after leaping past a barrier.

The primary objective was to lay the foundation for the analysis and correction of physical barriers to upstream migration, with fishways beinq one of the alternative solutions. Although many passage improvement projects are economically small compared with those at large dams, each year millions of dollars are spent on solving these smaller passage problems--and sometimes the money is wasted due to poor problem definition. This report will assist in both the definition of the problem and selection of the most beneficial solution.

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ANALYSIS OF BARRIERS TO UPSTREAM FISH MIGRATION

ABSTRACT

This paper presents a detailed analysis of waterfalls and culverts as physical barriers to upstream migration by salmon and trout. Analysis techniques are based on combining barrier geometry and stream hydrology to define the existing hydraulic conditions within the barrier. These conditions then can be compared to known fish capabilities to determine fish passage success. A systematic classification system is developed which defines the geometric and hydraulic parameters for a given stream discharge. This classification system is organized in a format that can he used to catalog barriers in fisheries enhancement programs. The analysis compares hydraulic conditions and fish capabilities in detail, as the fish enters the barrier, attempts passage and exits the barrier. From this comparison the parameters which prohibit passage can be determined. Hydraulic conditions are a function of the barrier qeometry and stream hydrology, and the stream flow is constant at the time each step in analysis is performed. Therefore, the barrier geometry must be modified to alter the hydraulics to meet fish capabilities. Modifications can he accomplished by: installing instream "control" structures which deflect the flow or raise pool levels; blasting to alter or remove rock; and installing a fishway to bypass the barrier. Modifications should not be attempted until the analysis defines the excessive parameters which should be modified.

INTRODUCTION

When adult salmon and steelhead trout enter freshwater, maturing fish stop feeding and rely on energy reserves stored in body fat and protein to carry them through migration and spawning. The rate of sexual maturity is established by heredity, and cannot adjust to delay. Barriers which cause excessive delay and abnormal energy expenditures can result in mortality either during the migration or in the spawning areas. These barriers can be natural or artificial, as well as physical, chemical or thermal. Natural barriers consist mainly of waterfalls and debris jams, and artificial barriers consist mainly of dams, culverts and log jams. This study will consider only those barriers consisting of waterfalls or culverts that partially or totally obstruct salmon and trout upstream migration. In addition to existing barriers which delay or totally block upstream migration, spawninq areas which were originally accessible have become inundated by reservoirs and other instream modifications. Therefore, existing barriers must be modified to further open the "window of passage" to spawning areas.

The potential for deriving benefits from alleviatinq barriers to migration is high, but in the remote areas where these barriers usually exist, the cost of traditional fish ladders and construction methods usually outweigh the benefits to be gained. Some barriers lend themselves to simple solutions such as blasting a series of pools to assist fish passage. Rut in many cases an analysis of the geometric, geologic, hydrologic and hydraulic characteristics needs to be made so that alternative solutions can be generated and compared. Stuart (1964) suggests that the behavior of migrating salmonids can be correlated directly with the hydraulic conditions in the stream channel. This relationship is the basis for this study.

Because stream flows and site geometry control stream width, depth and velocity, the hydraulic parameters are a function of the geomorphic and hydrologic parameters. Given the geomorphic conditions at a site, considered to be constant, and the hydrologic conditions which are variable within a range of values, an analysis of the hydraulic conditions related to fish capabilities can determine the impact the barrier has on fish passage success. These relationships can be seen in the flow chart in Figure 1. The objectives of this study are to:

1. develop a classification system for waterfall and culvert barriers;
2. develop methods for analyzing harriers using site geometry, hydrology and hydraulics, and by relating the hydraulics to fish capabilities; and
3. generate "parameter specific" solutions to assist fish past barriers without the installation of a typical fishway.

It is not within the scope of this study to develop analytical methods for more complex barrier structures but to develop the conceptual basis for these methods. Complex barrier analysis would require extensive field work and/or physical model testing. It is the author's intention to use this study as a foundation to further develop analytical methods for analyzing more complex barrier systems.

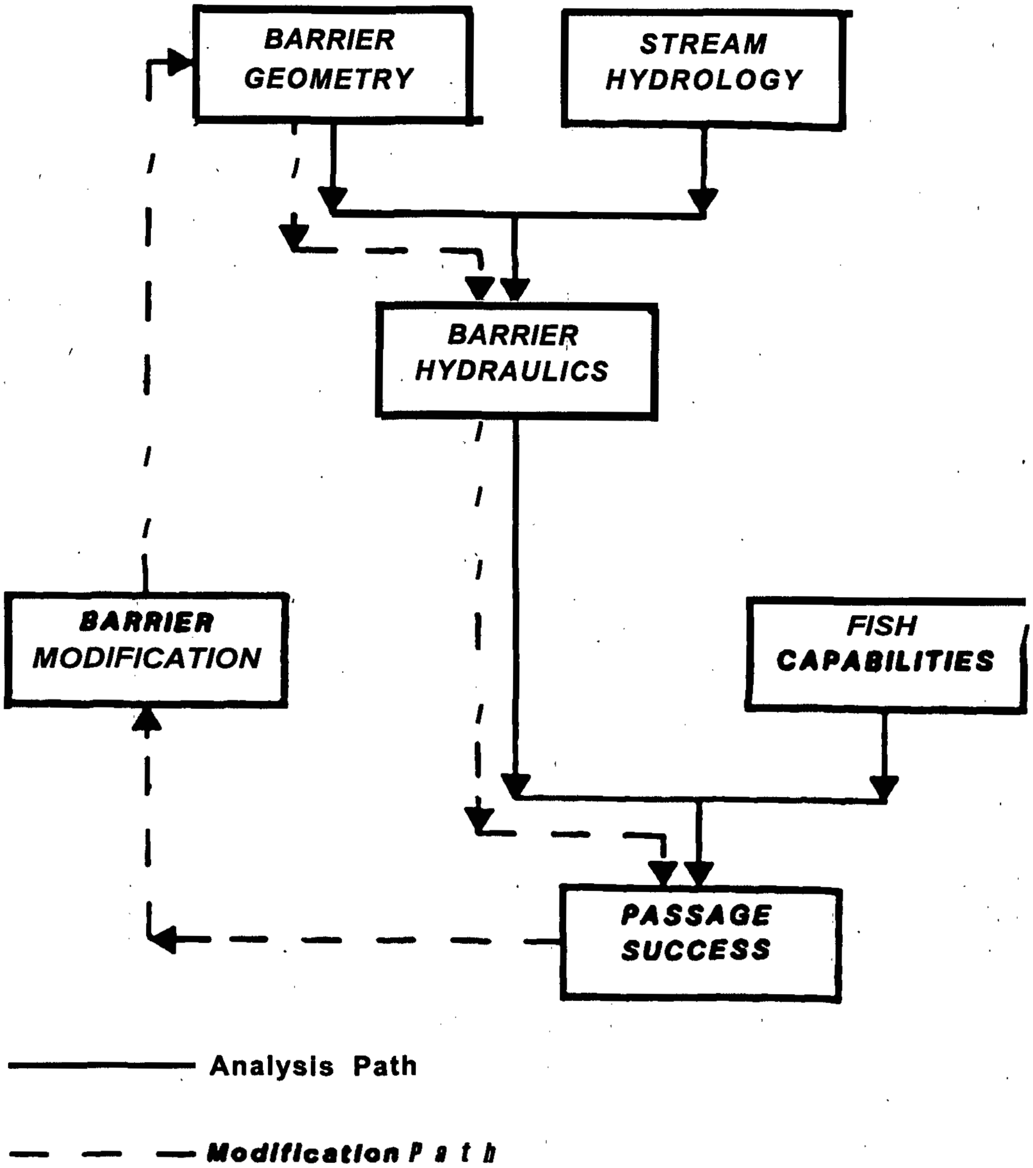


Figure 1. Flow chart analysis of a migration barrier.

Because of the wide variations in the forms of barriers, a classification system is required to facilitate the analysis and subsequent qeneration of solutions to fish passage problems. Evidence of waterfall classification in the literature points only to a system based on genetic grounds (Fairbridge, 1968). The writer is not aware of a systematic classification system of waterfalls which correlates fish passage success. The requirements for an adequate classification system include the following:

1. site geometry,
2. hydraulic conditions, and
3. fish passage success.

Based on these three factors a classification system for waterfall and culvert barriers was developed to aide in assessing, analyzing and modifying barriers.

Natural rock barriers can be in the form of falls, chutes or cascades. Falls (Fig. 2) are characteristic of steep (commonly vertical) overflow sections where the impact of the falling water scours a deep plunge pool at the foot of the falls. Falls form elevation barriers where the difference in water surface elevation between the upstream water surface and the plunge pool, and/or the horizontal distance from the falls crest to the plunge pool exceeds the leaping capabilities of the pertinent fish species. Often the leaping efficiency of the fish is constrained by unfavorable plunge pool conditions. If the pool is shallow, the falling water will strike the bottom creating violent pool conditions, thus affecting the fishes' orientation for leaping. Even if a fish has successfully leaped a falls, it can be swept back due to high velocities and/or shallow depths above the falls crest. A cantilevered culvert outfall (Fig. 3), where the fish must leap to enter the culvert, is similar geometrically to a fall. The only difference is the nature and geometry of the bed over which the water flows.

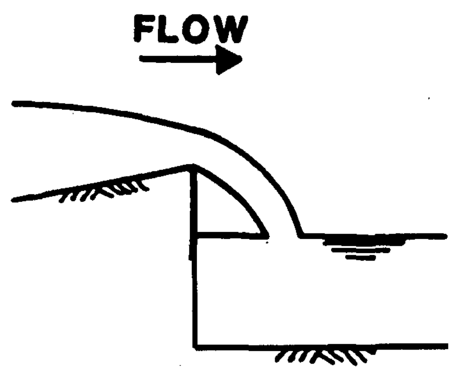


Figure 2. Profile view of a fall

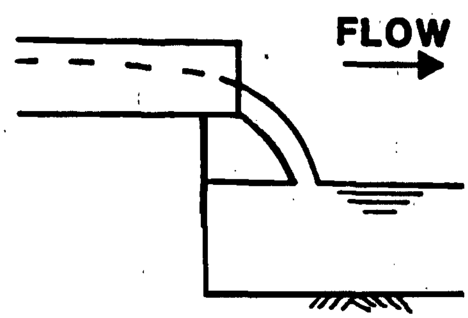


Figure 3. Profile view of a cantilevered culvert

Chutes (Fig. 4) are characterized by steep, sloping, rough open channels, offering the fish a high velocity medium in which to swim without resting areas. Chutes form velocity barriers where the water velocity near the downstream entrance to the chute exceeds the fishes' swimming speed. Often a standing wave will develop at the foot of the chute. If the downstream plunge pool is shallow, the standing wave may form too far downstream for the fish to rest before bursting into the chute. Even if the velocities down in the chute are within the fishes' swimming speed, the depth of flow and slope length could prohibit passage. Also, chutes often pass a bulked mass of water and entrained air which offers a poor medium for swimming. Stuart (1964) suggests that when flowing water entrains air, the density of the mixture will be reduced and will detract from the propulsive power of the fishes' tail and diminish the buoyancy of the fish. Air entrainment also reduces the stimulus of attraction flows. Chutes with steep slopes are very similar to culverts (Fig. 5) where the fish must swim a long slope length. The difference again is in the nature of the bed over which the water flows, and the shape of the flow area. Culverts do not offer an irregular natural boundary which can provide an occasional resting place.

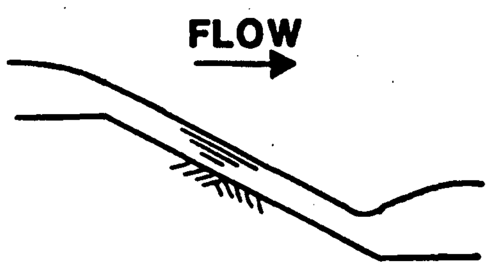


Figure 4. Profile view of a steep/ high velocity chute.

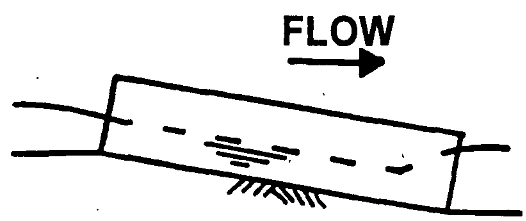


Figure 5. Profile view of a steep/ high velocity culvert.

Cascades (Fig. 6) are characterized by a reach of stream where large instream roughness elements, such as boulders and jutting rocks, obstruct and/or churn the flow into violently turbulent white water. Cascades often present fish with high velocities, excessive turbulence, and orientation difficulties which make it impossible for a fish to effectively use all its swimming power. If the rouqhness elements (or boulders) are large, they will often create periodic resting areas within the cascading reach.

Jackson (1950) noted that the sockeye salmon trying to pass Hell's Gate on the Fraser River in British Columbia almost succeeded in "eroding their noses back to their eye sockets" by contact with the bank while trying to maintain equilibrium in the turbulent water.

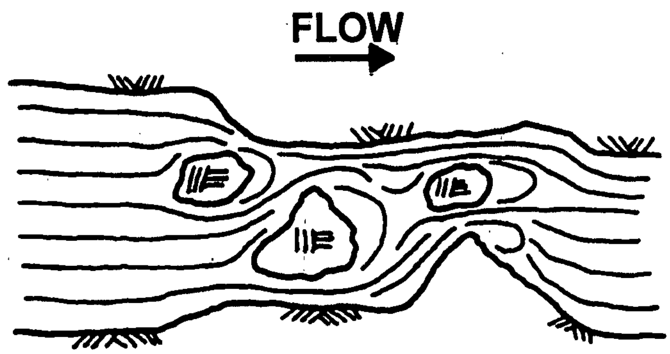


Figure 6. Plan view of a cascade.

Pioneering works in the field of analyzing waterfall barriers has been conducted mostly by fisheries biologists through methods such as field sampling by electrofishing, skin diving or just personal observation of fish passage. No significant research concerning the fluid mechanics of waterfalls has been conducted. There has been considerable work done on culverts to relate depth, velocity and discharge relationships, as reported by Dane (1978), Evans & Johnston (1980) and others. The obstruction at Hell's Gate focused a considerable amount of attention on the velocities and turbulence that sockeye salmon were facing. In that study, river velocities were measured by two methods:

1. the highest average velocities from the river discharge and the area of smallest cross section, and
2. average mid-stream surface velocities using a float.

Highest average velocities ranged from 12.9 to 17.5 fps, but Jackson (1950) noted that these computed velocities were inaccurate because of the extremely rough channels at Hell's Gate. The conclusion was that the combination of turbulence and high velocities prevented the passage of large runs of sockeye salmon. Clay (1961) suggests the following engineering field work that is required before design and construction of a fishway at a fall can be initiated:

1. topographic surveys;
2. record magnitude, direction and location of velocities;
3. locate points of turbulence, upwellings and the intensity and location of points of surge and how they relate to fish behavior; and
4. river discharge measurements.

Clay also suggests various types of fishways that can be installed at natural obstructions. He notes that because of the wide range of flows at a natural obstruction the vertical slot type of fishway should be used because it can accept a wide range of water level fluctuations while still working effectively.

Most of the design work on assisting fish past waterfalls without the installation of a fishway rests in project files. Many of these waterfalls were observed to be barriers due to shallow depths, high velocities and/or elevation drops, and were modified by blasting to try to reduce the magnitude of these constraints to passage. This study will develop detailed analysis procedures to generate "parameter specific" solutions to the "real passage problems" at barriers.

FISH CAPABILITIES

Swimming Speeds

The objective of this section is to document values for the upper limits of swimming speeds, leaping capabilities and swimming distances for adult salmon and steelhead trout, and to evaluate their performance in a format useful for analyzing barriers. In order to differentiate between water velocity, fish velocity and relative velocity of the fish to the water, the term "speed" will be used to denote the rate of motion of the fish as an object with respect to a reference plane. Relative speed will denote the difference between fish speed and the velocity of the water, that is:

$$VR = VF - VW \quad (1)$$

where VR = relative speed of the fish to the water; VF = speed of the fish; and VW = velocity of the water.

Ranqes of speeds are classified in the literature accordinq to the function, or relative speeds which fish can maintain. The classification of speeds published by Hoar and Randall (1978) which will be used in this study, is:

sustained - normal functions without fatigue,

prolonged - activities lasting 15 seconds to 200 minutes which result in fatigue

burst - activities which cause fatigue in 15 seconds or less.

Ranges of speeds for these classification are shown in Table 1 from Bell (1973).

Table 1. Fish speeds of average size adult salmon and steelhead trout as reported by Bell (1973).

Specie	Sustained[b]	Fish Speed (fps) Prolonged[b]	Burst
Steelhead	0-4.6	4.6-13.7	13.7-26.5
Chinook	o-3.4	3.4-10.8	10.8-22.4
Coho	o-3.4	3.4-10.6	10.6-21.5
Sockeye	0-3.2	3.2-10.2	10.2-20.6
Pink & Chum[a]	0-2.6	2.6-7.7	7.7-15.0

[a]Pink & Chum salmon values estimated from leap heights of 3 to 4 ft at waterfalls.
b Called cruising and sustained, respectively, in Bell (1973).-

Bell suggests that fish normally employ sustained speed for movement (such as migration), prolonged speed for passage through difficult areas, and burst speed for feeding or escape purposes.

For determining fish passage success over waterfalls and through culverts, some percentage of the upper limit of burst speed will be used which will depend on the physical condition of the fish. To determine actual values of these percentages, a study was conducted on coho and chum salmon swimming up a high velocity chute at Johns Creek Fish Hatchery near Shelton, Washington (see Appendix II). From this study it was concluded that most of the time the salmon were swimming at 50%, 75% and 100% of their maximum burst speeds suggested by Bell (1973), depending on the condition of the fish. These percentages will be used to define a coefficient of fish condition (C_{fc}). Values for C_{fc} are given in Table 2. with the corresponding characteristics of each. From Table 2. the actual speed that should be used for passage analysis is:

$$VF = VFB(C_{fc}) \quad (2)$$

where VFB = maximum burst speed suggested by Bell (1973) Table 1; and C_{fc} = coefficient of fish condition, Table 2.

Table 2. Coefficient of fish condition (C_{fc}). Values based on observations and data taken for coho and chum salmon at Johns Creek Fish Hatchery near Shelton, Washington, December, 1983.

Fish Condition	Coefficient(C_{fc})
Bright; fresh out of salt water or still a long distance from spawning grounds; spawning colors not yet developed	1.00
Good; in the river for a short time; spawning colors apparent but not fully developed; still migrating upstream	0.75
Poor; in the river for a long time; full spawning colors developed and fully mature; very close to spawning grounds	0.50[a]

[a] C_{fc} = 0.50, corresponds to the upper limit of prolonged speed from Table 1.

Leaping Capabilities

When fish leap at waterfalls, their motion can best be described as projectile motion (i.e. curved two-dimensional motion with constant acceleration). Neglecting air resistance, the equations for projectile motion are:

$$x = (V_0 \cos\theta)t, \text{ and}$$

$$y = (V_0 \sin\theta)t - (1/2)gt^2$$

where x = horizontal distance the projectile travels, y = vertical distance the projectile travels, V_i = initial velocity of the projectile, 8 = angle from the horizontal axis the projectile is fired, t = time, and q = acceleration of gravity (32.2 ft/sec^2). Rewriting the equations for x and y in terms of the components that relate to fish leaping at a waterfall yields:

$$XL = [VF(\cos\theta L)]t \text{ and} \tag{3}$$

$$HL = [VF(\sin\theta L)]t - (1/2)gt^2 \tag{4}$$

where XL = *horixontal distance or range of the leap at some time (t)*, HL = height of leap at some time (t), VF = fish speed, θL = angle of leap from the plunge pool, and g = acceleration of gravity acting downwards (32.2 ft/sec^2). By combining equations (3) and (4) and eliminating t from them, we obtain:

$$HL = (\tan\theta L)XL - g(XL)^2/2(VF\cos\theta L)^2 \tag{5}$$

which relates HL and XL and is the fish trajectory equation. Since VF, θL and g are constant for a given leap, equation (5) has the parabolic form of:

$$HL = b(XL) - C(XL)^2$$

Hence the trajectory of a fish is parabolic. Equation (5) is plotter! in Figures 7, 8 and 9 for six species of salmon and trout leaping at angles of HO, 60 and 40 degrees. These leaping curves will be utilized later to analyze leaping conditions at a barrier. At the highest point of the fish's leap, the vertical component of the velocity is zero, that is:

$$VF_y = VF(\sin\theta L) - gt = 0$$

Solving this equation for t gives:

$$t = VF(\sin\theta L)/g$$

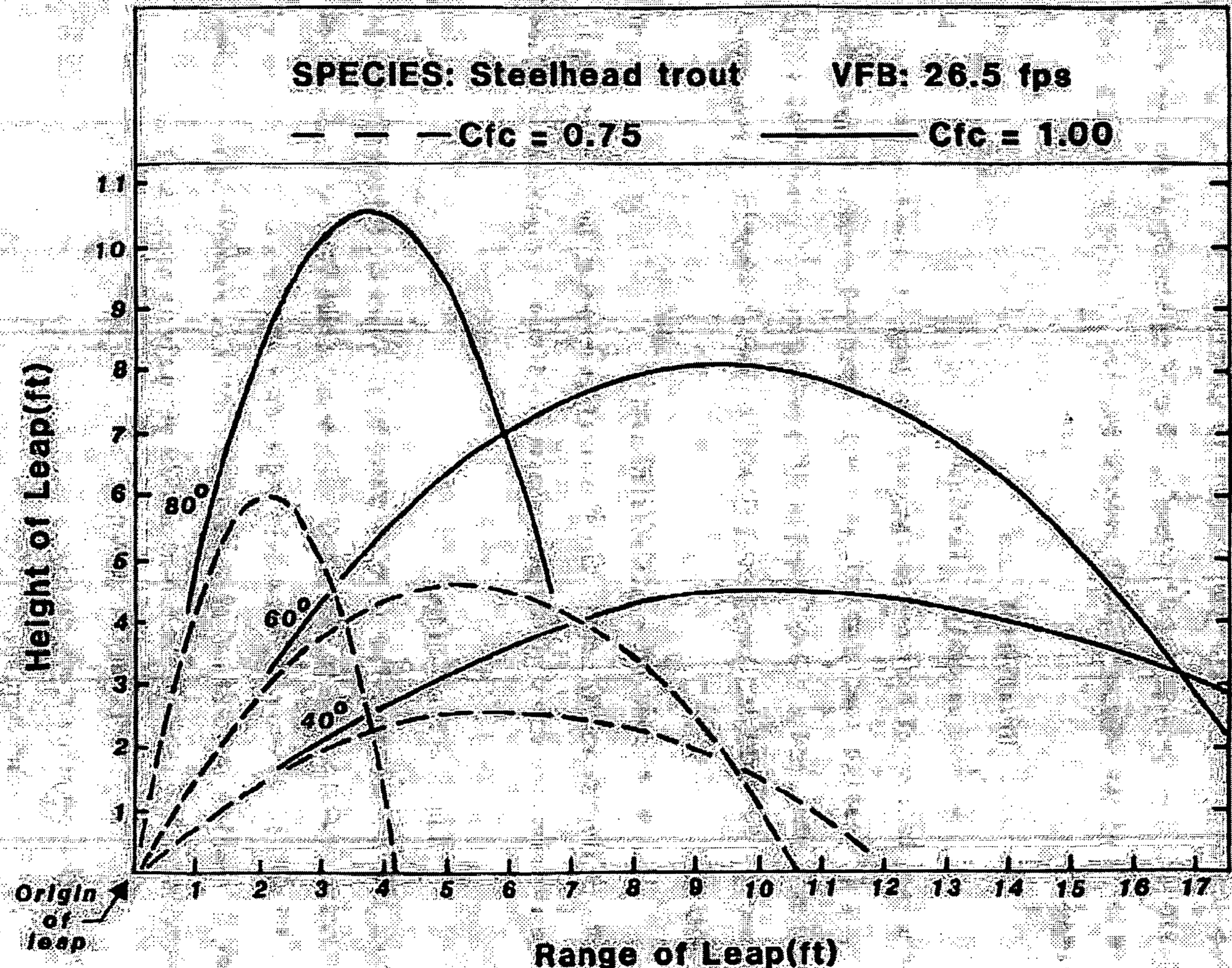


Figure 7. Leaping curves for steelhead trout.

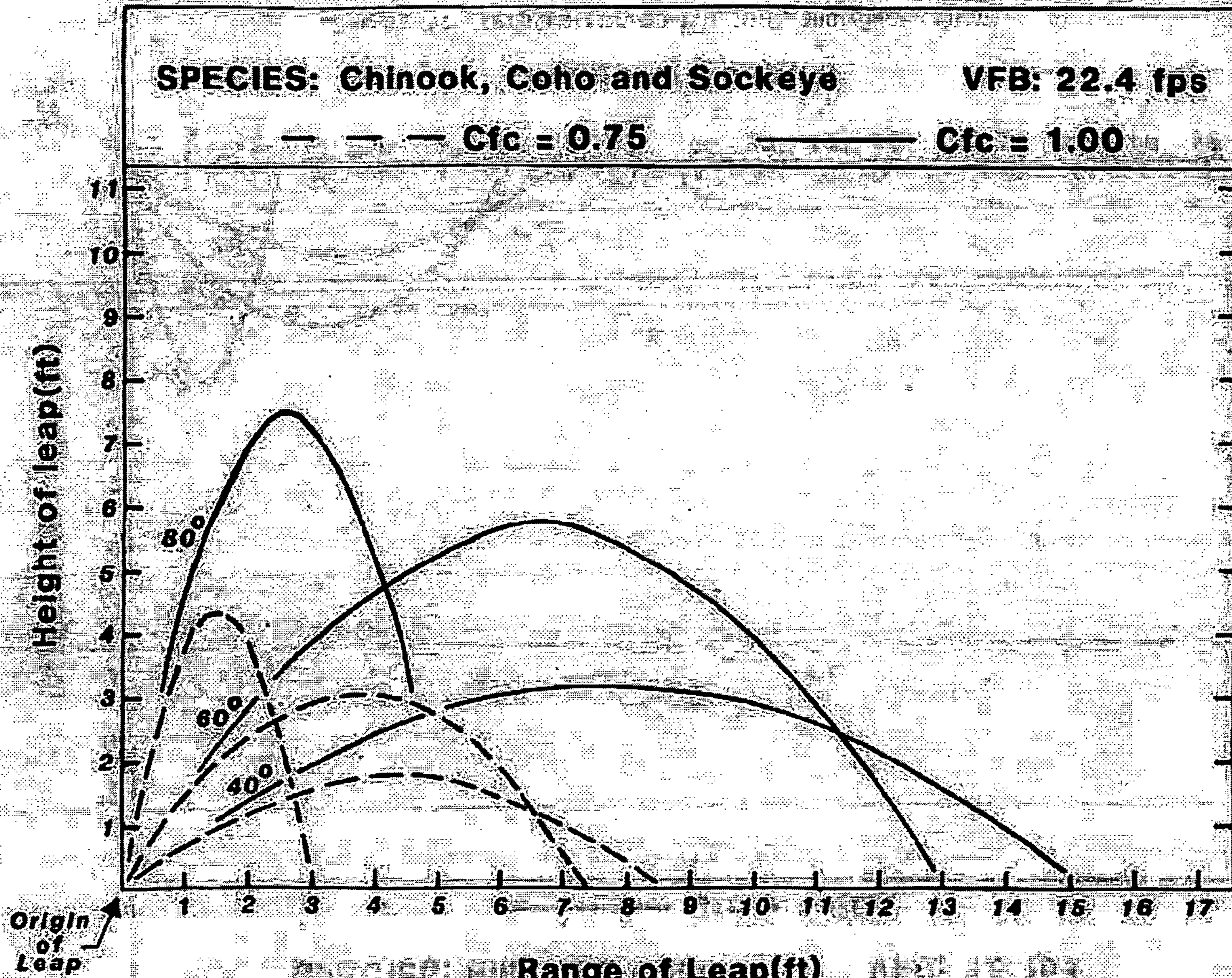


Figure 8. Leaping curves for chinook, coho and sockeye salmon.

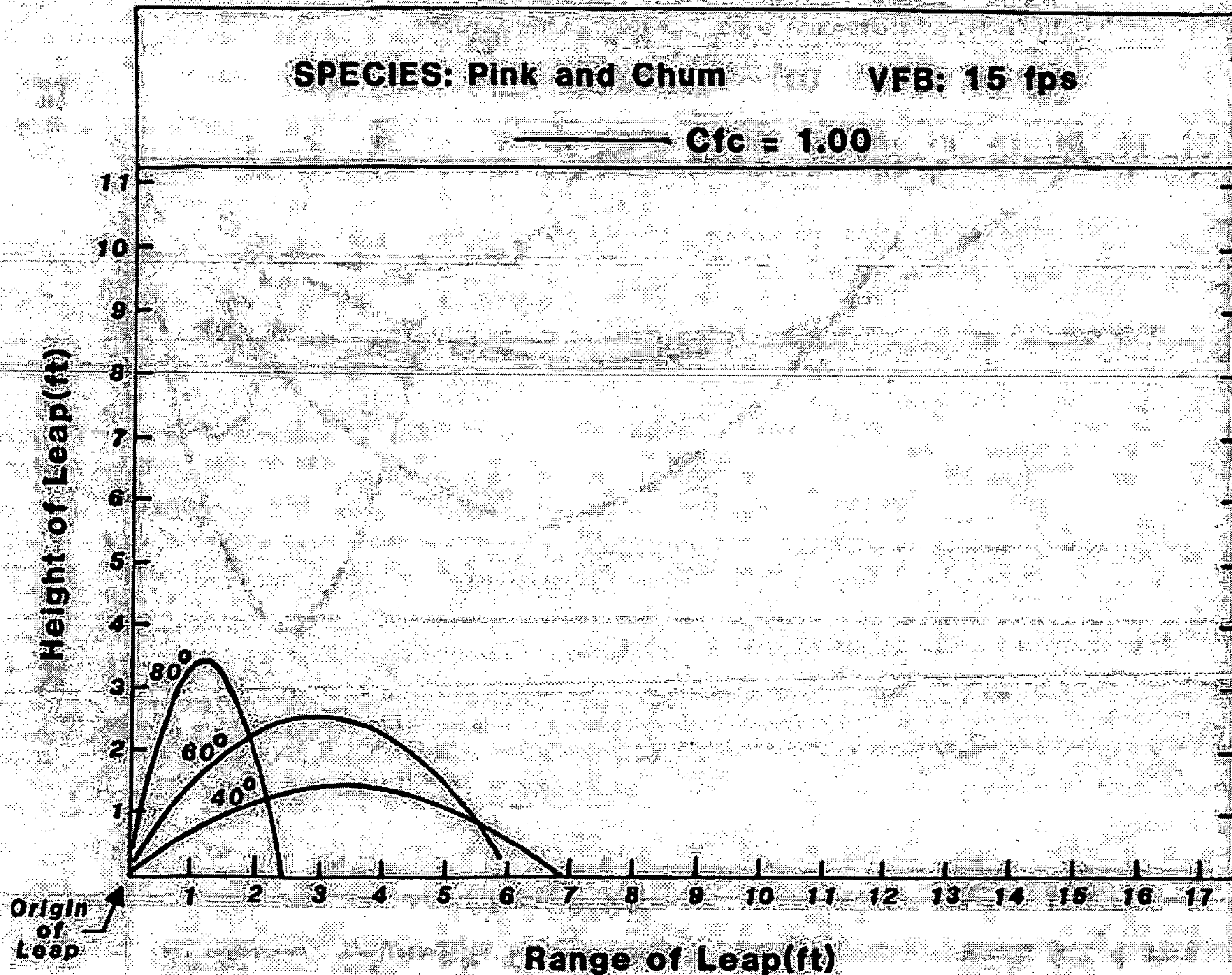


Figure 9. Leaping curves for pink and chum salmon.

Substituting this equation for t into equation (3) and (4) yields:

$$HL = (VF(\sin\theta L))^2/g - (1/2)(VF(\sin\theta L)^2)/g$$

$$HL = (VF(\sin\theta L))^2/2g \qquad (6)$$

$$XL = VF^2(\cos\theta L)(\sin\theta L/g) \qquad (7)$$

Equations (6) and (7) give the maximum height of the fish's leap and the horizontal distance traveled to the maximum height.

Bell (1973) suggests the following formula for computing velocities at which fish leave the water surface:

$$VF = (2g(HL))^{0.5}$$

Solving this equation in terms of the leap height (HL) gives the same result as equation (6), using a leaping angle of 90° to the water surface. Aaserude (1984) noted that to determine the true leaping height above the water surface, the length of the fish should be added to equation (6) because the fish uses its full propulsive power up until the point the fish's tail leaves the water, and once in the air skin drag can he neglected. Since equation (6) and (7) do not include the additive effects of fish length or an upward velocity component often found at the foot of a waterfall in the form of a standing wave (Stuart, 1964), they will be used here as conservative values from the accepted literature.

Swimming Performance

Swimming performance is a measure of the speed which a fish can maintain over a period of time (endurance). The distance a fish can swim is a function of the water velocity, fish speed and fatigue time. Bell

(1973) suggests that burst speed can be maintained for an estimated 5 to 10 seconds. Relating this range of fatigue time to the range of burst speeds from Table 1, the swimming distances can he computed from:

$$LFS = (VF - VW)TF \tag{8}$$

where LFS = length the fish can swim, VF = fish speed, VW = water velocity, and TF = time to fatigue. Equation (8) is plotted in Figures 10, 11 and 12 for six species of salmon and trout. An example calculation will show how these figures were derived.

Specie: steelhead

Burst Speed Range: 13.7 to 26.5 fps

Fatigue Time Range: 5 to 10 seconds

Water Velocity: 10 fps

Coefficient of Fish Condition: 0.75

$$LFS = [26.5\ (0.75) - 10]5 = 49\ \text{ft, or}$$

$$LFS = [13.7\ (0.75) - 10]10 = 3\ \text{ft.}$$

Therefore the maximum distance an adult steelhead trout can swim given the condition of the fish and a mean water velocity of 10 fps, is 49 ft. This calculation assumes the water depth to be great enough to submerge the fish and that no air is entrained in the flow. The results are in Fig. 12.

Evans and Johnston (1980) suggest that the distance the fish can swim against a given water velocity is best defined by the curves prepared by Ziemer (1961) which reflect the swimming performance of salmon, steelhead, and smaller trout (Fig. 13). This curve was developed assuming a relative fish speed (VR) of 2.0 fps. From the study reported in Appendix II, it was determined that the average relative speeds for coho and chum salmon swimming up the velocity chute were 1.9 and 2.1 fps respectively, but ranged from values of 1.0 to 3.0 fps. Because of this wide variation, it appears that calculating the maximum distance a fish can swim by simply using relative fish speed does not accurately describe the magnitude of a single passage attempt.

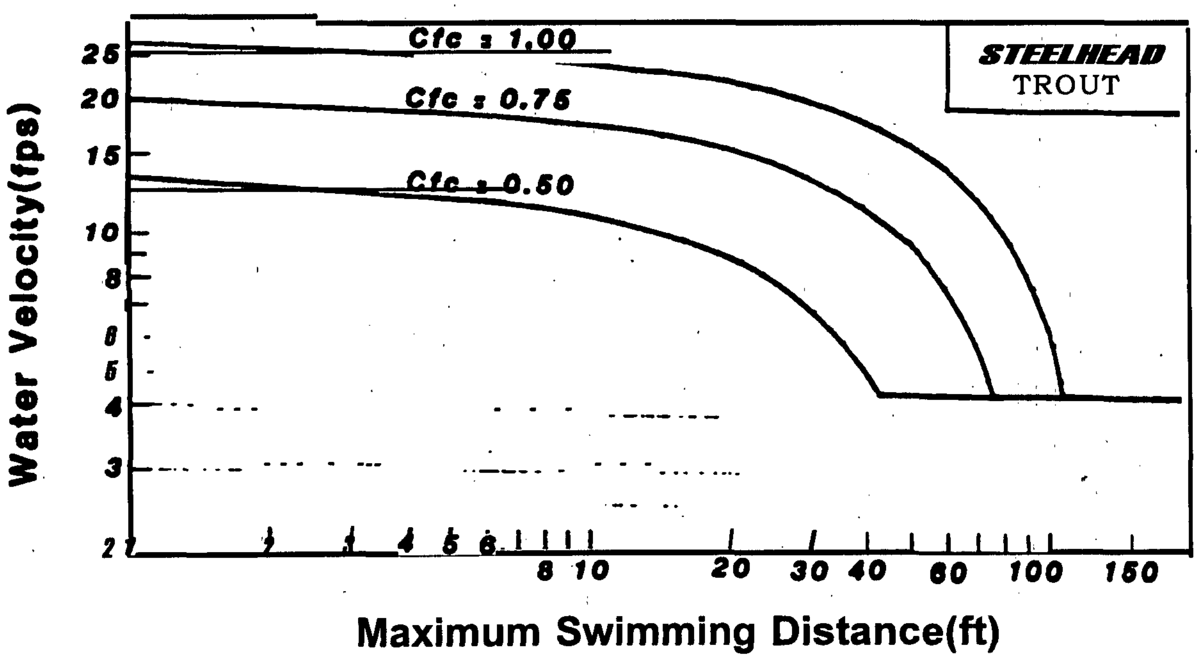


Figure 10. Maximum swimming distance for steelhead trout under three fish conditions.

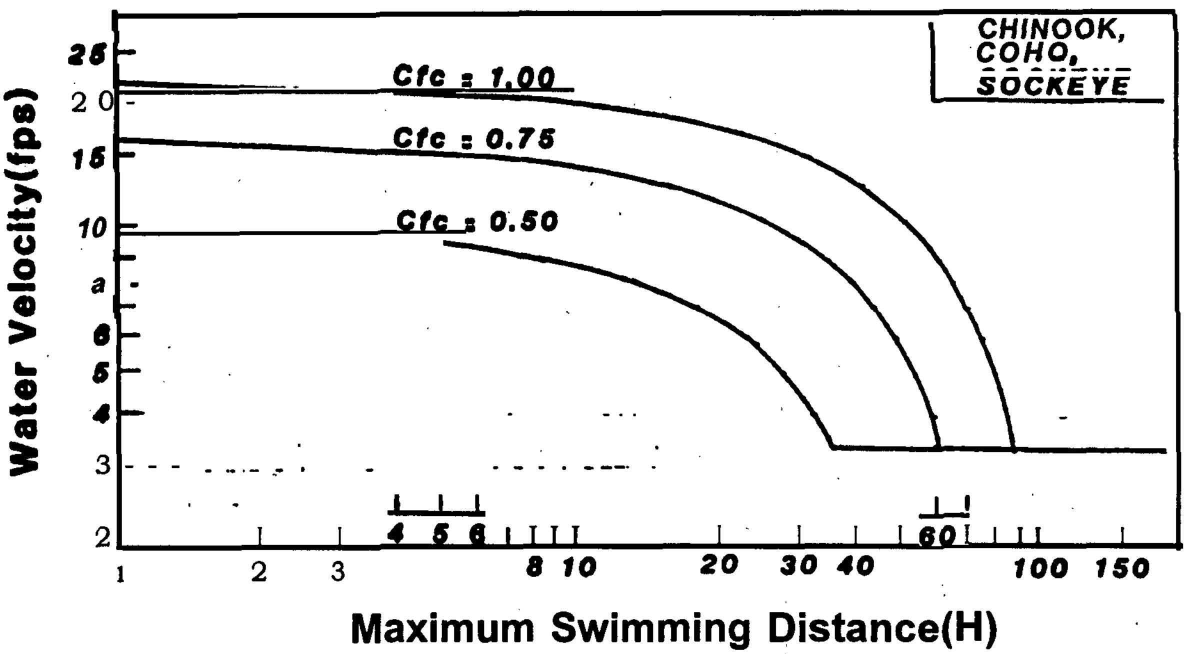


Figure 11. Maximum swimming distance for chinook, coho and sockeye salmon under three fish conditions.

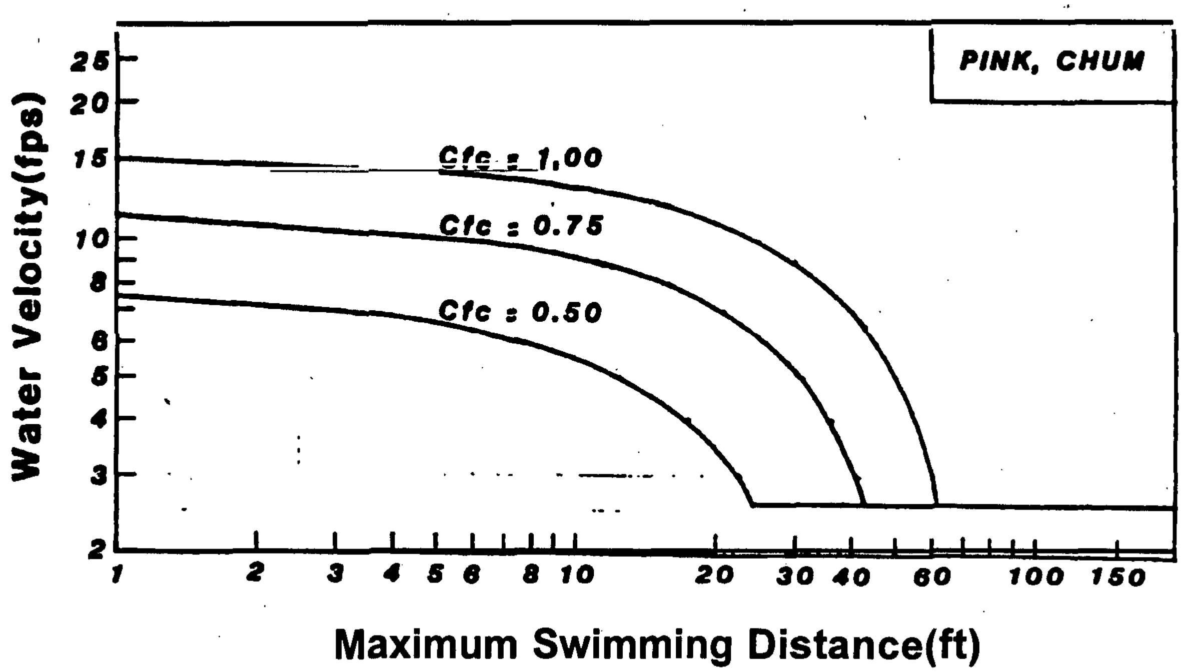


Figure 12. Maximum swimming distance for pink and chum salmon under three fish conditions.

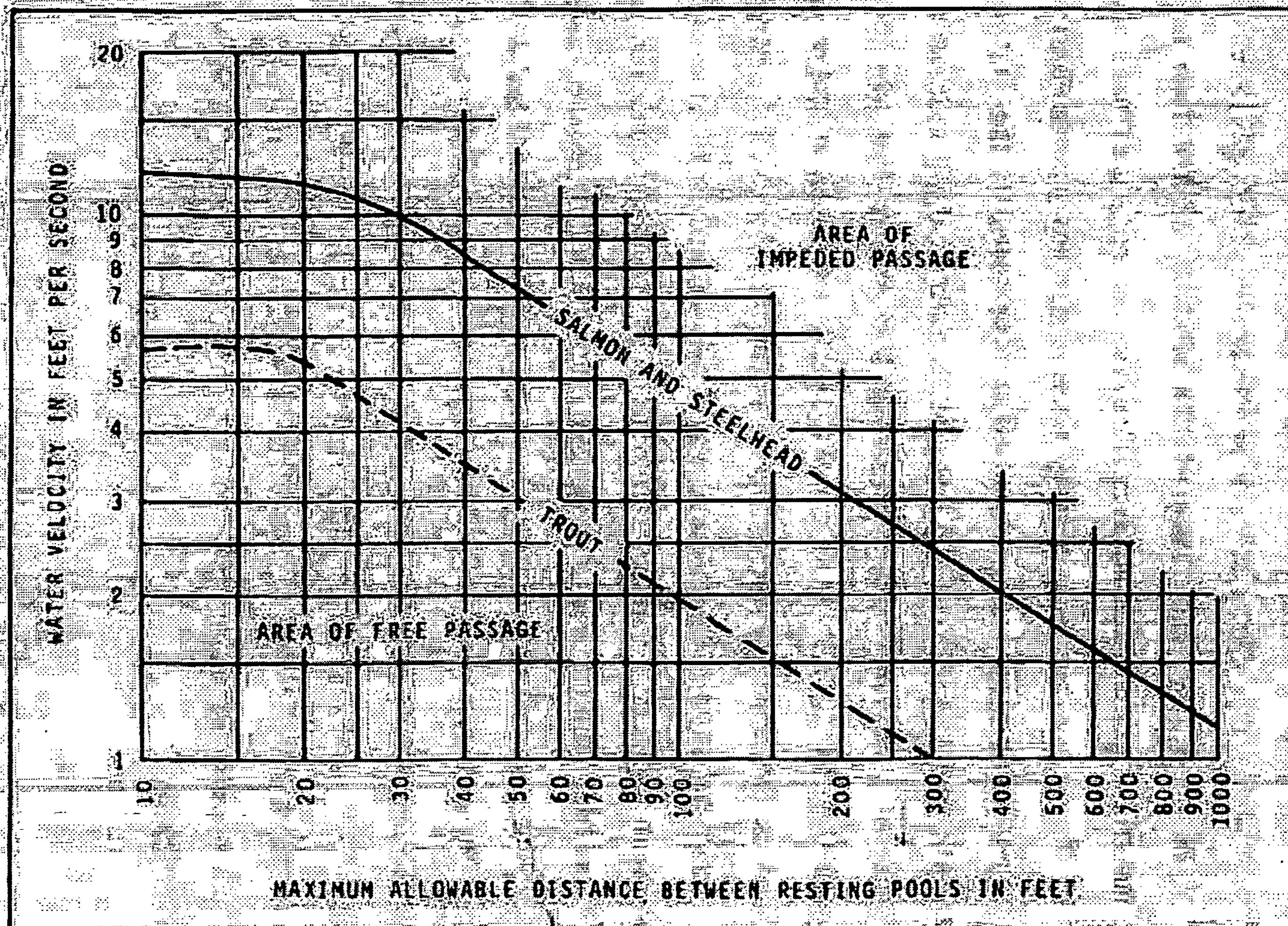


Figure 13. Swimming performance of salmon and trout from Evans and Johnston (1980). Curve developed by Ziemer, State of Alaska, Department of Fish and Game.

"Any factor interrupting or affecting the supply system (oxygen intake) as well as those affecting the propulsive system itself, affects swimming performance" (Webb, 1975). Both of these conditions exist when there is insufficient water depth to submerge the fish while it is swiminq. Partial submergence impairs the ability of the fish to generate thrust normally accomplished by a combination of body and tail movement. Also, if its gills are not totally submerged, they cannot function efficiently, promoting oxygen starvation while also reducing the fish's ability to maintain burst activity. Evans and Johnston (1972) suggest a minimum water depth of 6 in for resident trout and 1 ft for salmon and steelhead. Dryden and Stein (1975) state "In all cases, the depth of water should be sufficient to submerge the largest fish attempting to pass." This limitation will be used in analyzing barriers, because this would be the minimum depth requirement without affecting the fish's propulsive system.

It is important to note that the values of fish speeds suggested by Bell (1973) are for fish swiming in water without entrained air (black water). In extreme cases of sufflation the density of the water/air mixture (white water) will be reduced and detract from the propulsive power of the fish's tail, reducing its speed. To summarize the equations that describe the capabilities of fish in terms of swimming speed, leaping capabilities and swimming performance, Table 3 is provided with a nomenclature of terms.

Table 3. Fish capability equations for swimming and leaping.

Type of Motion	Equation	
Swimming	$VR = VF - VW$	(1)
	$VF = VFB(C_{fc})$	(2)
	$LFS = (VF - VW)TF$	(8)
Leaping	$HL = [VF\ (\sin\theta L)]^2/2g$	(6)
	$XL = VF^2(\cos\theta L)(\sin\theta L)/g$	(7)

where:

VR = relative swimming speed of the fish,

VF = fish speed,

VW = water velocity,

VFB = burst speed of fish,

C_{fc} = coefficient of fish condition,

LFS = maximum swimming distance of fish,

TF = time to fatigue,

HL = height of leap,

XL = horizontal distance of leap at fish's high point,

θL = angle of leap from water surface, and

g = acceleration of gravity (32.2 ft/sec^2).

CLASSIFICATION OF BARRIERS

To facilitate analyses and subsequent generation of solutions to fish passage problems a classification system needs to be introduced to define the parameters involved in the analysis. The objective of this chapter is to develop a systematic method for classifying barriers based on the conditions that affect fish passage success. Barrier classification sheets will be developed to enable fisheries personnel to make use of the classification system in fisheries enhancement programs, both to catalog waterfall and culvert barriers, and to design their modifications.

Evidence of classification for waterfalls in the literature was found only in terms of the site geomorphology (or origin of formation) (Fairbrige, 1968). No classification of waterfalls could be found in the literature that correlated site hydraulics or fish passage success to geometry. Pryce-Tannatt (1937) noted, "Obstructions are many and varied. It would be useless to attempt to classify them beyond distinguishing between the comparatively mild, the definitely difficult, and the completely impossible." Dane (1978) suggests a classification of obstructions for culvert barriers based on blockage as follows:

1. Total--impassable to all fish all of the time,
2. Partial--impassable to some fish all of the time, and
3. Temporary--impassable to all fish some of the time.

The classification system developed for this study will analyze the site geometry and hydraulics, and how they interrelate to fish passage success. Because waterfalls in nature consist of such a wide range of geologic and hydrologic combinations, a classification system for waterfalls should include several components, each of which describes waterfalls differently.

The classification system proposed here consists of four components: (1) class, (2) type, (3) magnitude and (4) discharge, extending from general to specific (Table 4). Class describes the flow patterns, number and characteristics of fish passage routes and site geometry in plan view. The class is determined by observing the characteristics in Table 4. Type describes the bed slopes, pool depths and geometry of the barrier in longitudinal profile, and therefore requires an engineering survey of the barrier site. Magnitude describes the elevation differences, water velocities and slope lengths the fish must negotiate. Because the class, type and magnitude of the barrier will vary with discharge, the fourth item for classification will be to accurately estimate or measure the discharge at the time of observation.

Also, a degree of passage difficulty rating will be applied, based on a range from 1 to 10, one being the least difficult to pass and ten the most difficult. This is a subjective comparative raating of barrier class characteristics in reference to fish passage difficulty which is independent of barrier height and velocity. The rating is based on the following assumptions:

1. The differential elevation and water velocities are within the swimming and leapinq capabilities of the species in question.

2. At higher swimming speeds (>9 fps) leaping is more energetically efficient that swimming (Blake, 1983).

3. Fish will be attracted to the area of highest momentum (flow x velocity) when migrating upstream; therefore if multiple paths arc present the fish may try to ascend the one with the highest attraction which will be created by the highest combination of drop, velocity, and discharge.

4. Turbulent flow (or white water) with surges, boils and eddies make it difficult for fish to orientate themselves and make full use of their swimming power.

Table 4. Characteristics of barrier classification components.

Classification Component	Characteristics
Class	Site geometry in plan view. Flow patterns Number of fish passage routes. Characteristics of fish passage routes.
Type	Site geometry in profile. Bed slopes Pool depths
Magnitude	Elevation drops Water velocities Slope lengths
Discharge	The flow rate at which the class, type and/or magnitude were measured.

Class

Waterfall barriers in nature are usually found in three forms; falls, chutes and cascades. From the author's field observations of many harriers, it appears that fall barriers are found either as single or multiple falls, chutes as either simple or complex, and cascades as boulder cascades or turbulent cascades. Combinations of falls and chutes will be denoted as compound barriers. These barrier classes and their characteristics are shown in Table 5 with their corresponding rating for degree of passage difficulty.

A single fall has the lowest degree of difficulty rating (DDR) because the fish has only one route to choose, and it leaps to pass. To determine the actual value of the DDR of 1 to 3, the upstream and downstream conditions must be analyzed. This will be done when barriers are classified by type. Multiple falls (falls in parallel) have a higher DDR than single falls because the fish has several routes from which to choose, and most likely will be attracted to the fall with the highest flow momentum (Stuart, 1964). Simple chutes have a slightly higher DDR than single falls because at high swimming speeds (>9 fps) leaping is more energetically efficient than swimming. Complex chutes have a higher DDR than simple chutes because the fish's propulsive power is reduced in white water. Poulder cascades have a slightly higher DDR than multiple falls because the fish have problems getting orient to leap due to the turbulent resting areas. This analysis can be continued,, comparing each barrier class based on the four original assumptions, for the degree of difficulty ratinq system.

Type

To classify barriers by type, conceptual models will he used which show the geometric and hydraulic relationships that are critical to fish passage success. Fiqures 14 and 15 show conceptual models and the notation used in profile view of a fall and chute respectively. These fiqures are not comprehensive for natural conditions, but the geometric dimensions apply and can fit any situation. Cascades are not included here because to determine the type of barrier requires measurements of bed slopes and pool depths. If these measurements could be made in a cascading reach, then a cascade would simply consist of a series of falls-and/or chutes and there would be several different types for one barrier class (i.e. several falls and/or chutes within a cascade).

Table 5. Subjective comparative rating of barrier class characteristics in reference to fish passage difficulty, independent of barrier height and velocity. Assumes passage success by strongest fish.

Class	Characteristics	Degree of Difficulty Range
Single falls	Entire stream flows through a single opening offering one path for fish passage.	1-3
Multiple falls	Flow divides through two or more channels offering the fish with several passage routes of varying difficulty.	3-5
Simple chute	Unvarying cross sections and constant bottom slope (steep), with supercritical flow at all stages	2-4
Complex chute	Varying cross sections, several changes in bed slope and/or curved alignment in plan view. White water at all stages.	4-6
Boulder cascades	Large instream boulders which constrict the flow creating large head losses from upstream to downstream sides of boulders. Intermediate resting areas in very turbulent pools.	5-7
Turbulent cascades	Large instream roughness elements or jutting rocks which churn the flow into surges, boils, eddies, and vortices. No good resting areas.	7-10
Compound	Combinations of single falls and/or simple chutes (e.g., culvert with high velocity and outfall drop)	3-7

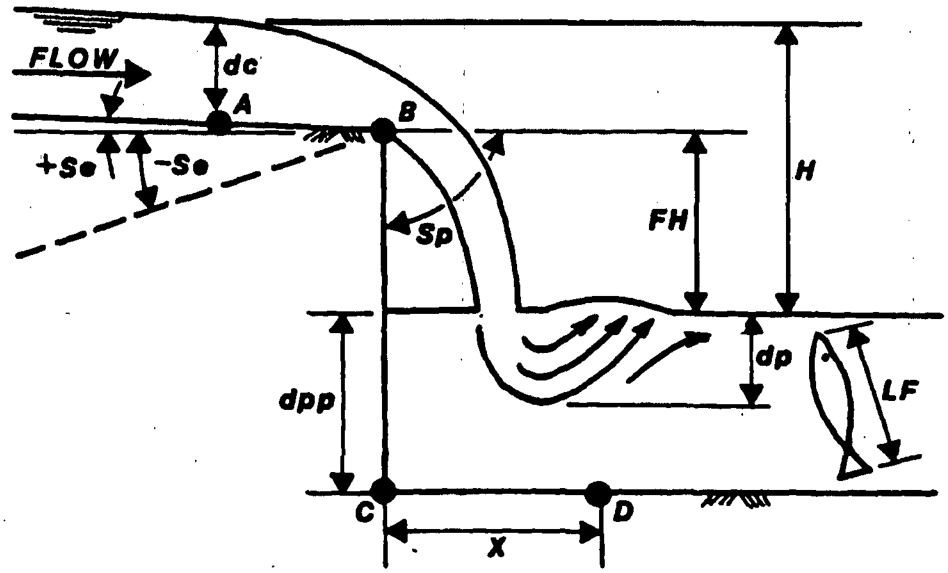


Figure 14. Conceptual model of a fall, where: A = point on fish exit bed slope where critical depth occurs; B = elevation of crest; C = furthest point upstream on bed of plunge pool; D = point just downstream of falling water (or standing wave) on bed of plunge pool; Se = fish exit slope; Sp = fish passage slope; dc = critical depth (point A); dpp = depth in the plunge pool; dp = depth the falling water plunges; X = horizontal distance from the crest (point B) to standing wave (point D); FH = fall height; H = change in water surface elevation; and LF = length of fish.

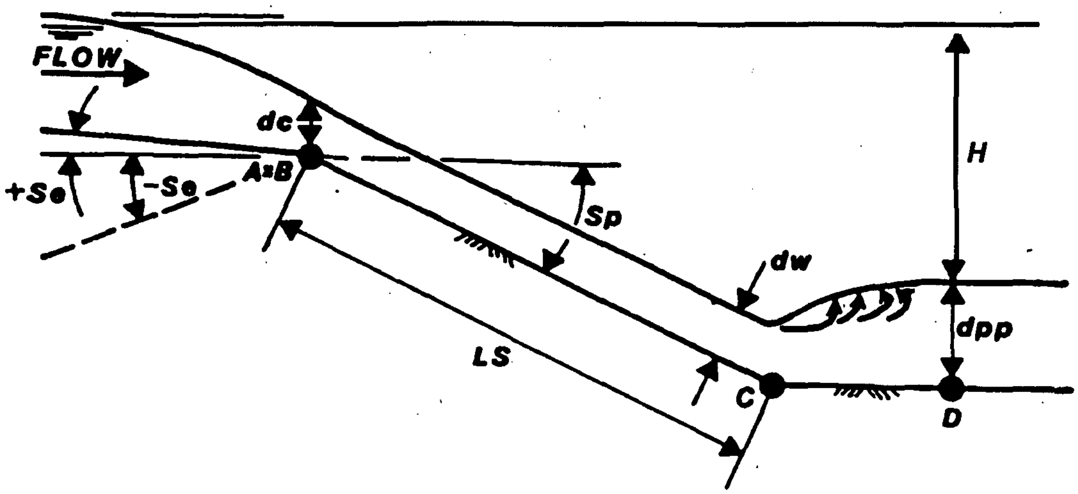


Figure 15. Conceptual model of a chute, where: A = point on fish exit bed slope Where critical depth occurs; B = elevation of crest; C = furthest point upstream on bed of plunge pool; D = point just downstream of standing wave (or hydraulic jump) on bed of plunge pool; Se = fish exit slope; Sp = fish passage slope; LS = length of slope; dc = critical depth (point A); dw = depth of water; dpp = depth in the plunge pool; and H = change in water surface elevation.

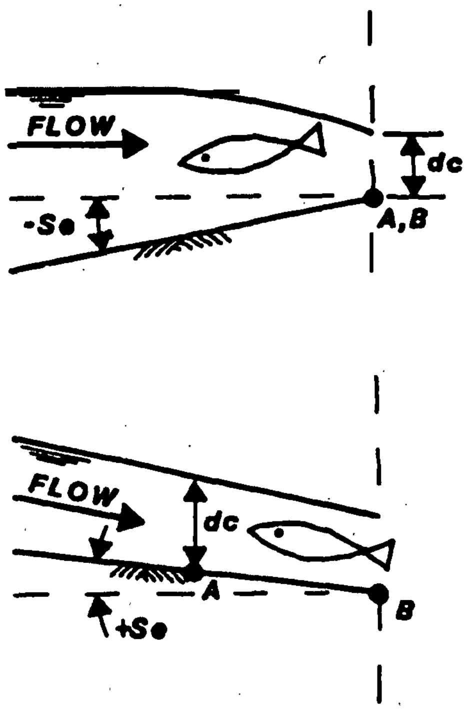
The conceptual models in Fiqures 14 and 15 consist of three zones: (1) the fish exit zone (point A to point B in Figure 16); (2) the fish passage zone (point R to point C in Figure 17); and (3) the fish entrance zone (point C to point D in Figure 18). The notation used to denote the barrier type is given in these figures, and follows outlininq logic from upstream to downstream. The type of barrier will be determined by measuring the exit slope, passage slope and plunge pool depth, and selectinq three characters from the notation, one each from the exit zone, passage zone and entrance zone (e.g. IIB2, would denote a chute barrier with a positive exit slope and a shallow plunge pool). From Figures 16, 17 and 18 it can be seen that there could be any of four different combinations of entrance and exit conditions for each of four passage zones; and thus 16 different types of barriers can exist according to this classification. These models are shown in Figure 19, along with the correspondinq degree of passage difficulty rating. The similarities with culvert flow and qeometry are denoted by dotted lines.

Magnitude and Discharge

To complete the classification, estimates of differential elevations, water velocities, length of slopes, etc., should be included, along with estimates of the discharge at the time of observation and migration season flows. These two components along with the barrier class and type then can be combined together to give the final barrier classification. A sample barrier classification sheet is shown in Fig. 20. This sheet can be used in the field to classify barriers and will be helpful in assessinq design modifications.

1 In profile, but one must consider the flow pattern in plan view because it can cause disorientation of the fish.

FISH EXIT/WATER INLET SLOPE POSITION — NOTATION

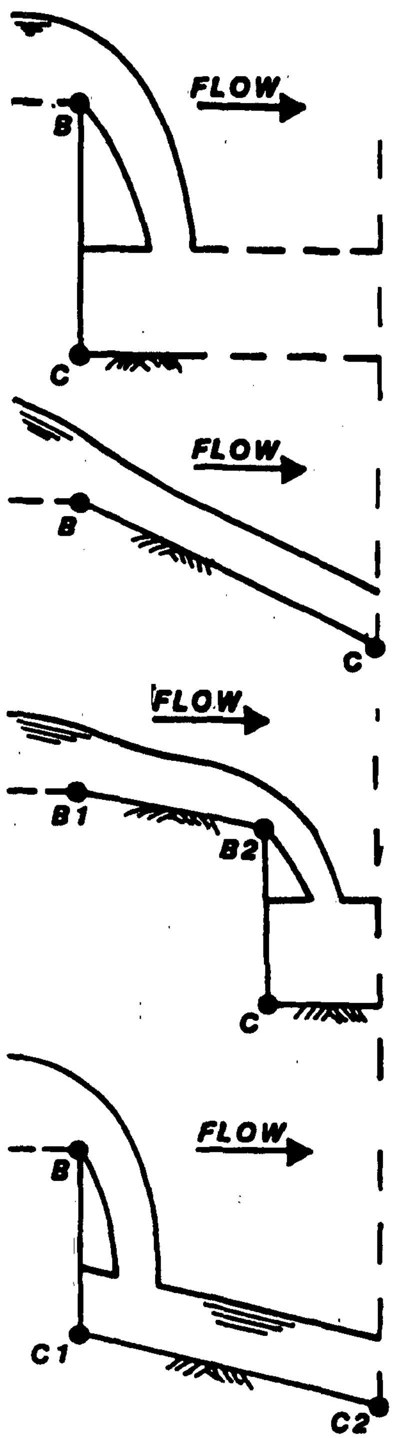


I (Good)

II (Poor)

Figure 16. Fish exit zone notation, where: I = negative or nonsustaining slope at the fish exit (or water inlet). Good conditions for fish, reduced velocities, increased water depth therefore good resting areas. II = positive or sustaining slope at the fish exit (or water inlet). Poor conditions for fish, increased velocities, decreased depths and therefore poor resting areas.

FISH PASSAGE/WATER TRANSITION ZONE | NOTATION



A (fall)
(simple)

B (chute)
(simple)

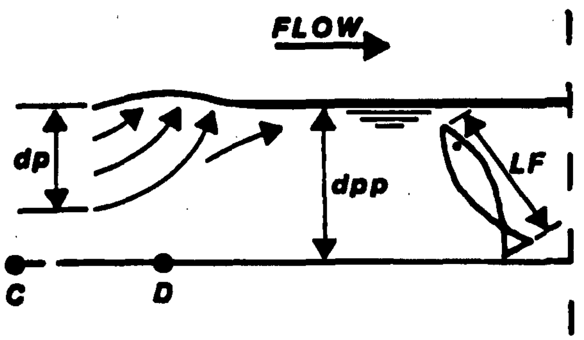
C (chute/fall)
(compound)

D (fall/chute)
(compound)

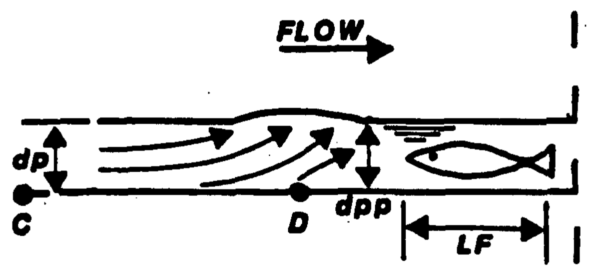
Figure 17. Fish passage zone notation.

FISH ENTRANCE/WATER EXIT ZONE

NOTATION

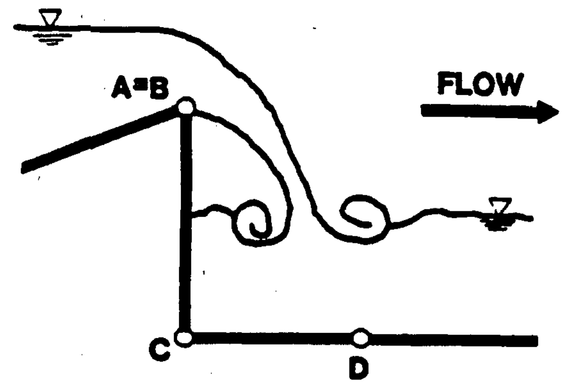


1
(Good)

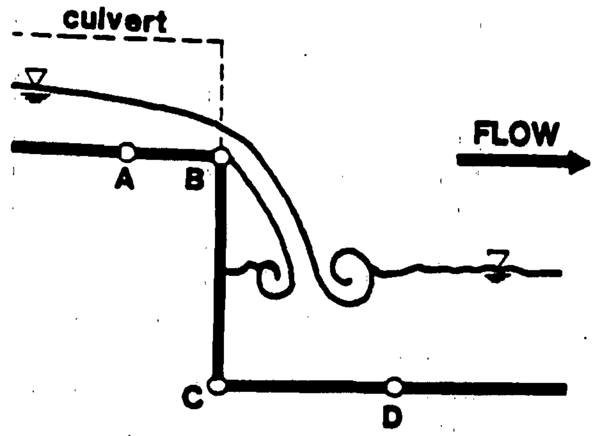


2
(Poor)

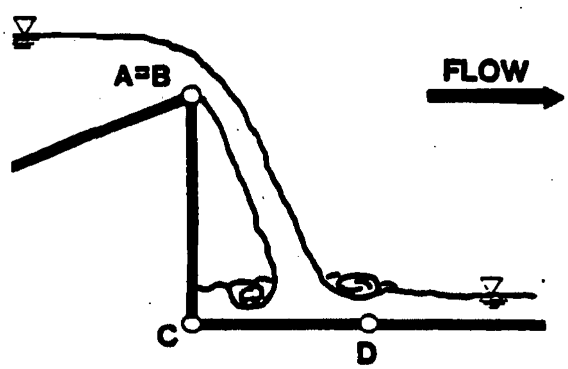
Figure 18. Fish entrance zone notation, where: 1 = deep plunge pool. Good conditions for fish, sufficient depth allows dissipation of falling water energy and standing wave to develop. Good leaping conditions. 2 = shallow plunge pool. Poor conditions for fish, falling water strikes bed of plunge pool, creates turbulence and moves standing wave downstream. Poor leaping conditions.



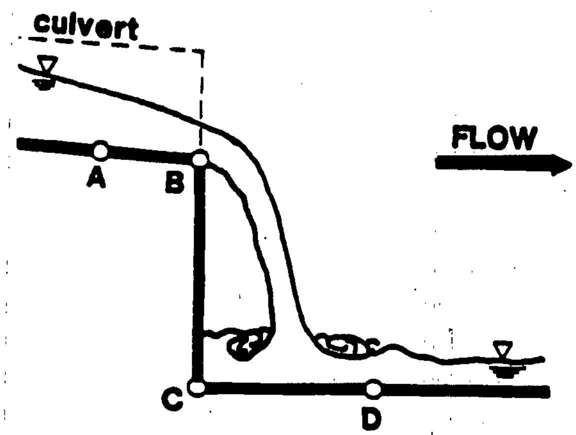
TYPE: I A 1
DEGREE OF DIFFICULTY: 1



TYPE: II A 1
DEGREE OF DIFFICULTY: 2

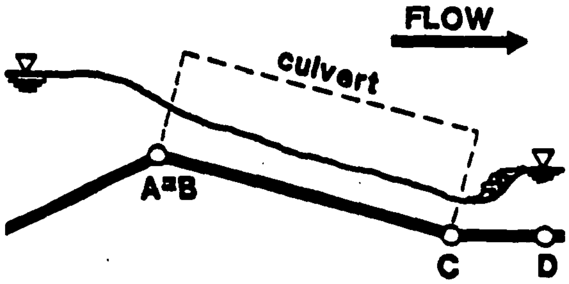


TYPE: I A 2
DEGREE OF DIFFICULTY: 2

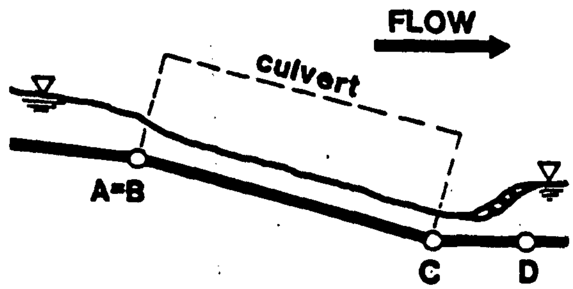


TYPE: II A 2
DEGREE OF DIFFICULTY: 3

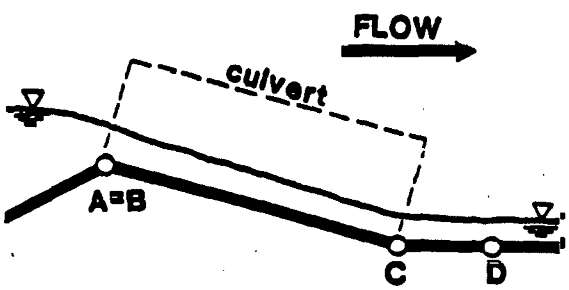
Figure 19. Conceptual models of barrier types with the corresponding degree of difficulty rating.



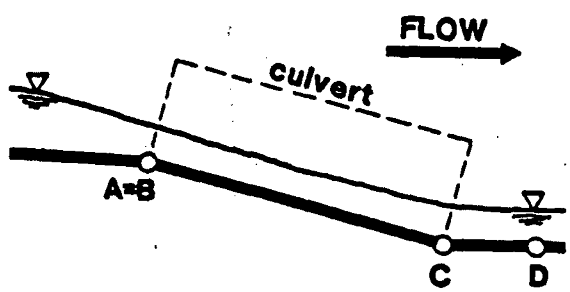
TYPE: I B 1
DEGREE OF DIFFICUTY: 2



TYPE: II B 1
DEGREE OF DIFFICULTY: 3

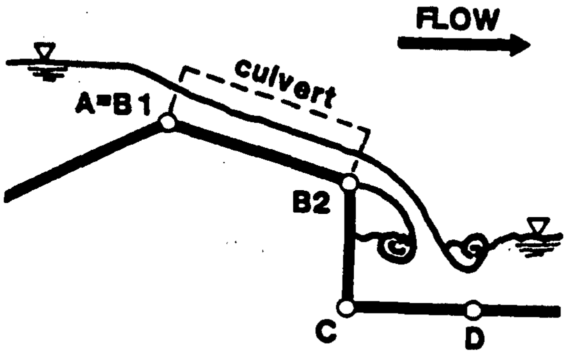


TYPE: IB2
DEGREE OF DIFFICULTY: 3

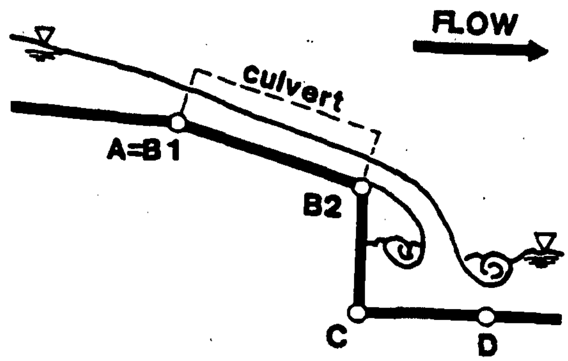


TYPE: II **B** 2
DEGREE OF DIFFICULTY: 4

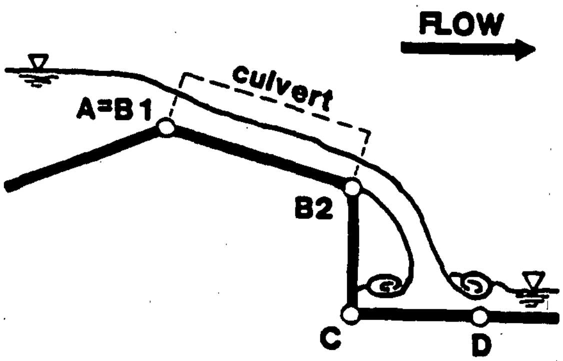
Figure 19. (Cont.)



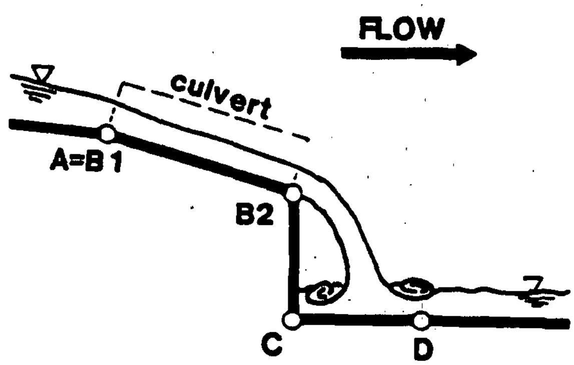
TYPE: IC1
DEGREE OF DIFFICULTY: 3



TYPE: II c 1
DEGREE OF DIFFICULTY: 4

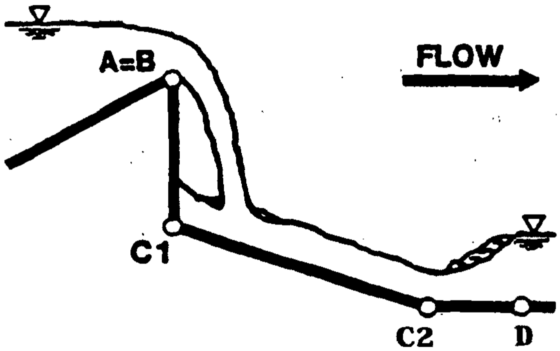


TYPE: IC2
DEGREE OF DIFFICULTY: 4

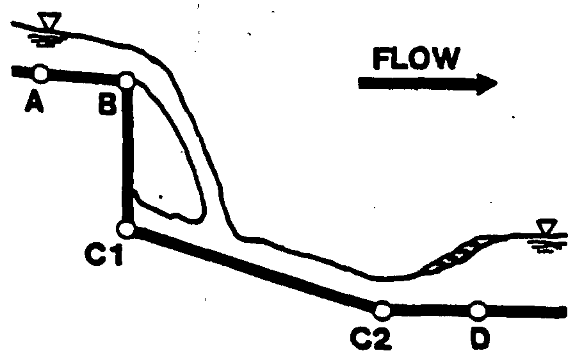


TYPE: II c 2
DEGREE OF DIFFICULTY: 5

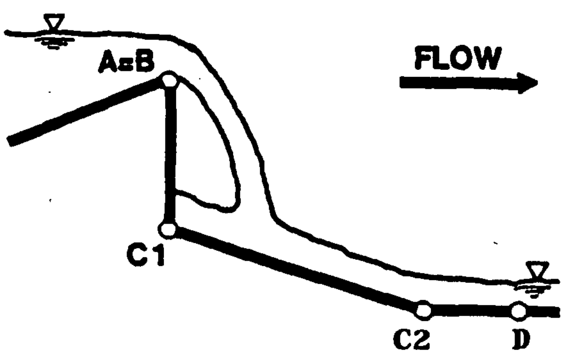
Figure 19. **(Cont.)**



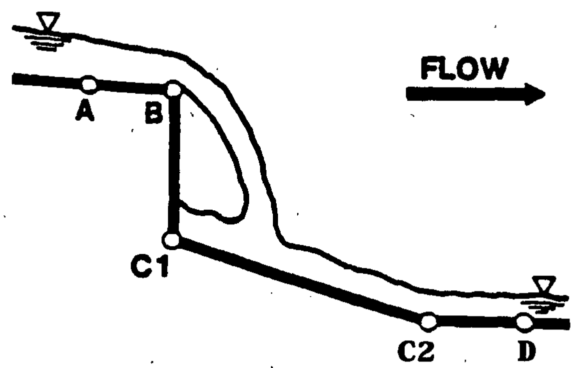
TYPE: ID1
DEGREE OF DIFFICULTY: 5



TYPE: II D 1
DEGREE OF DIFFICULTY: 6



TYPE: I D 2
DEGREE OF DIFFICULTY: 6



TYPE: II D 2
DEGREE OF DIFFICULTY: 7

Figure 19. **(Cont.)**

SITE: **DATE:**

LOCATION:

SITE SKETCH

CLASS:

TYPE:

DEGREE OF DIFFICULTY:

MAGNITUDE:

DISCHARGE:

COMMENTS:

Figure 20. Sample barrier classification sheet.

ANALYSIS OF BARRIERS

For determining fish passage success at waterfall and culvert barriers the hydraulic conditions must be evaluated and related to fish capabilities for the species in question. This chapter contains a detailed analysis of:

1. plunge pools (fish entrance zone);
2. landing conditions (fish exit zone);
3. falls (fish passage zone); and
4. chutes (fish passage zone);

and a discussion of the parameters which prohibit fish passage in cascades.

The most complicated aspect to analyze in barriers is determining how white water and turbulence affect the fish's swimming and leaping capabilities. Turbulence in "fluid mechanics" terms occurs when the viscous forces are weak relative to the inertial forces. The water particles move in irregular paths which are neither smooth nor fixed but which in the aggqregate still represent the forward motion of the entire stream. In open channel flow, turbulence is present if the Reynolds number $R = (VL)/\nu$ is large, say greater than 500 (Chow, 1959). For this study, turbulence will be used to visually describe flow patterns which are in a constant changing state of surges, boils, eddies, upwellings and vortices. Jackson (1950), noted turbulence deflects a swimming fish from its course, causing it to expend energy resisting upwellings, eddies, entrapped air and vortices, which in turn make it impossible for a fish to use its swimming power effectively. Stuart (1964) noted that the only known effect turbulence has on fish is that the reduced density of the air-water mixture reduces the propulsive power of the fish's tail.

Because of the violence in turbulent flow and the effect it has of reducing fish capabilities, it will be assumed for this study that any waterfall that is steep enough to accelerate the flow into violent turbulent white water is a total barrier to all fish species attempting to swim up the barrier. Fish can only pass if they leap and clear the area of turbulence before landing.

The analysis presented in this section is applicable to all waterfall and culvert barriers as long as the parameters needed for the analysis can he measured or estimated within ranges of practical values.

Plunge Pool Requirements

The behavior of a falling jet of water as it enters a pool depends to a great extent on the pool depth. If the pool is shallow the jet may strike the bottom and be deflected downstream. A good takeoff pool is essential if fish are to leap to any height. If the turbulent pool conditions created from the falling water impacting the shallow pool prevent a good take off, a relatively low fall may act as a total barrier. If the pool is deep enough to absorb the falling water, a standing wave will form, which assists the fish's leap, in the form of a vertical velocity component created by the pool surface (Aaserude, 1984). Air bubbles are created by the mixture of air and water as the falling water impacts the surface and entrains large quantities of air.

At falls and chutes aeration reduces the impact force of the falling water. The energy of a fall can be mostly dissipated due to transformation of aerated water into mist. At falls of medium height, but beyond the range of the fish's leaping capabilities, the impact produced by the emulsion of air and water may be reduced so that a false clue to the actual fall height is obtained by the fish. Stuart (1964) observed numerous salmon leaping over a period of several hours, constantly attaining a leap height of 4 to 5 ft, at a high impassable fall of around 30 ft; but the height attained by the fish was much less than the recorded maximum at other passable falls because of the reduced attraction flow.

Stuart (1964) suggests a ratio exists between the fall height (the vertical distance from the falls crest to the plunge pool surface) and the plunge pool depth which provides the best standing wave for leaping. He identifies this ratio as 1:1.25 (fall height/plunge pool depth). Aaserude (1984) studied standing waves and concluded that the character of the standing wave is closely related to the jet shape which strikes the plunge pool, and the depth of plunge can be estimated as S.5 (d), where d is defined as the diameter of the circle that can be superimposed completely within the boundaries of the jet cross-section at the plunge pool surface. Stuart's ratio does not consider jet shape.

From a research project the author participated in observing fish leaping over weirs at Johns Creek Fish Hatchery, near Shelton, Washington (Aaserude, 1984), it was concluded that two conditions should be satisfied to provide optimum leaping conditions in plunge pools:

1. depth of penetration of the falling water (dp) should be less than the depth in the plunge pool (dpp), and

2. depth of the plunge pool must be on the order of, or greater than, the length of the fish (LF) attempting to pass.

These two conditions assure the plunge pool will be stable with sufficient depth so the fish's orientation and propulsive power will be unimpaired. The relationships for analyzing a plunge pool are shown in Table 6.

Table 6. Relationships among plunge pool depth, depth of plunge and fish length for optimum and poor leaping conditions.

Depth and fish length relationships	Effect on fish
1. dp > dpp	Turbulent pool condition disorients fish. Standing wave reduced and moved downstream from where the falling water strikes the bed of the plunge pool.
2. dp < dpp	
a. LF > dpp	Propulsive power of fish's tail may be reduced for leaping.
b. LF < dpp	Optimum plunge pool conditions.

where: dp = depth the falling water plunges beneath the pool surface,

dpp = depth in the plunge pool measured at the point of plunge, and

LF = length of the fish attempting to pass.

Landing Conditions

When fish leap at waterfalls, often the landing conditions near the crest are such that the fish may be swept back by high velocities, or unable to propel themselves in water depths less than their body depths, where they are not totally submerged. Stuart (1964) notes that when fish leap towards the crest of a waterfall, they are geared for immediate propulsion when they land. The slightest delay in reaction would cause the fish to lose ground and be swept back over the waterfall. He also observed fish landing near the crest, relaxing their swimming effort immediately if they began to lose ground, and then were swept backwards. Even if fish are successfully passing a given waterfall, improvements of the landing conditions can reduce stress on the fish and further open the "window of passage".

If the velocity and depth of flow near the crest cannot be measured for a range of stream flows, an analysis near the crest of a fall or chute can be made by locating the point of critical depth and measuring the channel cross section at that point. Critical depth in open channel flow is that depth for which the specific energy (sum of depth and velocity head) is a minimum, and the Froude number $Fr = V/(gL)^{1/2}$, is equal to unity. Critical depth is also a "stream control," which determines a depth-discharge relationship. If the fish exit bed slope (S_e) is negative (increases in elevation in the direction of flow) critical depth will occur at the crest for a fall or chute. If the exit slope is positive (decreases in elevation in the direction of flow) critical depth will occur at the crest for a chute, but will occur some distance upstream of the crest for a fall. If critical depth does not occur at the crest, the following steps will locate the point where critical depth occurs:

1. measure the mean depth of flow some distance upstream of the crest,

2. calculate the equivalent pool elevation from

   pool elevation = bed elevation + measured depth of flow + hydraulic depth/Z, where: hydraulic depth = cross sectional area divided by the top width,

3. measure the pool elevation some distance upstream of the crest where the water is quiet,

4. if the pool elevation (measured) = pool elevation (calculated) the critical depth occurs at the point where the depth of flow was measured, and

5. if the pool elevation (measured) > pool elevation (calculated), move farther upstream and return to step 1.

This analysis is required because of the effect of the approach velocity. As Se increases from zero to some positive value the approach velocity will increase and critical depth will occur further upstream. If the fish exit slope is steep and thus flowing at supercritical flow, critical depth will not be reached and the landing condition should he analyzed as a velocity chute.

It can be shown mathematically (Henderson, 1966) that critical depth occurs in any channel shape when:

$$Q^2/g = A^3/W \qquad (9)$$

where Q = total stream discharge in cfs, W = surface width of the waterway in ft, g = acceleration of gravity in ft/sec^2, and A = flow area of the cross section. Since most natural channels are of irregular shape and can be composed of several distinct subsections, the solution of equation (9) for rectangular and triangular sections will -allow computation of the discharge as a function of the critical depth for any irregular channel shape. For rectangular shapes:

$$Q = (A^3 g/W)^{0.5},$$

but $A = W(d_c)$ where d_c = critical depth in ft, so substitution yields:

$$Q = (W)(g)^{0.5}(d_c)^{1.5},$$

and using $g = 32.2$ ft/sec^2 yields:

$$Q = 5.7(W)(d_c)^{1.5} \qquad (10)$$

For triangular shapes the substitution is:

$$A = W(d_c)/2$$

which yields the following equation for triangular shapes:

$$Q = 2W(d_c)^{1.5}$$

Rut substituting $W = d_c/S$ where S = slope of one side of a triangle in percent yields:

$$Q = [2(dc)^{2.5}]/S \qquad (11)$$

Once the discharge has been solved as a function of the critical depth, substitution of a range of migration flows will give the critical depths, which can then be compared to the fish depth (df) to determine if the fish will be totally submerged. Also, the mean velocities can be calculated from:

$$vc = Q/A, \qquad (12)$$

where V_c = mean velocity at critical depth, Q = stream discharge, and A = cross sectional flow area.

Optimum leaping conditions exist when the water velocity near the crest is less than or equal to the sustained swimming speed (VFS) for the species in question, and the depth of flow is greater than the fish depth.

At sustained speed, fish can function normally without fatigue (Hoar and Randall, 1978), and therefore are able to swim whatever distance is required before locating a resting area. If the water velocity is greater than the sustained swimming speed, the landing conditions should he analyzed as a chute because the distance the fish can swim will decrease as the water velocity increases above the sustained speed.

The relationships for analyzing the landing conditions at the crest of a fall or chute are shown in Table 7. An example calculation will show how this analysis can be used.

Table 7. Relationships between fish depth, critical depth, mean velocity and sustained swimming speed for optimum landing conditions.

Velocity, depth relationships	Effect on fish
1. $d_f > d_c$	Propulsive power of fish will be reduced
2. $df < d_c$	
a. $V_c >$ VFS	Landing conditions should be analyzed as a chute
b. $V_c <$ VFS	Optimum landing conditions

Where: df = depth of fish,

d_c = critical depth calculated from a range of migration flows (equation 9) if d_c occurs close enough to crest for fish to reach, or

= depth near the crest where fish may land if the critical depth occurs too far upstream for the fish to reach,

V_c = mean velocity at critical depth if critical depth occurs close enough to crest for fish to reach, or

= mean velocity near the crest where fish may land if the critical depth occurs too far upstream for the fish to reach, and

VFS = sustained swimming speed for the species in question from Table 1.

Example: Given the irregular channel shape in fig. 21, determine the discharge (0) in cfs as a function of the critical depth (dc) assuming critical depth occurs at the crest, and calculate the critical depth that will occur at migration flows of 5, 20 and 50 cfs, and the correspondig mean velocities from equation 12. Using Table 7, determine the effects on an adult steelhead trout with a maximum fish depth (df) of 0.5 ft.

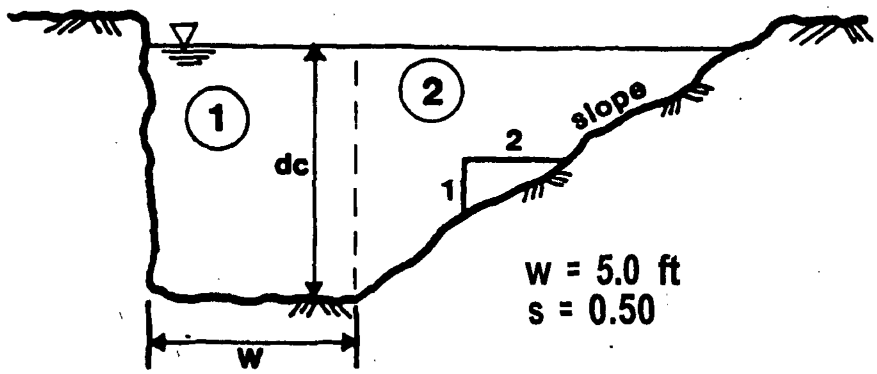


Figure 21. Irregular crest shape used for landing condition analysis example.

The channel shape in Fig. 21, can best be represented by the combination of a rectangle (section 1) and a triangle (section 2). Therefore:

$$Q_{total} = Q_1 + Q_2$$

where: $Q1 = 5.7(W)\ d_c^{1.5}$, from equation (10), and $Q_2 = [2(d_c)^{2.5}]/S$ from equation (11). Substituting, W = 5 ft and S = 0.50 yields:

$$Q_1 = 28.5(d_c)^{1.5} \text{ and } Q2 = 4(d_c)^{2.5}.$$

Therefore, the discharge as a function of critical depth is:

$$Q = 28.5(d_c)^{1.5} + 4(d_c)^{2.5}.$$

Substituting Q = 5, 20 and 50 cfs, and solving for d, and V_c gives:

Q (cfs)	d_c (ft)	V_c (fps)
5	0.30	3.1
20	0.74	4.7
50	1.30	6.1

From Table 1, the sustained swimming speed for steelhead is, VFS = 4.6 fps. Usinq Table 7, the effects on fish are:

1. At 5 cfs; $d_f > d_c$ and
2. At 50 cfs; $V_c >$ VFS.

The only discharge which provides good landing conditions from Table 7 is 20 cfs. At the other two flow rates, passage will not be blocked, but a higher passage success rate may be obtainable if these conditions were not present.

This example assumes the fish lands at critical depth, and therefore is not applicable if critical depth occurs some distance upstream of the crest. In that case the fish would land in higher velocities and shallower depths between critical depth and the depth at the falls crest.

In summary, for analyzing landing conditions near the falls crest, the following factors must be considered:

1. The depth of flow where the fish lands must be equal to or greater than the depth of the fish.
2. The velocity where the fish lands should be within the range of the sustained swimming speed for the species in question.
3. The velocity and depth should be analyzed under a range of fish migration flows.

Analysis of Falls

The most obvious obstruction at falls is when the change in water surface elevation between pools (H) exceeds the leaping height (HL) of the species in question. For Pacific salmon and steelhead trout, the highest calculated height of leap from level pool using equation (6) and $\theta L = 90°$ is 10.9 ft (steelhead). Therefore, falls where the change in water surface elevation is in excess of 11 ft can be considered for all practical purposes a total barrier to all species of Pacific salmon and steelhead trout. Evans and Johnstone (1980) suggest for natural bedrock waterfalls that if the vertical drop is more than 6 feet, it should he considered to he a barrier for salmon and steelhead without further study.

Often, though, the actual distance the fish must leap is greater than the vertical drop between pools. Unless the water is falling vertically, some horizontal component of the leap (XL) will be required for successful passage. If the horizontal distance the fish must leap cannot he measured, and the geometry of the falls is such that the water breaks off the crest and is unobstructed until it strikes the plunge pool, then this distance can be calculated. The calculation requires knowledge of the velocity of the water and the angle of trajectory at the crest (Fig. 22). An example of where this analysis would apply is at a cantilevered culvert outlet. Using the equations for projectile motion, developed in the fish capability section, the horizontal distance the water travels before striking the Plunge pool can be calculated from:

$$XP = VW_C[\cos(\theta W_C)]t \qquad (13)$$

where XP = horizontal distance from the crest to the point of the falling water, VW, = velocity of the water as it leaves the crest, θW_C = angle at which the water leaves the crest at in relation to the horizontal, and t = time. To use equation (13), measurements of VW, and θW_C are required before t can be calculated from:

$$H = [VW_C(\sin\theta W_C)]t - (1/2)gt^2 \quad (14)$$

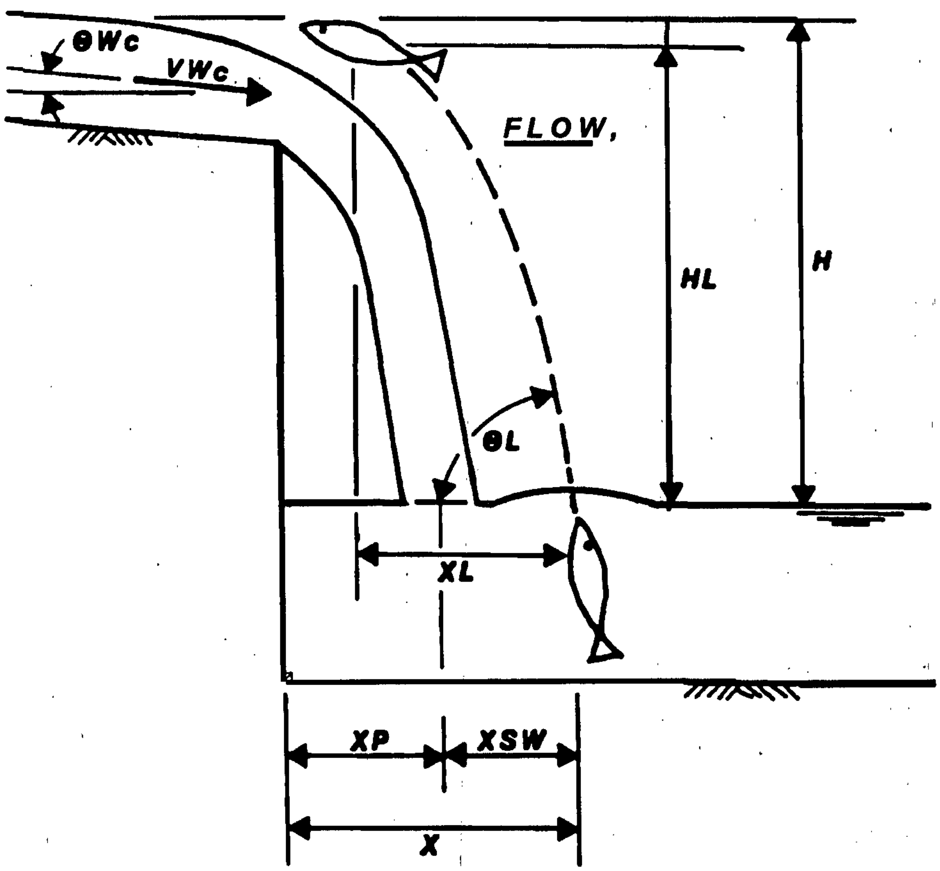


Figure 22. Leaping analysis parameters.

where H = change in water surface elevation (measured), and g = acceleration of gravity (32.2 ft/sec^2). If the approach flow is from a negative or nonsustaining slope (rises in the direction of flow) then $\theta W_c \leq 0$, and equation (14) can be solved as a function of t, or:

$$t = [2(H)/g]^{0.5},$$
$$\text{and } XP = VW_c[2(H)/g]^{0.5} \qquad (15)$$

If the approach flow is from a positive or sustaining slope (elevation decreases in the direction of flow) then $\theta W_c > 0$, t must be found by using the quadratic equation, and then substitute t into equation (13) to solve for XP. Once XP has been determined, adding the distance from the point where the falling water strikes the plunge pool to the standing wave (the point just downstream of the falling water from which fish most likely leap) gives X.

This analysis shows that even if the height the fish can leap (HL) is greater than the change in water surface elevation (H), and X is greater than XL, then a leaping fish will not reach the crest at the top of its leap. It will either fall short of the crest on its way down or reach the crest as it continues upstream on its descending parabolic path. These conditions are shown in Figure 23 for a steelhead trout. If the water surface profile of a barrier is superimposed on the fish leaping curves (Figure 23), the possibilities for a successful leap at a given leaping angle can be analyzed. The wide solid line shown is a falls barrier on Eldorado Creek in Idaho (Figure 24). The distances H and X were measured at the site. It can be seen from Figure 23 that a leaping angle of 60 degrees would allow passage. 80 and 40 degrees fall short of the crest by about 6 ft.

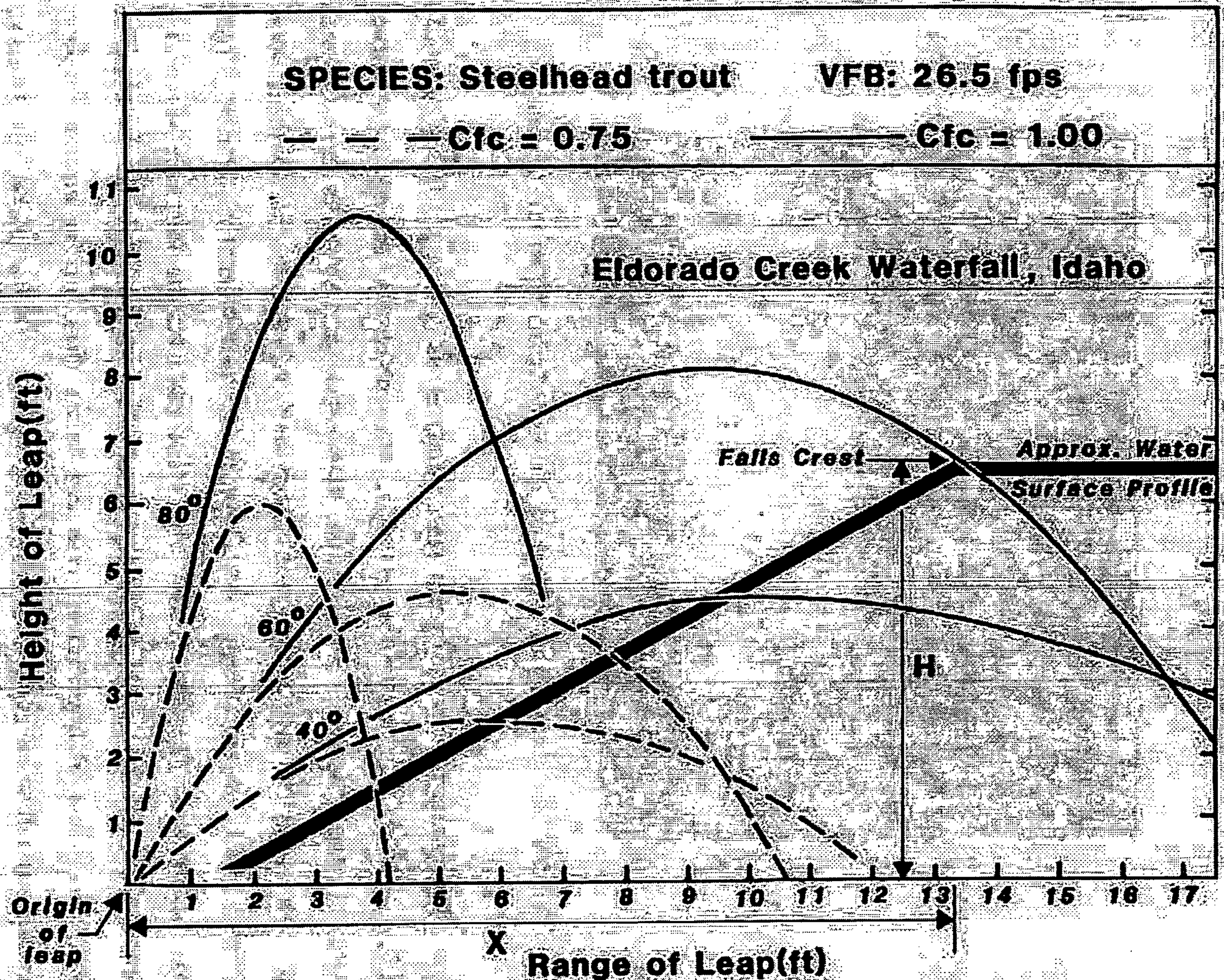


Figure 23. Eldorado Creek waterfall superimposed on steelhead leaping curves.

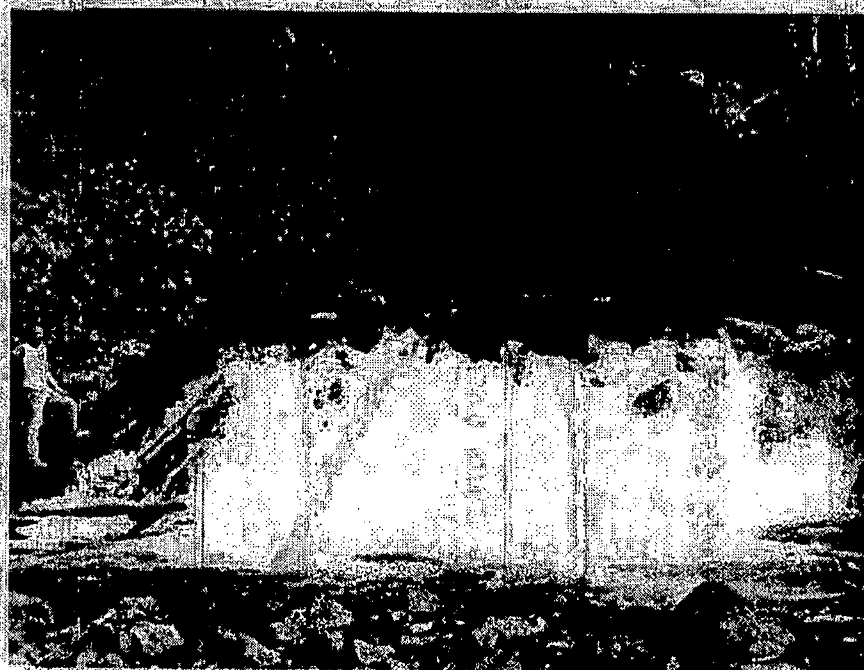


Figure 24. Looking upstream at Eldorado Creek Waterfall, Idaho.

One parameter that has not been discussed as yet is the leaping angle (θL). It is the author's opinion, from observations of coho salmon leaping, that the angle at which the fish leaves the standing wave depends on the location of the waterfall crest with respect to the standing wave. Stuart (1964) observed that fish aimed at sharp boundaries between light and shade when leaping. This sharp boundary can be found at waterfalls where the contrast at the boundary between water and background is clearly visible. This also coincides with the theory that leaping ceases abruptly at dusk and under heavily overcast conditions. To estimate the leaping angle, looking again at Figure 23, for a water surface slope of 29°, the optimum leaping angle was 60°. Since the fish is sighting the crest from some horizontal distance of 12.3 ft and a vertical distance of 6.7 ft the angle is some function of X and H. For this example in Figure 23, solving for H as a function of X gives:

$$H/X = \tan \theta L = \tan 60^\circ = 1.73$$

where H = change in water surface elevation, X = horizontal distance from the point where the fish will leap (or standing wave) to the crest, and θL = leaping angle. Holding X constant and solving for H gives:

$$H = X(1.73) = 12.3(1.73) = 21.3 \text{ ft}$$

Since the measured value of H was 6.7 ft, this value is approximately 3 times larger than the measured H. This is because the fish does not leap on a straight line, its path is parabolic and therefore to reach the crest the optimum leaping angle, θL, should be:

$$\theta L = \tan^{-1} [3(H/X)] \qquad (16)$$

This is the leaping angle equation.

Table 8 describes the two conditions that must be analyzed to determine whether or not a fall is a barrier, assuming the plunge pool and landing conditions are not adverse.

Table 8. Conditions for analyzing a fall assuming-plunge pool requirements and landing conditions are satisfied.

Water Surface Drop and Leaping Capability Relationships	Form of Barrier
1. H>HL	elevation barrier
2. H<HL	
a. X>XL (Superimpose water surface profile on fish leaping curves, Figures 7, 8 and 9)	passable or horizontal distance barrier
b. X<XL	passable

Where: H = change in water surface elevation (measured),

HL = height the fish can leap from Equation (6),

X = horizontal distance from the crest to the standing wave, and

XL = horizontal distance of the fish's leap at the highest point of the leap from equation (7).

Analysis of Chutes

In natural streams uniform flow is rare. However, the uniform-flow condition is frequently assumed in the computation of flow in natural streams. The results obtained are approximate and general, but offer a relatively simple and satisfactory solution for analyzing the velocities fish must swim against. Laminar uniform flow rarely occurs in natural channels, so turbulent uniform flow should be used for all velocity calculations in chutes.

From the definition of chutes, the flow must be supercritical down the chute (Froude number is greater than unity). At the start of the chute the flow will pass through critical depth and then into a transition zone of varied flow for some distance before uniform flow is established. If the chute length is shorter than the transition length required to reach normal depth, uniform flow cannot be attained. The length of the transition zone depends on the discharge and on the physical conditions of the channel, such as entrance condition, shape, slope and roughness.

For hydraulic computations the mean velocity of a turbulent uniform flow in chutes can be expressed by Mannings equation

$$v = (1.49/n)(R)^{0.67}(S_p)^{0.5} \qquad (17)$$

where V = mean velocity of flow in fps, n = empirical roughness coefficient, R = hydraulic radius in ft, and Sp = passage slope (or bed slope). Outlet velocities in chutes computed by assuming uniform flow will give conservative estimates of velocity, because as the fish approach the transition zone the mean water velocity will be reduced. In culverts, the water surface profiles can be calculated because of the unvarying cross section, constant bed slope and uniform roughness throughout. From equation (17) it can he seen that the mean velocity varies as the slope to the 0.5 power, hydraulic radius to the 0.67 power and roughness to the -1.0 power. Since the mean velocity is highly dependent on n, it is important that the proper value of n be used. Chow (1959),suggests the following values for Manning's n, shown in Table 9. A problem arises when one value of n is selected, because n changes as the depth of flow changes as well as the slope, discharge and cross-sectional shape. This is shown in Appendix II. Three tests were run with identical bottom and side roughness, and n increased as the slope and depth of flow increased.

Table 9. Manning's n value for corrugated metal pipe and bed rock (from Chow, 1959).

Surface Material	Manning's n	
Culverts (C.M.P.)	0.024	
Red Rock		
smooth	min-0.025	max-0.040
jagged	min-0.035	max-0.050

The hydraulic radius is calculated by dividing the flow area by the wetted perimeter. If the cross-section cannot be measured, a method can be applied to estimate the hydraulic radius that gives values with errors less than 5%. This method was suggested by Renard and Laursen (1975), but the author has expanded the method. It is used to estimate the hydraulic radius for rectangular and symmetrical triangular shaped channels, or combinations of such basic geometric shapes. For rectangular channels where the average stream width divided by the average depth is greater than 35, the hydraulic radius can be estimated by the average depth of flow. If the average width divided by the average depth is between 10 and 35, the hydraulic radius can be estimated by 0.9 times the average depth. If the average width divided by the average depth is less than or equal to 10, the hydraulic radius can be estimated by the following equation

$$R = \bar{d}[0.524 \log(\bar{w}/\bar{d}) + 0.35] \qquad (18)$$

where: R = hydraulic radius, $\bar{d}$ = average depth in a rectangular channel, and $\bar{w}$ = average width in a rectangular shaped channel. For symmetrical triangular shaped channels where the average stream width divided by the maximum depth in the center of the stream is greater than or equal to 7, the hydraulic radius can be estimated by 0.5 times the thalweg depth (maximum depth). If the average width divided by the thalweg depth is between 3 and 6, the hydraulic radius can be estimated by 0.45 times the maximum depth. If the average width divided by the maximum depth is less than or equal to 3, the hydraulic radius can be estimated by

$$R = d_t[0.36 \log(\bar{w}/d_t) + 0.23] \quad (19)$$

where: d_t = depth at the thalweg; and w = average stream width for the triangular channel section. These conditions are summarized in Table 10.

Table 10. Hydraulic radius as a function of the width and depth for rectangular and triangular shaped channels.

Channel Shape	Width : Depth Ratio $\bar{w}/\bar{d}$ (rectangle) $\bar{w}/d_t$ (triangle)	Hydraulic Radius (feet)
	≥ 35	$\bar{d}(1.0)$
Rectangular	$10<\bar{w}/\bar{d}<35$	$\bar{d}(0.9)$
	<10	$\bar{d}[0.524 \log(\bar{w}/\bar{d}) + 0.35]$
	≥ 7	$d_t(0.5)$
Symmetrical Triangle	$3<\bar{w}/d_t<6$	$d_t(0.45)$
	≤ 3	$d_t[0.36 \log(\bar{w}/d_t) + 0.23]$

An example will show how this information can be used to estimate the mean flow velocity in a chute.

Example: Determine the velocity at the bottom of a chute the fish must face given that the bed material is jagged rock, the channel shape is rectangular with an average width of 20 ft, and average depth at the bottom of chute is 1 ft. The bed slope is 0.4.

For jagged rock, n = 0.035 to 0.050.

For a rectangular channel shape and $\bar{w}/\bar{d}$ = 20, R = 0.9 ($\bar{d}$), or R = 0.9(1) = 0.9 ft.

Therefore, assuming uniform flow (because of the steep slope and a short transition from critical depth near the crest), the velocity can be estimated using equation (17):

$$v = (1.49/n)R^{0.67}S^{0.5}$$

using n = 0.035, yields:

$$V = (1.49/0.035)(0.9)^{0.67}(0.4)^{0.5}$$

$$\underline{V = 25.1 \text{ fps}}$$

using n = 0.050, yields:

$$V = (1.49/0.050)(0.9)^{0.67}(0.4)^{0.5}$$

$$\underline{v = 17.6 \text{ fps}}$$

Therefore, depending on the roughness, the velocity at the bottom of the chute will vary between 17.6 and 25.1 fps.

The actual velocity the fish must swim against can be reduced from the mean velocity if the water depth is great enough so the fish can swim near the boundary layer at velocities less than the mean.

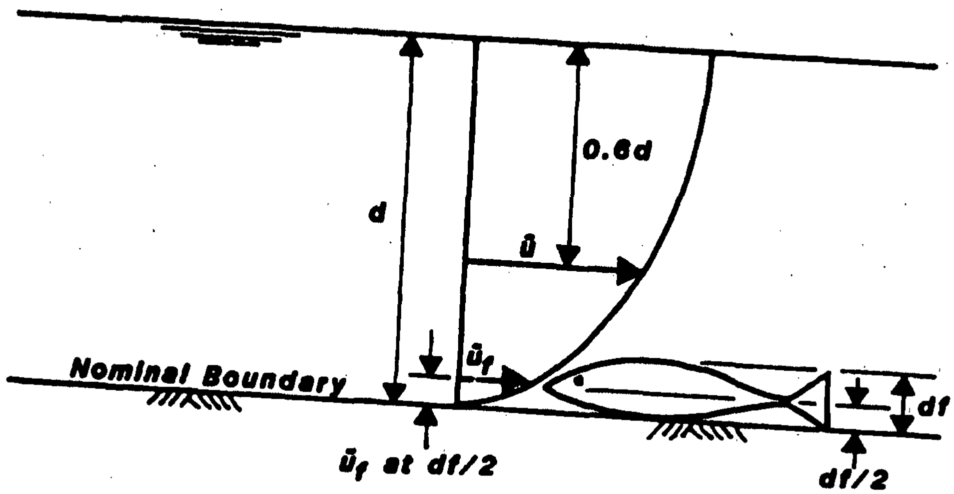


Figure 25. Fish swimming in reduced velocities near stream bed.

The velocity variation with depth in conduits is logarithmic, and the velocity at 0.6 of the depth below the water surface is very nearly equal to the mean velocity in a vertical section (Linsley and Franzini, 1979). The velocity reduction is most pronounced nearer the boundary where the local velocities may be irregular when vortices are being shed behind large roughness elements. Daily and Harlenan (1973), suggest the following formula for calculating the mean velocity in the case of a rough wall:

$$\bar{u}/u_* = 5.6 \log (y/k) + 6.1 \quad (20)$$

where: $\bar{u}$ = temporal mean velocity, u_* = shear velocity, y = mean depth of flow at which u is calculated and k = height of dominant bed material. The shear velocity (u_*) can be calculated from (Henderson, 1966)

$$u_* = (gRS_f)^{0.5}$$

where g = acceleration of gravity, R = hydraulic-radius and S_f = friction slope. Assuming uniform flow conditions exist, the friction slope is parallel to the bed slope as the resistance to the flow is balanced by the gravity forces.

An example of how the velocity in the boundary layer varies from the mean velocity of flow as depth increases along the centerline in a corrugated metal pipe will be shown (Table 11).

Table 11. Fish swimming in a culvert at velocities less than the mean velocity of flow.

Depth of flow (d), ft	Mean Velocity at 0.6 (d), fps	Mean velocity at y = 0.3 ft, fps (half fish depth)	Velocity Reduction
1	8.2	7.5	9%
2	13.3	10.0	25%
3	16.9	11.6	31%
4	19.5	12.6	35%
5	20.6	12.8	38%

Assumptions:
1. Culvert diameter (D) = 6 feet.
2. Height of corrugations (k) = 2 inches (Standard dimension, American Iron and Steel Inst., 1971).
3. Uniform flow occurs at a culvert bed slope of 5%.
4. Fish depth (df) = 0.6 feet, therefore to calculate the mean velocity the fish will swim against use $y = (d_f)/2 = 0.3$ feet, using Eq. (20).

This table shows that as the depth of water increases the velocity the fish must swim against near the culvert bottom (compared to the mean velocity) decreases. For smaller fish the gain will be more significant, but local eddies may disorient them. Equation (20) can be rearranged in terms of the minimum mean velocity the fish could swim against at the bed of a chute as:

$$\bar{u}_f = (5.6 \log (df/2)/k + 6.1)(gRS_f)^{1/2} \qquad (21)$$

where: $\bar{u}_f$ = minimum mean velocity the fish could swim against near the bed of a chute, df = depth of fish, g = acceleration of gravity, R = hydraulic radius and Sf = *friction slope or bed slope for uniform flow conditions.*

Velocities in natural rock chutes are seldom simple to analyze, because of the wide variations in channel shape and bed roughness. When flow occurs on a steep rock chute, large amounts of air may be carried below the water surface in the highly turbulent flow. This entrained air reduces the density of the fluid, resulting in an increase in volume called bulking. Although not strictly applicable, the Manning equation is often used to design channels on steep slopes and the cross-sections thus determined are increased by an arbitrary bulking allowance to provide for air entrainment. Hall (1943) has presented empirical data for smooth concrete chutes which permit use of a modified value of n in the Manning equation to allow for the effect of air entrainment.

If the channel shape can be surveyed and a cross section determined, applying the continuity equation:

$$Q = AV \qquad (22)$$

can yield estimates of the average water velocity-where: Q = flow rate in the measured cross section, A = cross-sectional area of channel, and V = mean velocity of flow. This method was used at Hell's Gate on the Fraser River in British Columbia to estimate the velocities sockeye salmon were facing as they attempted to negotiate the obstruction. The flow patterns at Hell's Gate could be described as a constantly changing state of turbulence, where the water surges, boils and entraps huge volumes of air. Because of these flow patterns and the extremely rough channels, Jackson (1950) noted that the average velocities computed this way are inaccurate. Using equation (22), if the cross-section is measured at some point in the chute, a staqe-discharge relationship can be developed so as the discharge increases or decreases, the mean flow-through velocity can be estimated.

When analyzing a chute, the depth of flow should be greater than the depth of the fish, or the fish will not be able to make full use of its propulsive power. In a study conducted at Johns Creek Fish Hatchery near Shelton, Washington by the author (Appendix II), chum and coho salmon were observed swimming up a velocity chute. At a depth of 0.13 ft, a 0% passage success rate was recorded for both species. When the depth was increased to 0.66 ft, a passage success rate of 100% was recorded for chum salmon at a water velocity only slightly less than the first test. The maximum depth of chum salmon was 0.65 ft. The results of these two tests show the importance of the depth of flow for the fish to achieve successful passage. Table 12 describes the two conditions that must be analyzed to determine whether or not a chute is a barrier assuming the plunge pool requirements, landing conditions and depth of flow are sufficient.

Table 12. Conditions for analyzing a chute assuming plunge pool requirements, landing conditions and depth of flow are sufficient.

Water velocity, fish speed, slope length and fish performance relationships	Form of Barrier
1. VW > VF	velocity barrier
2. VW < VF	
a. LS > LFS	distance/velocity barrier
b. LS < LFS	passable

where: VW = velocity of water (measured or calculated),

VF = fish speed from equation (2),

LS = lenqth of slope (measured), and

LFS= distance the fish can swim from Figures 10, 11 or 12.

Cascade Barriers

A cascade was described in the introduction as a reach of stream with large boulders or jutting rocks that obstruct the flow. This obstruction usually results in a narrower stream width, sharp changes in flow boundaries, and consequently high velocities and violent conditions. If the bed slope over the reach is steep enough to accelerate the flow, white water and turbulence will consume most of the channel and offer little or no resting areas for the migrating fish. If the reach is not too steep, the obstructions in the stream can create good resting areas as the fish work their way through the cascade.

Cascades are usually located in areas with steep topography (canyons) and are very difficult to survey because of the high velocities, deep pools and turbulence. Cascades usually persist as either boulder cascades or turbulent cascades. Boulder cascades consist of boulders in the stream that are large enough to provide resting areas for the fish in their wakes. To analyze a boulder cascade, application of the four following steps can be helpful:

1. measure the total drop in water surface over the entire reach,
2. determine the number of paths and/or steps per path the fish must pass within the reach,
3. estimate the water surface drop and/or velocity the fish must negotiate to successfully pass each step in each path, and
4. locate resting areas between each step (on each path) where the fish may rest before attempting to pass the next step.

Often the flow between obstructions (boulders) can act like flow down a short chute. Douma (1943) noted that for short chutes, the velocity may be determined by:

$$V_{sc} = (2gH)^{0.5} \qquad (23)$$

where V_{sc} = velocity down a short chute, g = acceleration of gravity, and H = total vertical drop between two pools. Using this analysis, if any step within the reach has velocities or elevation drops in excess of the fish's capabilities, or resting areas are not present between each step, the cascade would be a barrier to fish.

Turbulent cascades present the fish with a variety of difficulties, but usually the excessive velocities and excessive turbulence is enough to obstruct passage. These two conditions were studied extensively at the Hell's Gate obstruction (Jackson, 1950). Velocities were measured by methods described earlier, but the turbulence could not be measured in any manner that could be related to passage success. Turbulence in cascades serves to deflect a swimming fish from its course, causing it to expend energy to resist up-wellings, eddies, entrained air and vortices. Most of the fish's energy is utilized simply to maintain position and direction at the foot of a high velocity obstacle (Jackson, 1950).

To analyze a turbulent cascade, application of the three following steps can be helpful:

1. time floats through the cascade to get an approximate surface velocity (floats may be delayed in eddies);
2. observe possible resting areas and zones of reduced turbulence and velocity near the banks and behind obstacles; and
3. locate points of extreme upwellings and surges in the cascade which might deflect a fish from its swimming path.

If the surface velocities are excessive, there may be a path for the fish to pass along the stream bank, away from the excessive velocities and upwellings in the main channel..

In summary, this section has presented a detailed analysis of four components which affect fish passage at waterfalls and culverts:

1. plunge pools;
2. landing conditions near waterfall crest;
3. falls; and
4. chutes.

A discussion of the parameters involved in each component, followed by a table summarizing the important conditions to analyze have been presented. Also, a discussion of hydraulic/fish capabilities in cascades is introduced with steps to follow which will aid in determining the effect on fish passage success.

SITE ANALYSIS AND SOLUTIONS

The generation of solutions to fish passage problems at barriers is dependent on the parts of the analysis performed. If the barrier is total, the analysis will reveal the parameters which exceed fish capabilities. The geometric conditions can be altered to reduce the excessive parameters and assist fish passage. Evans and Johnston (1980), suggest the following corrections for natural bedrock waterfall barriers:

1. Dam the plunge pool below the falls.
2. Blast a plunge pool below the falls.
3. Blasts series of pools through the falls.
4. Provide a fish ladder over the falls.

According to Evans and Johnston (1980), the plunge pool should be raised so the depth is 1.5 to 2 times deeper than the barrier is high. They also suggest that blasting a series of pools through the falls is only practical for bedrock falls under 10 feet in height.

These correction methods have been employed successfully by the U.S. Forest Service and State Agencies in Washington (Schoettler[2], 1953), Oregon and Alaska. To build vertical-slot fishways at remote barrier sites on British Columbia rivers, engineers working for the Salmonid Enhancement Program (SEP) have perfected blasting techniques that allow natural rock to be used as the floor and sides of the fishway (Salmonid, 1983). This

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2 Schoettler, R.J., Improvement of Minor Falls, Federal Project No. 852-W-SI-10, Dept. of Fisheries, State of Washington, 1953.

innovation, along with the use of precast concrete panels flown in by helicopter, has resulted in substantial cost savings. Kerr, et al. (1980) suggest techniques to remove or bypass obstructions:

1. A steel bar can be used to hand pry and roll rocks for selective placement.
2. Larqe rocks and boulders may be removed and/or relocated utilizing slings with block and tackle.
3. Large boulders may be reduced to a size that can he readily removed, using a portable gas-powered rock drill or with explosives.

Removal of an obstruction during egg incubation could cause serious mortality by silting the downstream spawning bed.

Of the few project reports published, no information was found on the pre-construction or analysis phases except the mention of the height of the barrier.

The objective of this section is to evaluate "parameter specific" solutions with varying degrees of construction difficulty. For example, if the height of a harrier is determined to not be excessive, but the fish cannot reach the crest, then one of three things (or a combination) may he happening:

1. The plunge pool hydraulic characteristics are such that the propulsive power and the orientation of the fish's leap are affected (Table 6); and/or
2. The horizontal distance (or range) which a fish leaps is excessive compared to the actual horizontal distance the fish must leap to reach the crest; and/or

3. Flow over the waterfall is diagonal, or concentrated on one side, thus providing the fish with a false directional stimulus.

Analyzing these components will suggest the excessive parameter(s), that must be reduced. Without this analysis the height of the falls may have been reduced when it was not excessive to fish passing in the first place. In-depth analysis of this type will often reduce site construction' costs and assure correction of the real passage problems.

The solutions to waterfall and culvert barrier physical problems are directly dependent on the analysis. If the velocity in a rock chute or culvert is excessive (Table 12), then the velocity and/or the length must be reduced. Assuming that Mannings equation (17) is exact, the components that would reduce the velocity in descending order of effectiveness are:

1. increase the roughness coefficient(n);
2. decrease the hydraulic radius; or
3. decrease the slope.

Adding baffles to culverts essentially increases the roughness and decreases the hydraulic radius. If the depth of flow at the crest of a falls is shallow, then to increase the depth requires one of three hydraulic changes:

1. increase the discharge,
2. decrease the crest width, or
3. decrease the velocity.

These solutions can be incorporated at the crest of a waterfall barrier by using instream control structures such as gabion baskets, rock weirs and small retaining walls as flow deflectors to concentrate the flow. in order to create an adverse slope, one would need to blast a pool above the crest. Each structure placed instream must be carefully analyzed hydraulically to assure proper functioning as the forces in the stream channel change with discharge, ice and debris.

To show how this analysis/solution approach to barriers can be used, two sites were chosen in Western Washington and analyzed for the discharge recorded during the site visits. It is important to note that these examples address changes in parameters which were determined to be excessive from the analysis. When these parameters are changed, the analysis must be repeated, because the hydraulics of the entire barrier system may have changed.

Red Cabin Creek - Analysis

Red Cabin Creek is a small tributary that flows into the Skagit River near Lyman, Washington. The barrier on the creek is a culvert located in the SE 1/4 of Section 3, Township 35 North and Range 6 East. The culvert runs underneath Camp 17 Road about 3 miles from Hamilton, Washington. The creek is used by chinook and pink salmon for spawning and contains good coho spawning and rearing habitat. The culvert barrier is 35 river miles from saltwater. The outlet of the culvert is shown in Figure 26. Note the 2 ft wide wooden scour apron.

> Culvert Description: Starting at the water inlet, the circular culvert is concrete lined with some patches of corrugated metal on the bottom. This continues until about the last 30 ft which is steel pipe. There is a debris jam about 2 feet high in the middle of the culvert which should be removed.

Culvert Dimensions: Diameter = 6.0 ft

Length = 150 ft

Slope = 4.4%

Hydraulic Analysis: Velocities in the culvert must be determined so that the distance the fish can swim can be compared to the culvert length.

Figure 26. Looking upstream at Red Cabin Creek culvert outlet.

Using equation (17)

$$V = (1.49/n)R^{0.67}S^{0.5}$$

where V = average velocity of flow in fps, n = roughness coefficient (0.012 for smooth steel surface, Chow, 1959), S = bed slope (measured at 4.4%) (for assumed normal flow depth), and R = area of flow/wetted perimeter in ft. For circular culverts the flow area can be calculated by:

$$A_f = (\pi/180)\cos^{-1}[(r-d)/r]r^2 - [r^2-(r-d)^2]^{0.5}(r-d)$$

where A_f = area of flow, r = radius of culvert, and d = depth of flow (or uniform depth). At the culvert outlet, the flow can he assumed to be uniform, and this depth was measured at 0.55 ft on December 8, 1983.

The wetted perimeter of the flow area can be calculated by:

$$Yp = (2\pi/180)\cos^{-1}[(r-d)/r]r$$

where W_p = the wetted perimeter, r = radius of culvert, and d = depth of flow. Solving for A_f and W_p yields:

$$A_f = 1.29\ ft^2 \text{ and } W_p = 3.69\ ft$$

Substituting these into equation (17) yields:

$$v = (1.49/.012)\times((1.29/3.69)^{0.67}(.044)^{0.5}$$

$$\underline{V = 12.9\ fps}$$

Multiplying this velocity by the flow area, equation (22) yields a discharge of:

$$Q = VA_f = (12.9)(1.29) = \underline{16.6\ cfs}\ (\text{on } 12/8/83)$$

The distance the fish can swim is a function of the fish condition, water velocity and depth of flow. For average sized adult chinook, coho and pink salmon, a depth of 0.55 ft is probably a minimum, and will therefore not reduce the swimming capabilities. Since Red Cabin Creek is a short tributary, with the barrier located near the spawning grounds, a coefficient of fish condition (Cfc) of 0.75 will be used (description is given in fish capability section). Using Figures 11 and 12, a water velocity of 12.9 fps, and C_{fc} = 0.75, yields the following distances the fish can swim:

Specie	Maximum Swimming Distance
Chinook	16 ft
Coho	16 ft
Pink	Impassable

Because the culvert is 150 ft long, the fish will not be able to negotiate the culvert swimming against the mean velocity. Also, the shallow depth forces the fish to swim against the mean flow velocity.

The measured outfall height at the end of the culvert was 2.3 ft, but because of the high exit velocity, there was some horizontal component to the falling jet. This distance can be calculated from equation (13):

$$XP = VW_c[\cos(\Theta W_c)]t,$$

where t can he determined from the equation (14):

$$H = [VW_c(\sin \Theta W_c)]t - (1/2)gt^2,$$

where H = 2.3 ft (measured), VW, = 12.9 fps, and ΘW_c = 2.5°.

Substituting in these values yields:

$$2.3 = 0.56(t) + 16.1(t^2),$$

and solving for t yields:

$$t = 0.36 \text{ seconds}.$$

Substituting this into equation (13) gives:

$$XP = (12.9 \cos 2.5°)0.36 = 4.6 \text{ ft}.$$

Because of the wooden scour apron, the distance to the standing wave could not he observed. Therefore, this distance, XSW (Fig. 22) will be assumed equal to 1 ft. with the apron removed. This gives a X value of:

$X = XP + XSW = 4.6 + 1.0 = 5.6$ ft

Now X and H can be substituted into the leaping angle equation (16):

$$\theta L = \tan^{-1} 3(H/X),$$

where H = 2.3 ft (measured), and X = 5.6 ft (calculated). Therefore:

$$\theta L = \tan^{-1} 3(2.3/5.6) = 51°$$

Superimposing H and X on Figures 8 and 9 shows coho and chinook will land right at the crest, and pink salmon about 1 ft short of the crest, at a leaping angle of 60 degrees (dotted lines Figures 27 and 28). This angle corresponds well with the calculated leaping angle of 51°. Because of the high velocities at the culvert outlet, the fish will not be able to land successfully and swim through. Therefore, the outfall drop is considered a horizontal distance (or range) barrier with adverse landing conditions.

This analysis has shown that at a discharge of 16.6 cfs, Red Cabin Creek culvert is a velocity - length barrier and a leaping range harrier. Classification for this harrier is shown in Figure 29.

<u>Red Cabin Creek - Solutions</u>

To negotiate the culvert length of 150 ft, the velocities would need to be less than or equal to 3.4 fps for chinook and coho, and 2.6 fps for pink salmon. In the corrugated metal pipe section with increased roughness coefficient, the velocity would only be reduced to 6.4 fps. Dane (1978) recommends for culverts greater than 80 ft in length, the average velocity should not exceed 2.9 fps for adult salmon, and that the culvert slope should not exceed 0.5%, unless appropriate compensation is made by the addition of baffles within the culvert. The design on culvert baffles can he found in McKinley and Webb (1956), Engel (1974) and Watts (1974). The addition of baffles essentially increases the value of the roughness

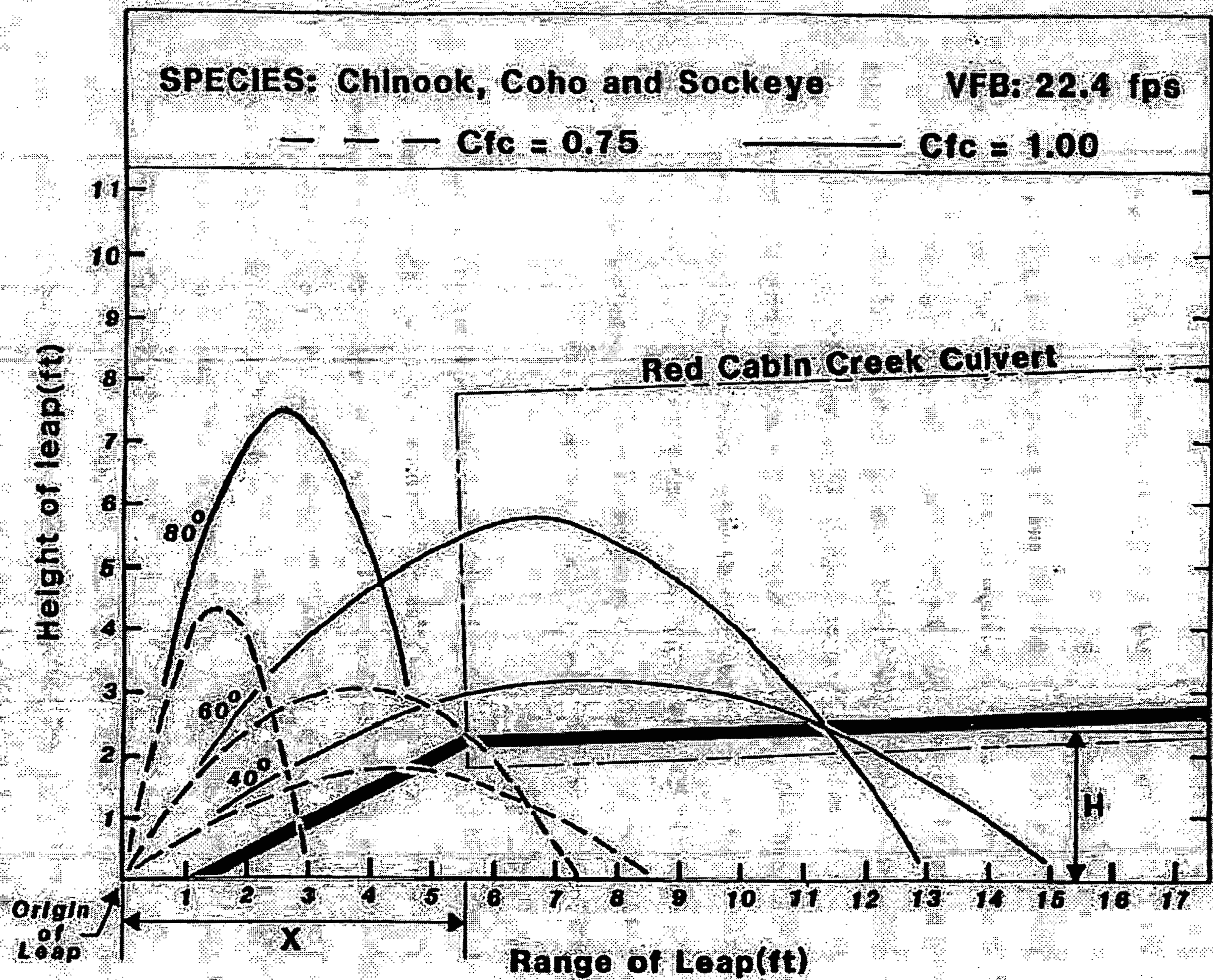


Figure 27. Red Cabin Creek culvert outlet superimposed on chinook and coho salmon leaping curves.

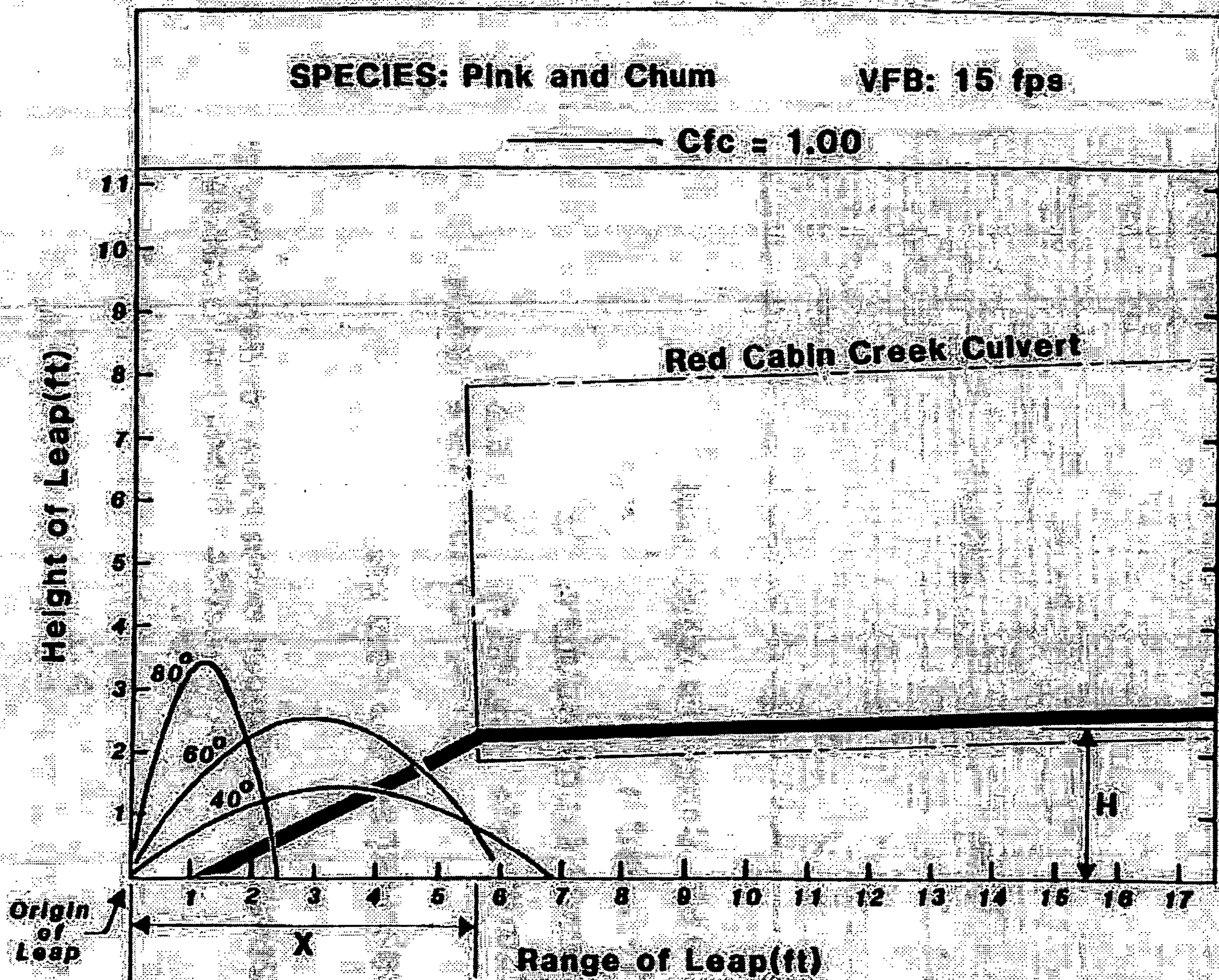
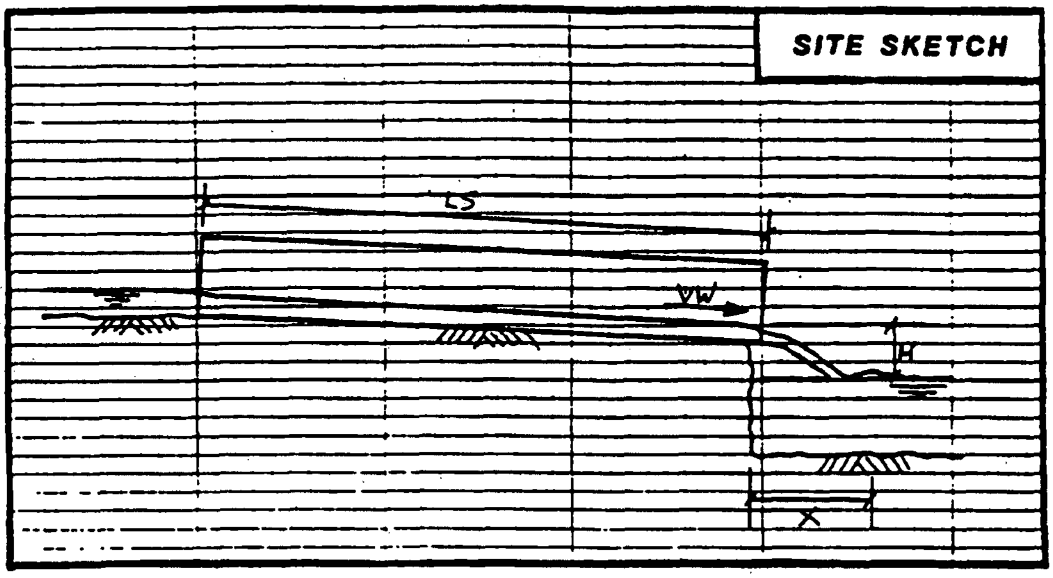


Figure 28. Red Cabin Creek culvert outlet superimposed on pink salmon leaping curves.

SITE: Red Cabin Creek Culvert DATE: 12/8/84

LOCATION: SE 1/4 of Section 3, T35N, R6E



CLASS: Compound (chute/fall)

TYPE: II C 1

DEGREE OF DIFFICULTY: 4

MAGNITUDE: H = 2.3 ft X = 5.6 ft
VW = 12.9 fps LS = 150 ft

DISCHARGE: Q = 16.6 cfs

COMMENTS: Wooden scour apron deflects flow at culvert outlet. Debris jam in middle of culvert.

Figure 29. Classification of Red Cabin Creel: culvert.

coefficient, therefore decreasing the velocity and increasing the depth of flow, creating a pool and weir fishway at lower flows. This could be accomplished simply by placing roughness elements on the culvert bottom, but would not provide resting places as baffles do. Since the slope cannot be changed, the parameters that could be variedto decrease the velocity to 2.6 or 3.4 fps in equation (17) is the roughness coefficient, assuming Manning's equation is exact, and the hydraulic radius. To achieve these velocities, the roughness coefficient should equal:

Water Velocity	n(roughness coefficient
2.6 fps	0.059
3.4 fps	0.045

In Chow (1959) these roughnesscoefficients correspondto a natural steam channel with cobbles or large boulders. The actual size of the roughness elements could best be determined by a model study so that velocity measurements could be made over a range of discharges and roughness element heights and arranqements.

At the culvert outlet, because the velocity is excessive, the fish could leap into the culvert and then be swept back. Therefore assume here that the velocity in the culvert is reduced in some manner to a value suggested earlier for passage to be achieved. An average of 2.6 and 3.4 fps, will he used OF 3.0 fps. From equation (13) this reduces XP to 1.1 ft, and X to 2.1 ft, adding 1 ft for the distance to the standing wave. Calculating the leaping angle for the new outlet geometry gives:

$$0L = \tan^{-1} 3(2.3/2.1) = 73°$$

Superimposing the outfall geometry again on Figures 8 and 9 shows that coho, chinook and pink salmon can successfully enter the culvert at a leaping angle of about 60°, shown as dotted lines in Figures 30 and 31.

Again, this angle is close to the calculated leaping angle of 73°. Therefore, decreasing the velocity in the culvert to 3 fps will allow the fish to successfully swim the culvert length of 150 ft and reduce the horizontal leaping distance. Table 13 is a summary of the problems and suggested solutions for Red Cabin Creek culvert.

Table 13. Red Cabin Creek problems and solutions.

Problems	Solutions
Wooden scour apron prevents fish from entering culvert.	Remove apron.
Horizontal leaping distance is excessive, caused by high velocities at crest of 12.9 fps.	Decreasing velocity to 3 fps at the crest would reduce the horizontal leaping distance and allow successful passage.
Velocity in the culvert is excessive for a culvert lenath of 150 ft.	Add baffles or some type of roughness elements to decrease the velocity. Check culvert capacity to pass flood flows.
Debris jam in middle of culvert prevents fish passage.	Remove debris

Chuckanut Creek Waterfall - Analysis

Chuckanut Creek is located just south of Bellingham, Washington; it flows along the Old Samish Highway and discharges into Chuckanut Bay. The barrier in Question, figure 32, is located at river mile 1.8, in the middle of the western 1/2 of Section 17, Township 37 Noth, Range 3 East. The creek. be the barrier is used by chum Salmor in the lower part below the harrier and coho and steelhead spawn in the creek above the barrier.

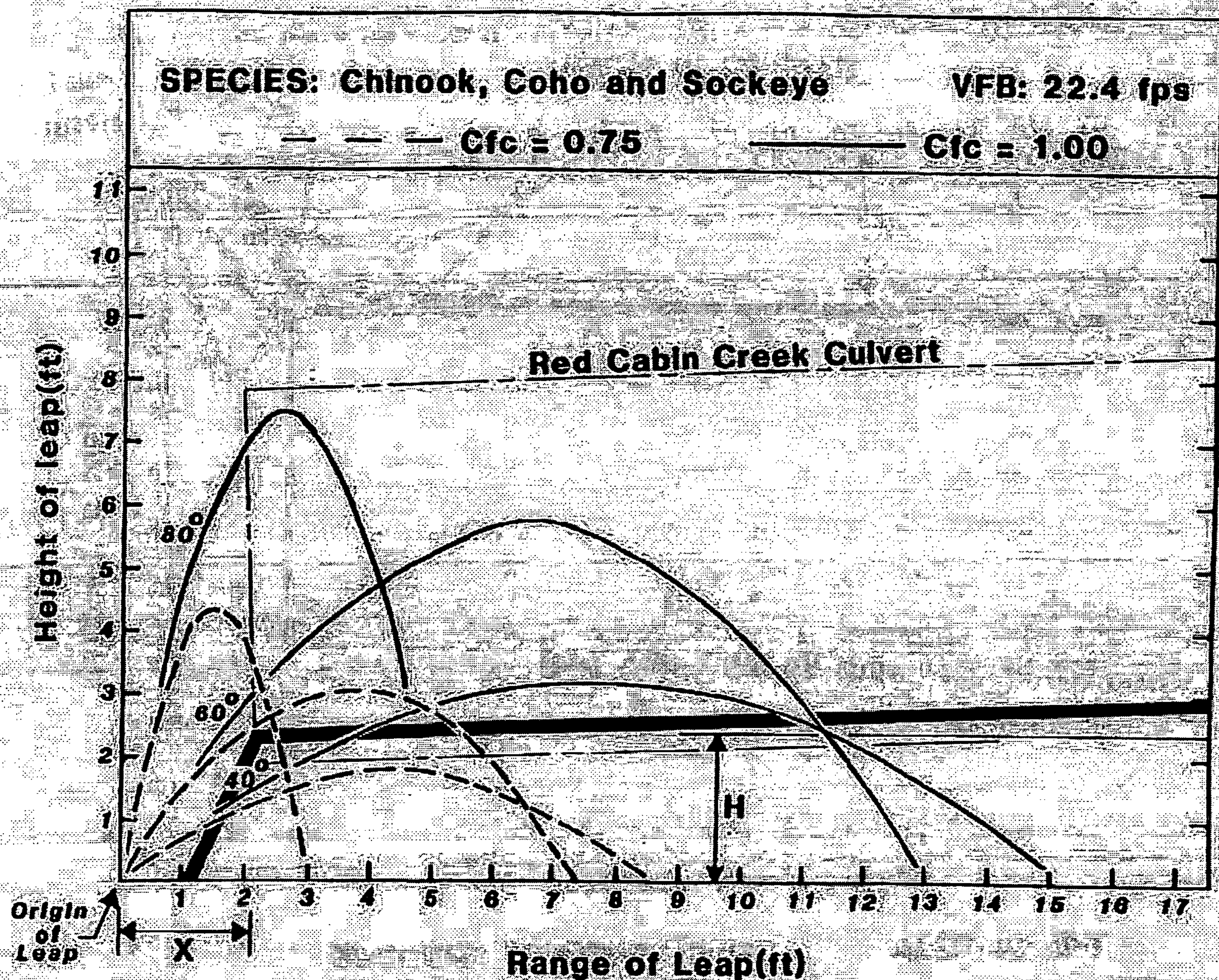


Figure 30. Red Cabin Creek "revised" culvert outlet superimposed on chinook and coho salmon leaping curves.

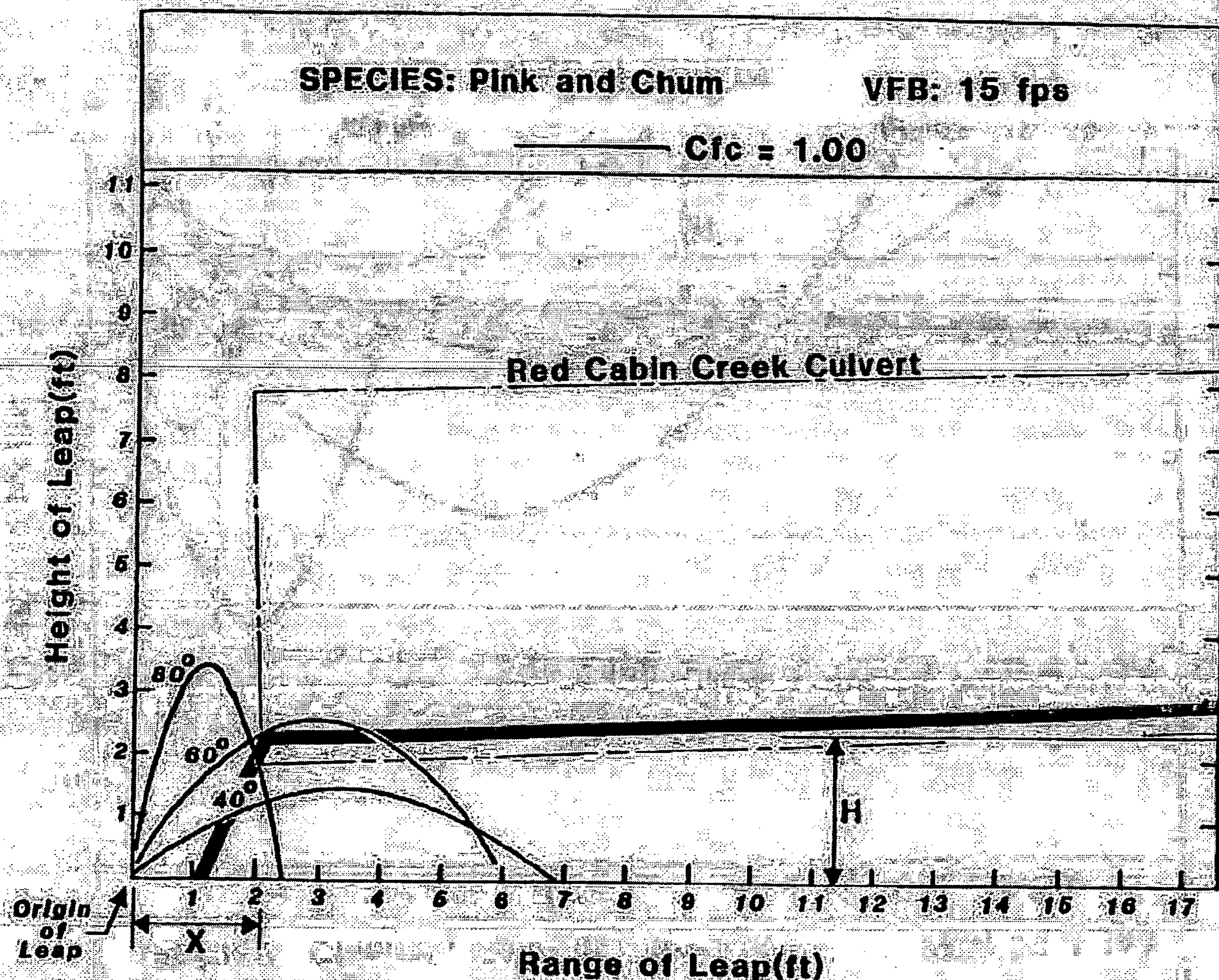


Figure 31. Red Cabin Creek "Revised" culvert outlet superimposed on pink salmon leaping curves.

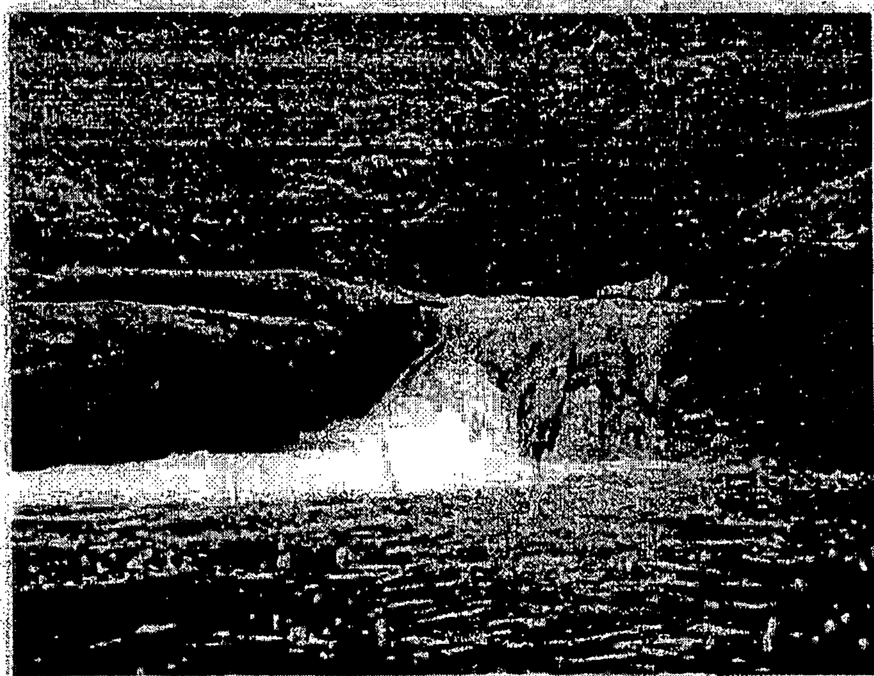


Figure 32. Looking upstream at Chuckanut Creek waterfall.

Figure 33. Plan view of obstructing rock near Chuckanut Creek waterfall crest.

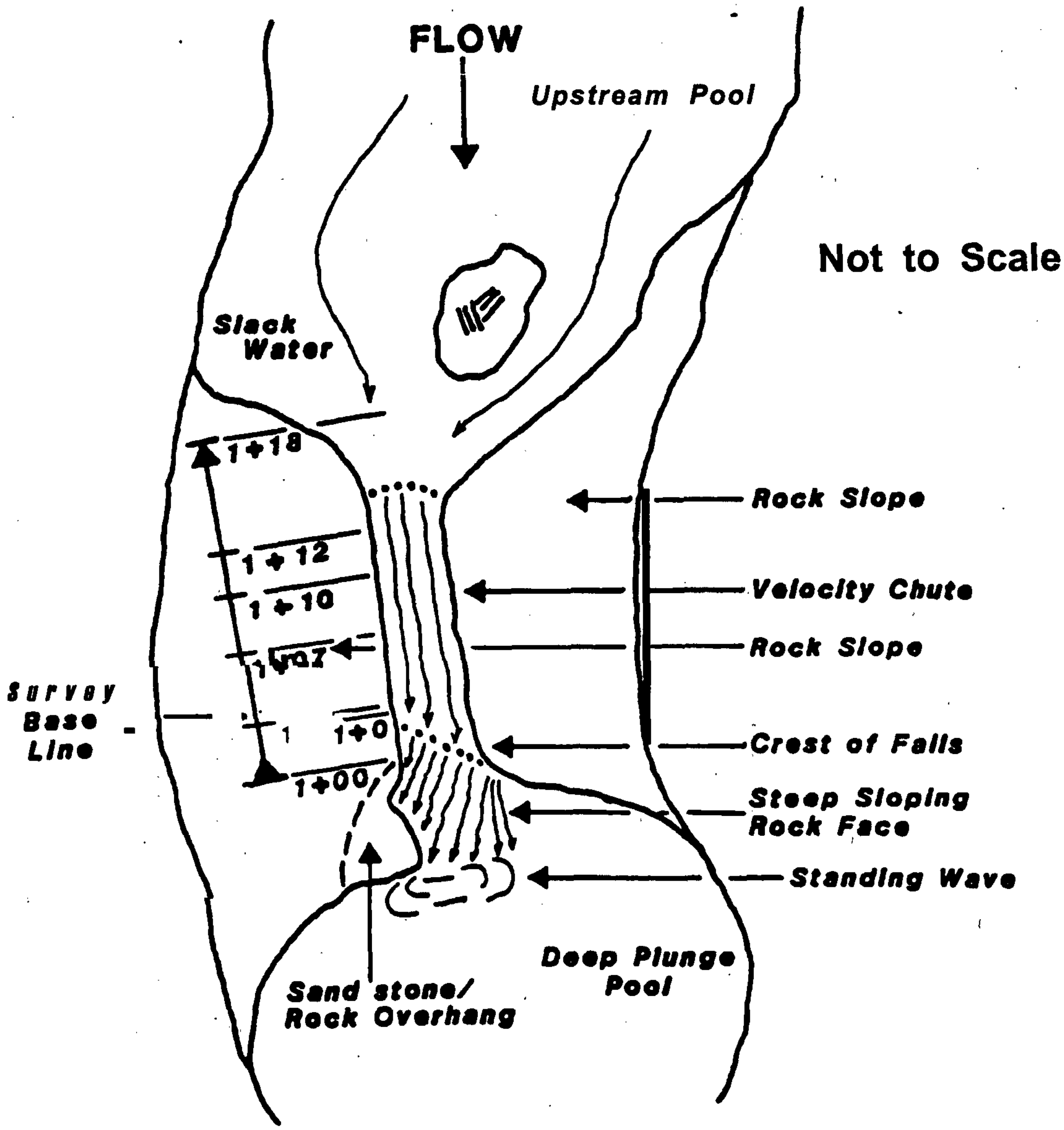


Figure 34. Plan view sketch of Chuckanut Creek waterfall.

Waterfall Description: In the upstream section the harrier begins with a short, narrow rock chute (triangular Cross section) which terminates in a 2 to 3 it drop. At the drop there is 3 rock/sandstone overhang which say obstruct passage to the upper chute of the barrier, Figure 33. The main openinq for passage appears to present a very shallow depths near the crest. This waterfall does not appear to he an elevation or velocity barrier, but because of the rock overhang it may present orientation problems. Steelhead have been observed by Dept. of Fisheries personnel to successfully pass the barrier, hut have also been observed falling back after landing near the crest.

Hydraulic Analysis: To analyze the hydraulics at Chuckanut Falls, an engineering survey was conducted on 12/8/83 to determine the chute cross sections and significant topographic points throughout the barrier site. A survey base line was established (Figure 34) and measurements of channel cross-sections taken. Using station 1+07 as a representative cross-section (Figure 35) for the chute, the velocities can be calculated using equation (17) with the following values: bed slope (assume uniform flow) = 7.7- (measured), flow area (measured from Figure 35) = 1.5 ft^2, wetted parameter (from Figure 35) = 3.9 ft, and roughness coefficient (jaqqed rock 0.035 to 0.050, Table 9). Substituting these values into equation (17) yields for the average velocity at station 1+07:

$$V = (1.49/0.035)(1.5/3.9)^{0.67}(0.077)^{0.5} = \underline{6.2 \text{ fps}}, \text{ and}$$

$$V = (1/49/0.050)(1.5/3.0)^{0.67}(0.077)^{0.5} = \underline{4.4 \text{ fps}}.$$

Multiplying the average velocity by the flow area, equation (22) yields a discharge of:

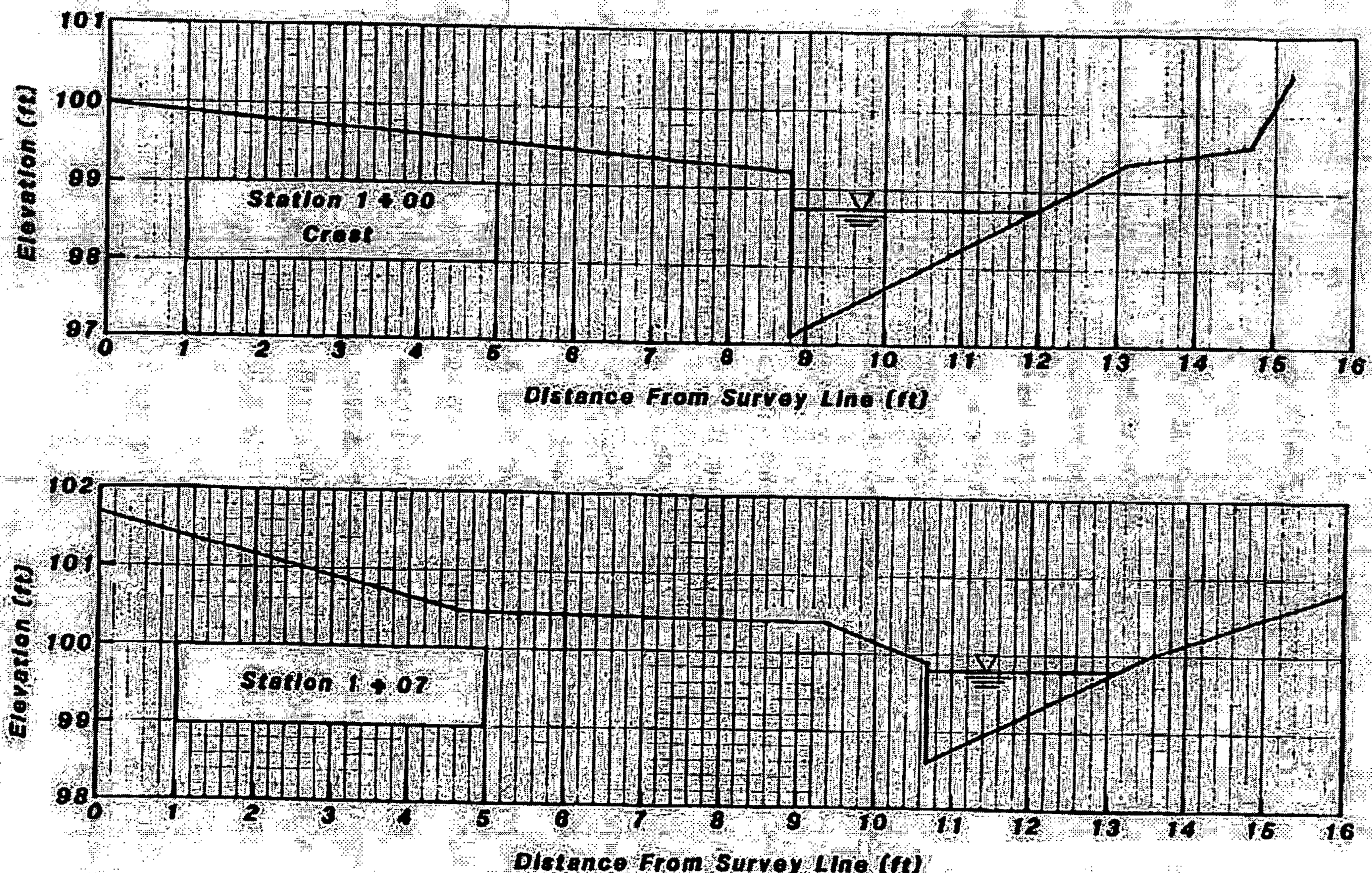


Figure 35. Cross sectional areas of stations 1+00 and 1+07 at Chuckanut Creek waterfall looking upstream.

$Q(n=0.035) = VA = 6.2(1.5) = \underline{9.3\ cfs}$ and

$Q(n=0.050) = VA = 4.4(1.5) = \underline{6.6\ cfs}$.

Therefore at station 1+07, the average velocity the fish must face assuming a discharge of 8.0 cfs is 5.3 fps. A similar analysis was applied to station 1+00 (Figure 35, the crest), and an average velocity of 3.1 fps was calculated. The velocity decreases near the crest because of the increased flow area from station 1+07 to 1+00.

The barrier is located only 1.8 river miles from the salt water, so a coefficient of fish condition, Cfc, of 1.0 will be used. The distance the fish can swim for the average velocity calculated (5.3 fps) is given by Figures 10, 11 and 12 as:

Specie	Maximum Swimming Distance
Steelhead	105 ft
Coho	80 ft
Chum	48 ft

Since the chute is only 12 ft in length, if the fish can get into the chute they will easily pass the barrier.

The upper chute terminates in an overfall where the water breaks off the crest (which is angled to the flow) and strikes the plunge pool. The change in water surface elevation from the crest to the plunge pool was measured at 2.7 ft. Because of the overhanging rock on the right side of the fall (left looking upstream in Figure 32) the fish are forced to leap at the right side (looking upstream), where the water breaks off the crest and flows down a short chute (7.5 ft long) at a measured depth of 0.1 ft. Because of the shallow depth it is not possible for the fish to swim up this chute, and therefore they must leap to pass.

The distance X was measured to be 8 ft. Using equation (16), and the measured H and X values of 2.7 ft and 8.0 ft respectively gives a leaping angle of:

$$\theta L = \tan^{-1} 3(H/X) = 45°$$

Superimposing H and X on the fish leaping curves (Figures 7, 8, 9) shows the following:

1. Steelhead and coho can successfully pass at leaping angles of 60 and 40 degrees (Figures 36 and 37).
2. Chum salmon will fall short of the crest by about 4 ft at leaping angles of 60 and 40 degrees (Figure 38).

The calculated leaping angle of 45° will extend to the point of maximum leaping distance for this falls geometry. The fish that successfully leap will probably land in very shallow water and higher velocities because of disorientation caused by the overhanging rock.

The plunge pool depth was measured at 5.5 ft, and therefore provides a good leaping situation. Under the present conditions, Chuckanut Creek falls appears to be an elevation and orientation barrier at low flows (8 cfs) to chum salmon, but not to steelhead and coho, except for the overhanging rock obstructing the path to the upper chute. Classification of this barrier is shown in Figure 39.

<u>Chuckanut Creek - Solutions</u>

A very good low flow channel is present above the falls, upstream from the falls crest. Referring to Figure 33, if the overhanging rock was removed, the fish would have a "straight-shot" into the upper chute. Also, they would be attracted to leap at the area of highest flow momentum because of the deep channel on the left side (looking upstream). This would also allow the fish to get further upstream before they attempt their leap, and decrease the horizontal leaping distance (X). Even at high flow, the majority of the flow would he concentrated in the deeper low flow channel.

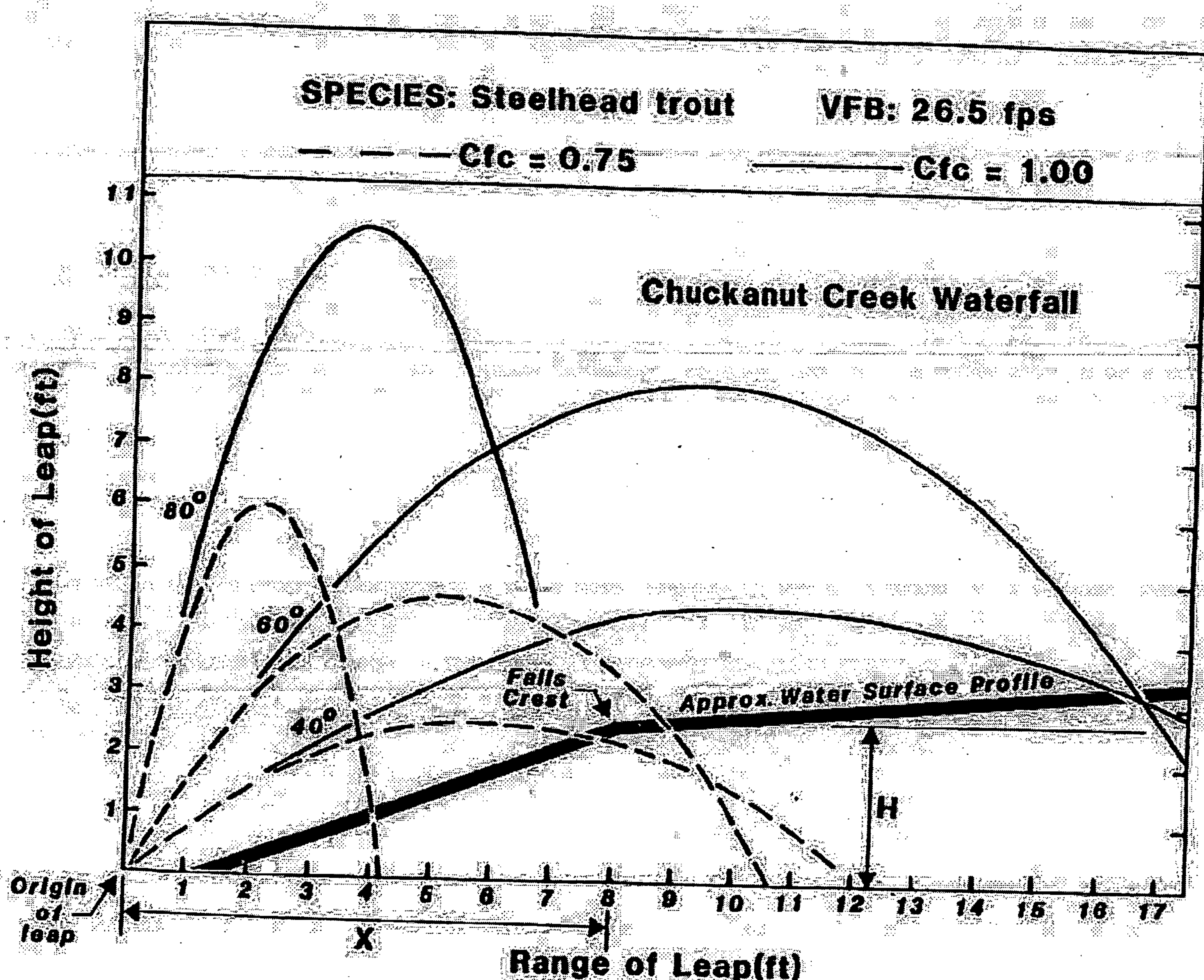


Figure 36. Chuckanut Creek fall superimposed on steelhead leaping curves.

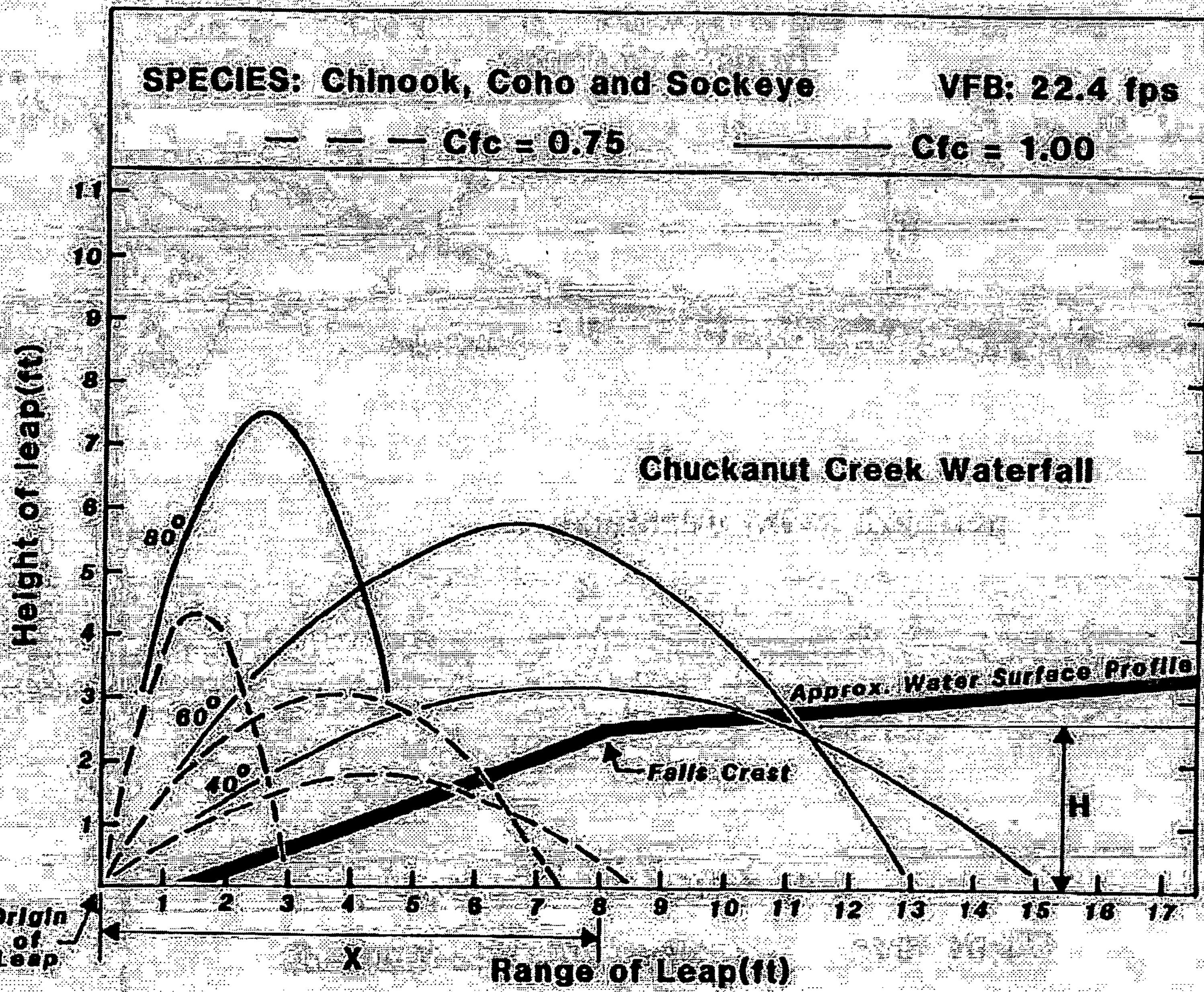


Figure 37. Chuckanut Creek fall superimposed on coho salmon leaping curves.

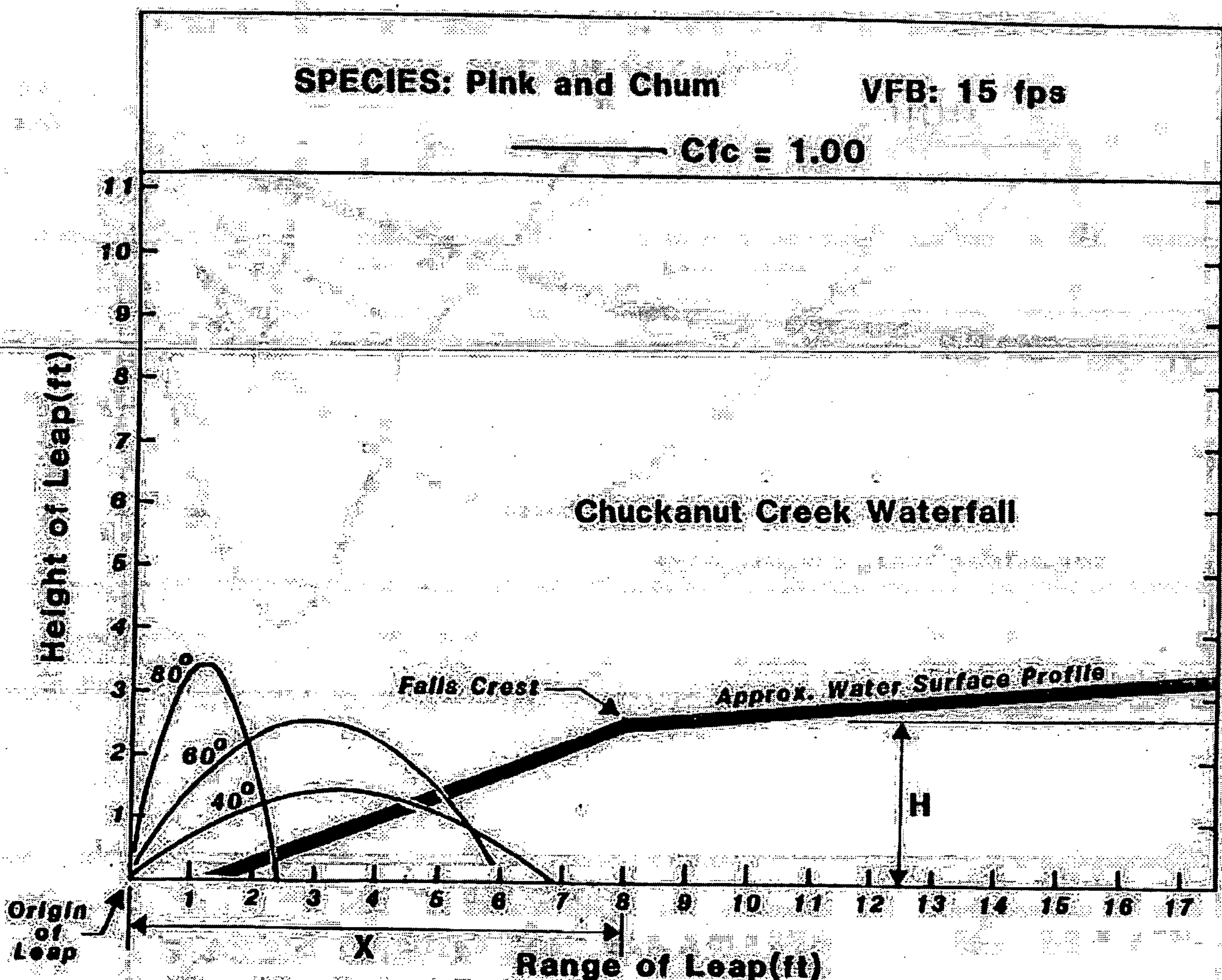
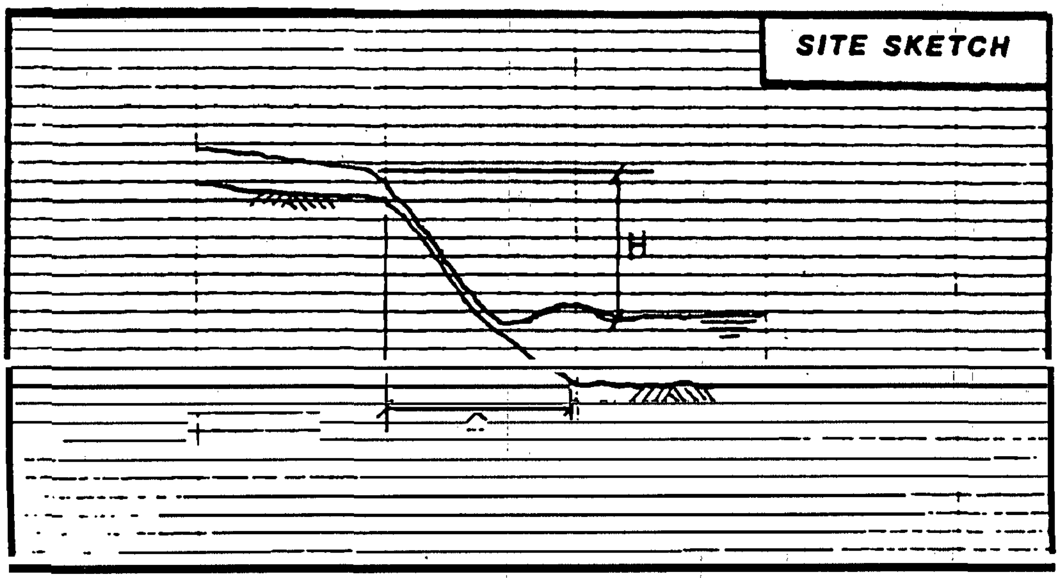


Figure 38. Chuckanut Creek fall superimposed on chum salmon leaping curves.

SITE: Chuckanut Creek Waterfall DATE: 12/8/84

LOCATION: Middle of the Western 1/2 of Section 17, T37N, R3E



CLASS: Single Fall

TYPE: II A 1

DEGREE OF DIFFICULTY: 2

MAGNITUDE: H = 2.7 ft
X = 8.0 ft

DISCHARGE: Q = 8 cfs

COMMENTS: Rock overhang at crest may obstruct orientation for leaping.

Figure 39. Classification of Chuckanut Creek waterfall.

CONCLUSIONS

The guidelines for analyzing a waterfall or culvert barrier in this report are relatively simple. With the expertise of a fisheries biologist and a hydraulic engineer these guidelines can be used effectively to resolve the dilemmas of fish passage problems at barriers. The following is a list of significant conclusions developed:

1. Unstable plunge pools disorient and reduce the fish's leap trajectory and height respectively.
2. Velocities and depths can be estimated for any irregular shaped falls crest as a function of the discharge at critical depth from:

   $$Q^2/g = A^3/W$$

   where Q = stream discharge, g = acceleration of gravity, A = cross sectional flow area and W = top stream width.
3. Water surface profiles at barriers can be superimposed on fish leaping curves to analyze passage success. The optimum leaping angle can be estimated by:

   $$\theta L = \tan^{-1} 3(H/X)$$

   where H = the difference in water surface elevations, and X = horizontal distance from the standing wave to the crest of the falls or chute.
4. For rectangular and triangular shaped channels the hydraulic radius can be estimated as a function of the average width and depth with errors less than 5%; this allows the mean velocity to be calculated.

5. For depths greater than 1 feet in corrugated metal pipe culverts, fish can swim in reduced velocities near the boundary where the velocity opposing the fish is less than the mean velocity by as much as 30 .

6. Stage-discharge relationships, when compared with migration season flows, will define hydraulic conditions at the barriers which the fish must negotiate.

SUGGESTIONS FOR FURTHER STUDY

Concepts for analyzing harriers to upstream fish migration have been presented in this paper. As each section was written, more and more ideas about methods for analyzing barriers were unveiled. The urge to go back and include these new ideas was eventually offset by the necessity to complete the study. Further study of the following areas will increase the accuracy of analyzing and finding solutions to fish passage problems.

1. Plunge pool: guidelines should be developed to accurately determine the plunge pool depth for the given barrier geometry and hydraulics which create optimum leaping conditions.
2. Fish speeds in an air-water mixture: there should be some reduction in the fish's burst speed in a air-water mixture because of the reduced water density. Calculations need to be made using fish locomotion equations (Blake, 1984) to determine the reduction of the propulsive power of the fish's tail in a medium with reduced density. Corresponding leaping heights and trajectories can then be calculated.
3. Leap success ratios: as the height of barrier increases, the number of attempts required for a successful pass should increase. This could he studied in a hatchery fishway, where the leap success ratio (successful leaps:leap attempts) is recorded for a range of water surface drops.
4. Migration distance from ocean to barrier reducinq fish capabilities: a survey could be taken to record the river miles to a barrier, height of barrier and species which pass or are blocked.

Aerial photography: the design of low-level, balloon mounted photoqraphic equipment could he used. These photograph can greatly reduce site survey tine and provide excellent visualization when used with ground survey controls and at different stages of stream flow.

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APPENDIX I

NOTATION

NOTATION

Elevation (H)

H	in water surface elevation
t!L	Height of the fishes leap

Distances (L and X)

LS	Length of slope
X	Horizontal distance from the crest to standinq wave
XP	Horizontal distance from the crest to point where falling water plunges
XSW	Horizontal distance from point where falling water plunges to standing wave
LF	Length of fish
LFS	Length the fish can swim

Velocities (V)

VW	Velocity of water
VF	Fish speed
VFB	Burst speed of fish
VFP	Prolonged speed of fish
VFS	Sustained speed of fish
ii	Temporal mean velocity
$\bar{u}_f$	Temporal mean velocity at which the fish swim
u_*	Shear velocity
VR	Relative speed of the fish to the water
VW_c	Velocity of water at falls crest

Depths (d)

d_w	Depth of water
d_c	Critical depth
d_{pp}	Depth in the plunge pool

d_p	Depth of plunge by waterfall jet
d_f	Depth of fish

<u>**Slopes (S)**</u>

S_e	Fish exit (water inlet) slope
S_p	Fish passage (water transition) slope

<u>**Others**</u>

C_{fc}	Coefficient of fish condition
θW_c	Angle in degrees from horizontal at which the velocity leaves the crest
θL	Angle in degrees from the horizontal at which the fish leaps
R	Hydraulic radius
g	Acceleration of gravity
n	Manning's emperical roughness coefficient
W	Width

APPENDIX II

AN ANALYSIS OF COHO AND CHUM SALMON SWIMMING UP A VELOCITY CHUTE

AN ANALYSIS OF COHO AND CHUM SALMON SWIMMING UP A VELOCITY CHUTE

Waterfalls and culverts sometimes form velocity barriers to the upstream migration of adult salmon and steelhead trout. Often, the swimming capabilities of the species in question will determine the success of passage. Other factors which effect the success of passage are: depth of flow, distance the fish must swim, and violent turbulence (unstable flow patterns). In order to analyze how these factors effect fish passage, a "velocity chute" study was conducted at Johns Creek Fish Hatchery near Shelton, Washington. This study was done in conjunction with the Bonneville Power Administration (BPA) Fisheries Project 82-14, "New Concepts in Fish Ladder Design." At the conclusion of the study, it became apparent that a velocity chute could be used as an efficient and economical method of passing fish. With a fishway pool length of 12 ft (3.66 ml and a chute length of 8 ft. (2.44 m) chum salmon (Onchorhynchus keta) were observed passing a change in water surface elevation of 1.8 ft (0.55 ml with a passage success rate of 100%.

<u>Experimental Facilities</u>

The chute was installed in the existing fishway bulkhead slots. It was constructed with 3/4 inch plywood at a length of 8 ft (2.44 ml. In test +1 the chute width was 2 ft (0.61 m) with a wall height of 1 ft (0.30 m). After completion of test #1, the width was decreased to 1.25 ft. (0.38 m) and the wall height was increased to 1.5 ft (0.46 m) in order to obtain a greater depth of flow (test #2). At the inlet (crest) the chute was supported by two hinges, which allowed adjustment of the slope. Near the fish entrance it was supported by adjustable vertical and horizontal support rods (Fig. 1).

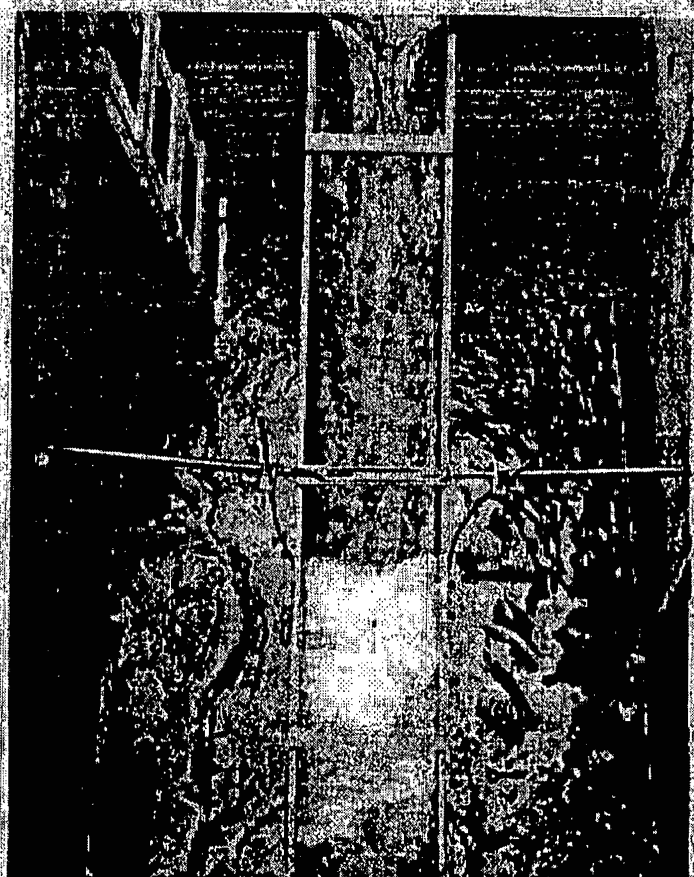

Figure 1. Plan view of the 8 ft long and 1.25 ft wide velocity chute test apparatus installed in the Johns Creek Fishway.

Chute Hydraulics

The approach velocity from the upstream pool was negligible, and critical depth (Froude No. = 1) always occurred at the chute water entrance or crest. The three zones of flow observed during testing were: 1) transition zone; 2) uniform flow zone; and 3) hydraulic jump/standing wave zone. In the transition zone, the flow was passing through critical (at the crest) to uniform depth approximately 2 ft (0.61 m) down the slope from the crest. The depth is greater in the transition zone than in the uniform flow zone and when the fish approached the transition zone they "burst" through it into the upstream pool because of the decreased flow velocity. The uniform flow zone began at approximately 2 ft (0.61 m) from the crest and remained at constant depth until it dissipated into the downstream pool. At this point, a hydraulic jump developed which increased in intensity as the chute velocity increased.

The addition of roughness elements on the floor of the chute had the effect of increasing the depth and decreasing the velocity for a given slope. The spacing between the roughness elements was filled with circulating water containing stable eddies, creating a pseudo wall. Chow (1959) classifies this as "quasi-smooth flow." Quasi-smooth flow has a higher friction factor than flow over a true smooth surface because the eddies in the grooves consume a certain amount of energy. These hydraulic conditions were observed in a plexiglass model of the chute in Albrook Hydraulics Laboratory at Washington State University. The model was also used to verify field measurements of velocity and discharge.

Study Objective

The objectives of this field study were to observe and record the following:

1. The response of coho and chum salmon to outflow conditions at the downstream end of the chute:
   a. leaping;
   b. swimming; and
   c. attraction conditions.

2. Water depths which affect passage:

   a. minimum depth;

   b. depth where swimming is unimpaired; and

   c. effect of roughness elements on water depth/fish passage.

3. Swimming speeds of coho and chum salmon:

   a. relative velocity of fish with respect to water (fish speed),

   b. relative velocity of fish with respect to chute, and

   c. passage time.

Results

Test No. 1; Chute Width = 2.0 ft (0.61 m)

In this test observations were made of the chute hydraulics and fish movements. The majority of fish tested were adult coho salmon (Onchorhynchus kitsutch) which were in poor physical condition, displaying full spawning colors and averaging about 2 ft (0.61 m) in length. The few chum salmon tested also displayed full spawning colors and averaged 30 in (76.2 cm) in length. The maximum depths of the fish bodies were: coho 0.4-0.5 ft (0.12-0.15 m) and chum 0.65 ft (1.65 cm).

An immediate problem developed because the depth of flow at 0.2 to 0.3 ft (0.06 to 0.09 m) was too shallow. The smaller coho could pass but the larger chum could not. Average velocities in the chute ranged from 5 to 8.3 fps (1.74-2.9 m/s) which is in the range of the upper prolonged speed of 10.6 fps (3.23 m/s) for coho salmon suggested by Bell (1973).

The fish response to different types of hydraulic jumps (or standing waves) was observed. The Froude number for all tests was in the 1.2 to 4.1 range. Chow (1959) suggests for this range the jump type is just beginning to oscillate as was observed. Stuart (1964) describes these water surface oscillations as points from where fish are often seen leaping. The fish that passed were observed to be holding in the standing wave, then bursting into the uniform flow zone (Fig. 2), and proceeding at a constant speed until the transition zone was reached. Coho salmon that reached the transition zone always swam successfully into the upper pool. Unsuccessful fish were usually slow starters who, after several attempts, were observed leaping out of the standing wave.

Test No. 2; chute width = 1.25 ft (0.38 m)

The coho tested were in worse condition than in test #1 but a fresh run of chum salmon entered Johns Creek only a few days before the testing started. Fish sizes were the same as Test No. 1. The channel width was decreased to 1.25 ft (0.38 m) and roughness elements were added to the chute floor. The height of the roughness elements was 1.5 in (3.8 cm), spaced at a distance of 3 in (7.6 cm) and 6 in (15.2 cm) in separate removable false floors. The data obtained from these tests are summarized in Table 1.

Figure 2. Coho salmon bursting out of hydraulic jump into uniform flow zone.

Table 1. Velocity chute test #2 data.

Test No.	Uniform Depth From Floor (ft)	Uniform Depth Above Roughness El. (ft)	Uniform Velocity (fps)	Length Slope (ft) (Slope) (%)	Passage Success (%)	Flow (cfs)
2a[a]	0.13	---	8.3	5.5	0(coho)	1.1
				(26)	0(chum)	
2b[b]	0.41	0.28	5.2	7.5	95(coho)	2.3
				(15)	92(chum)	
2c[c]	0.51	0.38	5.0	8.0	64(coho)	2.9
				(19)	89(chum)	
2d[c]	0.66	0.54	6.8	7.0	78(coho)	5.0
				(27)	100(chum)	
2e[c]	0.56	0.44	6.7	7.0	No coho	4.1
				(36)	23(chum)	

Notes: a - roughness elements not used, floor consisted of plywood (n=0.021).

b - Roughness elements with 3 inch longitudinal spacing (n=0.044).

c - Roughness elements with 6 inch longitudinal spacing (n=0.055, 0.053 and 0.059 for tests 2c, 2d and 2e respectively).

In test 2a, roughness elements were not used, and the depth of flow was 0.13 ft (0.04 m) with an average velocity of 8.3 fps (2.53 m/s). The success passage was 0X for coho and chum, so this depth was a barrier. Once the roughness elements were added to the floor the depth increased to 0.4 ft (.12 m) - 0.6 ft (0.18 m) range which was adequate for fish passage. This is the depth from the floor to the water surface. Dane (1978) suggests a minimum depth of 0.75 ft (0.23 m) for Pacific Salmon, and Dryden and Stein (1975), suggest that "in all cases, the depth of water in a culvert should be sufficient to submerge the largest fish to use the structure." This field study has shown how partial submergence impairs the ability of the fish to generate thrust.

Fish Movements

As noted in Test #1 results, fish were observed holding in the hydraulic jump where the velocity is decreased and then bursting into the uniform flow zone as shown in Figure 3. Once into the uniform flow zone (zone of highest velocity) the fish always moved laterally to the chute side wall and continued through the uniform flow zone along the wall (Fig. 4). Near the wall boundary the water velocity was decreased as much as 60% of the centerline velocity, because of the shearing resistance created. When fish approached the transition zone and the velocity decreased, they moved out into the middle of the chute (Fig. 5) and burst through the crest into the upper pool. Some of the unsuccessful or slower fish were observed crossing back and forth laterally in the chute searching for a zone of lower velocity.

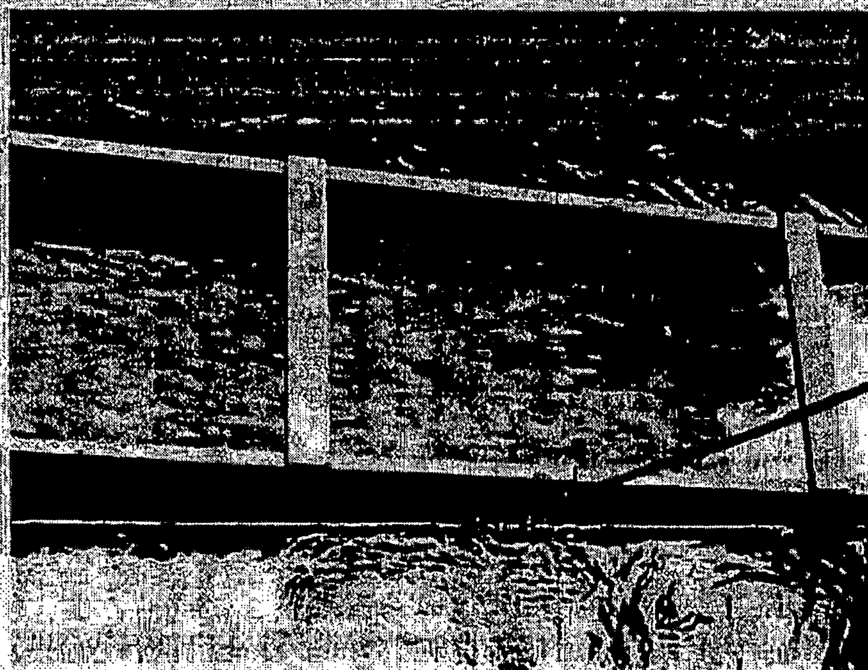

Figure 3. Chum salmon bursting out of hydraulic jump after several seconds of holding in the jump.

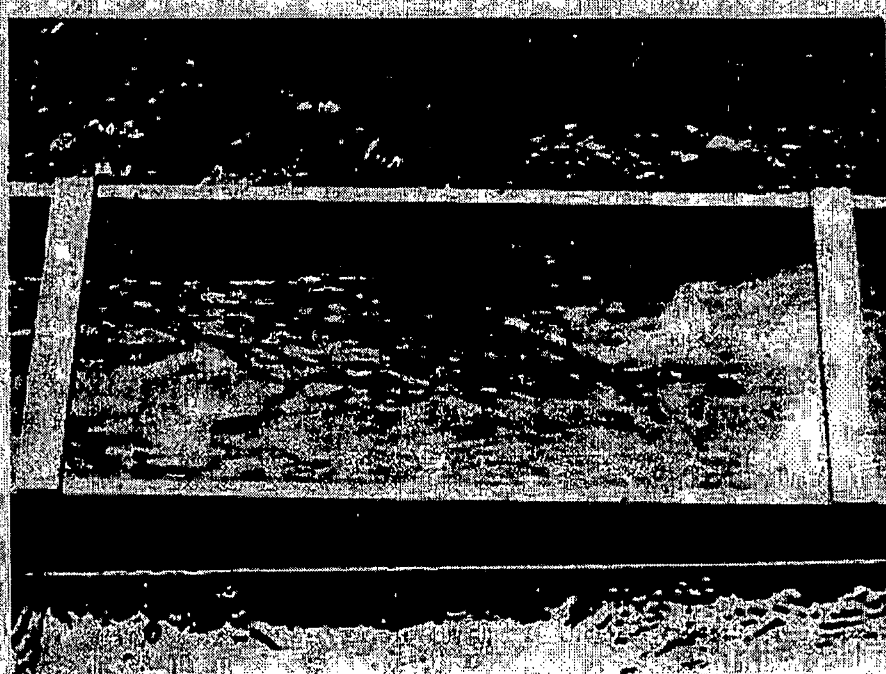

Figure 4. Chum salmon swimming up chute taking advantage of reduced velocities in boundary layer.

Figure 5. Chum salmon approaching transition zone moving laterally into middle of chute.

Analysis of Fish Speeds

Tests Results

The time required to successfully pass the chute was recorded with a stop watch. Knowing the distance that the fish swam to reach the crest, the velocity of the fish with respect to the chute can be calculated. When the water velocity is determined the actual swimming speed of the fish can be calculated. This calculation assumes constant velocity down the chute which is not exactly true because of the transition zone near the crest. But as noted earlier, uniform depth was reached within 2 ft (0.61 m) of the water inlet. As the slope was increased in subsequent tests the flow approached uniform depth in an even shorter distance.

A calculation of fish speeds for test #2b is shown below

Length of Slope(LS) = 7.5 ft.

Water Velocity (VW) = 5.2 fps

Passage Times (PT) in seconds:

Test #2b:

	coho	chum
maximum	4.7	5.5
average	3.5	4.0
minimum	2.0	2.3

Fish Velocity (fps) = (LS)/(PT) + VW

Species	Fish Velocity (fps)		
	Maximum	Average	Minimum
Coho	8.9	7.3	6.8
Chum	8.5	7.1	6.6

Velocities for the other tests are summarized in Table 2.

Table 2. Maximum, average and minimum swimming speeds of coho and chum salmon passing the velocity chute.

Test No.	Species	Fish Velocity (fps) Minimum	Average	Maximum
2b	Coho	6.8	7.3	8.9
	Chum	6.6	7.1	8.5
2c	Coho	6.0	6.5	7.6
	Chum	6.0	6.4	7.1
2d	Coho	9.1	9.5	10.7
	Chum	8.6	8.8	8.9
2e	Chum	8.8	9.1	10.0

Discussion

Swimming speeds of fish are usually reported in three categories: sustained, prolonged and burst. Burst speed is defined as causing fatigue in 5 to 10 seconds (Bell, 1973). From observations and fatigue times recorded, the fish passing the chute were assumed to be using burst activities. Bell (1973) suggests a burst speed range of 10.6 to 21.5 fps (3.2 to 6.5 m/s) for coho salmon. The maximum swimming speed (or burst speed) recorded in these tests for coho salmon was lg.7 fps (3.26 m/s), definitely on the lower range of Bell's suggested speeds. But as noted earlier, these coho were in very poor physical condition. Therefore, the maximum speed of 10.7 fps (3.26 m/s), which is 50% of the maximum burst speed suggested by Bell (1975), is probably the upper range of burst speed for a coho salmon near its spawning time.

Burst speeds of chum salmon have not been recorded in the literature, but they are generally thought to be a weaker fish in comparison to coho. Observations1 of chum salmon leaping 3 and 4 ft (0.91 and 1.2 m) suggest a burst speed of about 15 fps (4.6 m/s) to achieve these heights. The maximum swimming speed recorded for chum salmon was 10.0 fps (3.05 m/s) or 67% of the maximum burst speed of 15 fps (4.6 m/s). The chum tested were in good shape, but their spawning colors and teeth were fully developed.

This information can he helpful in analyzing waterfalls and culverts as barriers to upstream fish migration. The speed of the fish can be based on some percentage of the maximum burst speed suggested by Bell (1973), depending on the condition of the species in question. This will be termed the "coefficient of fish condition" (C_{fc}). Table 3 gives a range of C_{fc} and the corresponding fish conditions based on observations made of coho and chum salmon in Johns Creek.

Table 3. Coefficient of fish condition (C_{fc}); values based on observations and data taken for coho and chum salmon at Johns Creek Fish hatchery near Shelton, Washington.

Fish Condition	C_{fc}
Bright, fresh out of the ocean or still a long distance from spawning grounds, no spawning colors yet developed.	1.00
Good, in the river for a short time, spawning colors apparent but not fully developed, still migrating upstream.	0.75
Poor, in the river for a long time, full spawning colors developed and fully mature, very close to spawning grounds.	0.50

Relative Fish Velocity

Another concept tested in this study was that of the relative velocity at which fish swim with respect to the chute. Studies on fish passing through culverts have assumed this "fish passage velocity" to be 2 fps (0.61 m/s) in relation to the culvert (Dane, 1978). This is an important parameter for passage analysis because, given the water velocity, one can determine the speed the fish must swim to pass. Values obtained in this study were average4 over four runs and are given in Table 4.

Table 4. Relative velocity of chum and coho salmon with respect to chute.

Species	Relative Fish Velocity (fps)
Coho	2.1
Chum	1.9

Feasibility for Fish Passage

All tests were conducted with a pool length of 12 ft (3.66 m) and the change in water surface elevations (H) were measured for each test. The water surface drop was not a variable in this study because the velocity down the chute is independent of the change in water surface elevations, as can be seen by Manning's equation:

$$V = (1.49/n)\ R^{2/3}\ S^{1/2}$$

The change in water surface elevation (H) was varied to obtain the same chute length at a steeper slope. When the values of H are compared with the passage success rates and fishway slope, the feasibility of using slightly roughened chutes for fish passage becomes obvious (Table 5). Currently fishway designers suggest a maximum water surface drop of 1.0 ft (0.305 m) for coho salmon, 0.75 ft (0.23 m) for chum salmon, and a maximum fishway slope of 1 on 8. In test 2d, with a water surface drop of 1.85 ft (0.567 m) and a fishway slope of 1 on 6.5 a 100% passage success rate was recorded for chum salmon. This was achieved by adding only roughness elements 1.5 x 1.5 in (3.81 x 3.81 cm) at 6 in (15.2 cm) clear spacing to the floor of the chute.

Table 5. Change in water surface drop, percent successful passage and fishway slope for chum salmon testing at Johns Creek Fish Hatchery near Shelton, Washington.

Test No.	H (ft)	Chute Slope (%)	% Passage (Chum)	Overall Fishway Slope Including Pool Length
2b	1.03	15	92	1/11.7
2c	1.80	19	89	1/6.7
2d	1.85	27	100	1/6.5
2e	2.52	36	23	1/4.8

Conclusions

This study showed how an 8 ft (2.44 m) wooden rectangular chute can be used to estimate the swimming capabilities of coho and chum salmon and to determine the feasibility of using chutes in series to pass fish. Some of the findings can be summarized:

1. When passing the chute, coho salmon only leaped after several unsuccessful attempts at swimming. Chum salmon always swam to pass.
2. Minimum suggested depths for passage are: coho 0.4 ft (0.12 m) and chum 0.5 ft (0.15 m). Depth of water where fish are unimpaired should be equal to the maximum depth of the fish body.

3. The maximum speed obtained for coho and chum salmon are 10.7 and 10 fps (3.26 and 3.05 m/s), respectively.

4. Coho salmon were swimming at a level of 50% of their maximum burst speed and chum salmon at 67%.

5. The average relative velocities of the fish with respect to the chute were coho 2.1 fps (0.64 m/s) and chum 1.9 fps (0.58 m/s).

6. The use of a velocity chute 1.25 ft (0.38 m) wide by 1.5 ft (0.46 m) high with roughness elements can be used to pass salmon with a high passage success rate and water surface drops of up to 2 ft (0.61 m) with a pool length of 12 ft (3.66 m). The pool length is the dimension from one chute inlet to the next,

Suggestions for Future Testing

To measure the response of fish to a certain parameter, all others must he held constant. For example, in test #2 the velocity was increased by increasing the slope of the chute, but because the depth was not held constant it was hard to determine whether the depth of flow or the increased velocity was affecting the passage success rate. This could be solved by keeping the depth of flow always greater than or equal to the maximum depth of the fish at the midsection. Other suggestions for further testing might address the following:

1. At what slope does the velocity increase creating a velocity barrier, by species, assuming the depth is sufficient?

2. What is the fish response at a velocity barrier; does leaping commence or do the fish continue to try to swim up the chute?

3. At one velocity where the passage success is low, try three different sizes of roughness elements and observe behavior.

4. **As the velocity increases, does the relative velocity of the fish with respect to the chute increase cr remain constant?**

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State of California
The Resources Agency
DEPARTMENT OF FISH AND GAME

2005 ANNUAL REPORT

UPPER REDWOOD CREEK
JUVENILE SALMONID (SMOLT) DOWNSTREAM MIGRATION STUDY
2000 - 2005 Seasons
PROJECT 2a5

Prepared by

Michael D. Sparkman
Northern California, North Coast Region

Anadromous Fisheries Resource Assessment and Monitoring Program

December 7, 2005

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ABSTRACT

Juvenile anadromous salmonid trapping was conducted for the sixth consecutive year in upper Redwood Creek, Humboldt County, California during the spring/summer emigration period (March – August). The purpose of the study is to describe juvenile salmonid out-migration and estimate smolt population abundances for wild 0+ Chinook salmon, 1+ coho salmon, 1+ steelhead trout, and 2+ steelhead trout using mark/recapture methods. The long term goal is to monitor the status and trends of out-migrating juvenile salmonid smolts in upper Redwood Creek in relation to watershed conditions and restoration activities in the basin; and to provide data needed for Viable Salmonid Population (VSP) Analysis.

The trap operated 146 nights out of 154 nights possible, and captured 9,329 0+ Chinook salmon, zero 1+ Chinook salmon, 41,671 0+ steelhead trout, 4,912 1+ steelhead trout, 628 2+ steelhead trout, 2 cutthroat trout, 2 0+ pink salmon, and zero juvenile coho salmon. Catches in YR 2005 were markedly less than previous study years, with the greatest reduction (93%) occurring for 0+ Chinook salmon. Average weekly trapping efficiency was 33% for 0+ Chinook salmon, 23% for 1+ steelhead trout, and 26% for 2+ steelhead trout. Trapping efficiency was inversely related to stream discharge and stream gage height for 0+ Chinook salmon, 1+ steelhead trout and 2+ steelhead trout. The total 0+ Chinook salmon population estimate with 95% confidence intervals in YR 2005 equaled 39,614 (34,961 - 44,268), and was 94% less than emigration in YR 2004 and 90% less than emigration for the previous five year average. The large decrease in YR 2005 may be attributable to: 1) high bedload mobilizing flows during egg incubation in spawning redds, which could account for 89% of the variation in emigration over the six study years, 2) large decrease in adult spawners upstream of the trap site, or 3) a combination of the two factors. The population estimate for 1+ steelhead trout equaled 26,176 (22,726 – 29,625) and was 37% less than emigration in YR 2004 and 40% less than emigration for the previous five year average. 2+ steelhead trout population emigration equaled 2,364 (1,933 – 2,796) and was 59% less than emigration in YR 2004 and 64% less than emigration for the previous five year average. 0+ Chinook salmon, 1+ steelhead trout, and 2+ steelhead trout showed a negative trend (preliminary) over study years, however, significance was only detected with 1+ steelhead trout. Twenty-seven pit tagged 0+ Chinook salmon fingerlings released at the upper trap site were recaptured 29 miles downstream at the second trap in lower Redwood Creek. Travel time ranged from 1.5 – 19.5 d and averaged 7.5 d, and travel rate ranged from 1.5 – 19.3 mi/d and averaged 8.2 mi/d. On average, 0+ Chinook salmon migrated 29 miles downstream faster than 1+ and 2+ steelhead trout did in YR 2004. Fifty-two percent of the recaptured 0+ Chinook salmon fingerlings in YR 2005 showed positive growth in FL and Wt, 18% showed a decrease in Wt, 48% showed no change in FL, and 30% showed no change in Wt. Growth was positively related to travel time and travel time explained more of the variation in growth than any other variable tested. The percent change in FL ranged from 0.0 – 17.1 and averaged 3.6. The final size of recaptured pit tagged 0+ Chinook salmon was positively related to the initial size at tagging and release. Thus, for the pit tagged Chinook salmon juveniles, larger fish released at the upper trap were more likely to be the larger fish at the lower trap.

[1/] This paper should be referenced as: Sparkman MD. 2005. Upper Redwood Creek juvenile salmonid (smolt) downstream migration study, study year 2005. CDFG AFRAMP, 2005 Annual Report 2a5: 115 p.

INTRODUCTION

This report presents results of the sixth consecutive year of juvenile salmonid downstream migration trapping in upper Redwood Creek, Redwood Valley, Humboldt County, California during the spring/summer emigration period. The study began in YR 2000, and was funded by the Redwood Creek Landowners Association (RCLA). Study years 2001 – 2005 have been a cooperative effort between the California Department of Fish and Game Anadromous Fisheries Resource Assessment and Monitoring Program (AFRAMP) (formerly Steelhead Research and Monitoring Program) and RCLA. AFRAMP and RCLA plan on continuing the study for a longer period of time (>10 yrs) in order to more fully address biological and environmental variability, and to determine the status and trends of smolt production in upper Redwood Creek.

The initial impetus for the study was to determine how many wild salmon and steelhead smolts were emigrating from upper Redwood Creek. Prior to this study, no information about smolt emigration and population estimates from upper Redwood Creek existed; this also applied to the remainder of mainstem Redwood Creek as well. Scientific studies which quantified anadromous salmonids within the Redwood Creek watershed were primarily limited to the estuary (juveniles) and Prairie Creek (adults and juveniles), which is tributary to lower Redwood Creek at river mile (RM) 3.7.

Redwood Creek is a difficult stream to monitor adult salmon and steelhead populations because the adult fish migrate upstream during late fall, winter and early spring. Thus, when the adults are present, the stream flow is often high and unpredictable, which limits the reliability and usefulness of any adult weir. Additionally, the stream flow during this time period often carries large amounts of suspended sediments, which render visual observations of adult fish and redds (eg spawning surveys) unreliable and unlikely for long term monitoring. Scientific studies which focus on salmonids in tributaries to Redwood Creek are less affected by these processes, however, the tributaries are less likely to adequately represent or account for the majority of the salmonid populations in Redwood Creek because the majority of adult salmon and steelhead spawn in the mainstem. A possible exception is the Prairie Creek watershed which probably accounts for a considerable amount of the coho salmon production in Redwood Creek. Tributaries to Redwood Creek are often steep, with limited anadromy (RNP 1997, Brown 1988). Additionally, some of the tributaries can dry up prior to late summer, which cause the juvenile fish to migrate into the mainstem Redwood Creek

Determining and tracking smolt numbers over time is an acceptable, useful, and quantifiable measure of salmonid populations which many agencies (both state and federal), universities, consultants, tribal entities, and timber companies perform each year. Juvenile salmonid out-migration can be used to assess: 1) the number of parents that produced the cohort (Roper and Scarnecchia 1999, Ward 2000, Sharma and Hilborn 2001, Ward et al. 2002, Bill Chesney pers. comm. 2005), 2) redd gravel conditions (Cederholm et al. 1981, Holtby and Healey 1986, Hartman and Scrivener 1990), 3) in-stream habitat quality and watershed health (Tripp and Poulan 1986, Hartman and Scrivener 1990, Hicks et al. 1991, Bradford et al. 2000, Sharma and Hilborn 2001, Ward et al. 2002), 4) restoration activities (Everest et al. 1987 *in* Hicks et al. 1991, Slaney et al. 1986, Tripp 1986, McCubbing and Ward 1997, Solazzi et al. 2000, Cleary 2001, Ward et al 2002, McCubbing 2002, Ward et al. 2003), 5) over-winter survival (Scrivener and Brown 1993 *in* McCubbing and Ward 1997, Quinn and Peterson 1996, Solazzi et al. 2000, McCubbing 2002, Ward et al. 2002, Giannico and Hinch 2003), and 6) future recruitment to adult populations (Holtby and Healey 1986, Ward and Slaney 1988, Ward et al. 1989, Unwin 1997, Ward 2000).

This paper will present the results of trapping in study year 2005 with comparisons to the average of the previous five study years (YRS 2000 - 2004).

Site Description

Redwood Creek lies within the Northern Coast Range of California, and flows about 67 miles through Humboldt County before reaching the Pacific Ocean (Figure 1). Headwaters originate at an elevation of about 5,000 ft and converge to form the main channel at about 3,100 feet. Redwood Creek flows north to northwest to the Pacific Ocean, and bisects the town of Orick in Northern California. The basin of Redwood Creek is 179,151 acres, and about 49.7 miles long and 6.2 miles wide (Cashman et. al 1995). The study area upstream of the trap site encompasses approximately 65,000 acres of upper Redwood Creek watershed, with about 37 stream miles (59.5 km) of accessible salmon and steelhead habitat (Brown 1988).

Geology

The Redwood Creek watershed is situated in a tectonically active and geologically complex area, and is considered to have some of the highest uplift and seismic activity rates in North America (CDFG NCWAP 2004). The geology of the Redwood Creek basin has been well-studied and mapped (Cashman et. al 1995).

> "Redwood Creek drainage basin is underlain by metamorphic and sedimentary rocks of the Franciscan assemblage of Late Jurassic and Early Cretaceous age and by shallow marine and alluvial sedimentary deposits of late Tertiary and Quaternary age. These units are cut by a series of shallowly east-dipping to vertical north to northwest trending faults. The composition and distribution of bedrock units and the distribution of major faults have played a major part in the geomorphic development of the basin. Slope profiles, slope gradients, and drainage patterns within the basin reflect the properties of the underlying bedrock. The main channel of Redwood Creek generally follows the trace of the Grogan fault, and other linear topographic features are developed along major faults. The steep terrain and the lack of shear strength of bedrock units are major contributing factors to the high erosion rates in the basin" (Cashman et al. 1995).

Climate and Annual Precipitation

The climate of Redwood Creek basin varies dependent upon location within the watershed and season. Coastal areas have a moderate climate due to proximity to the

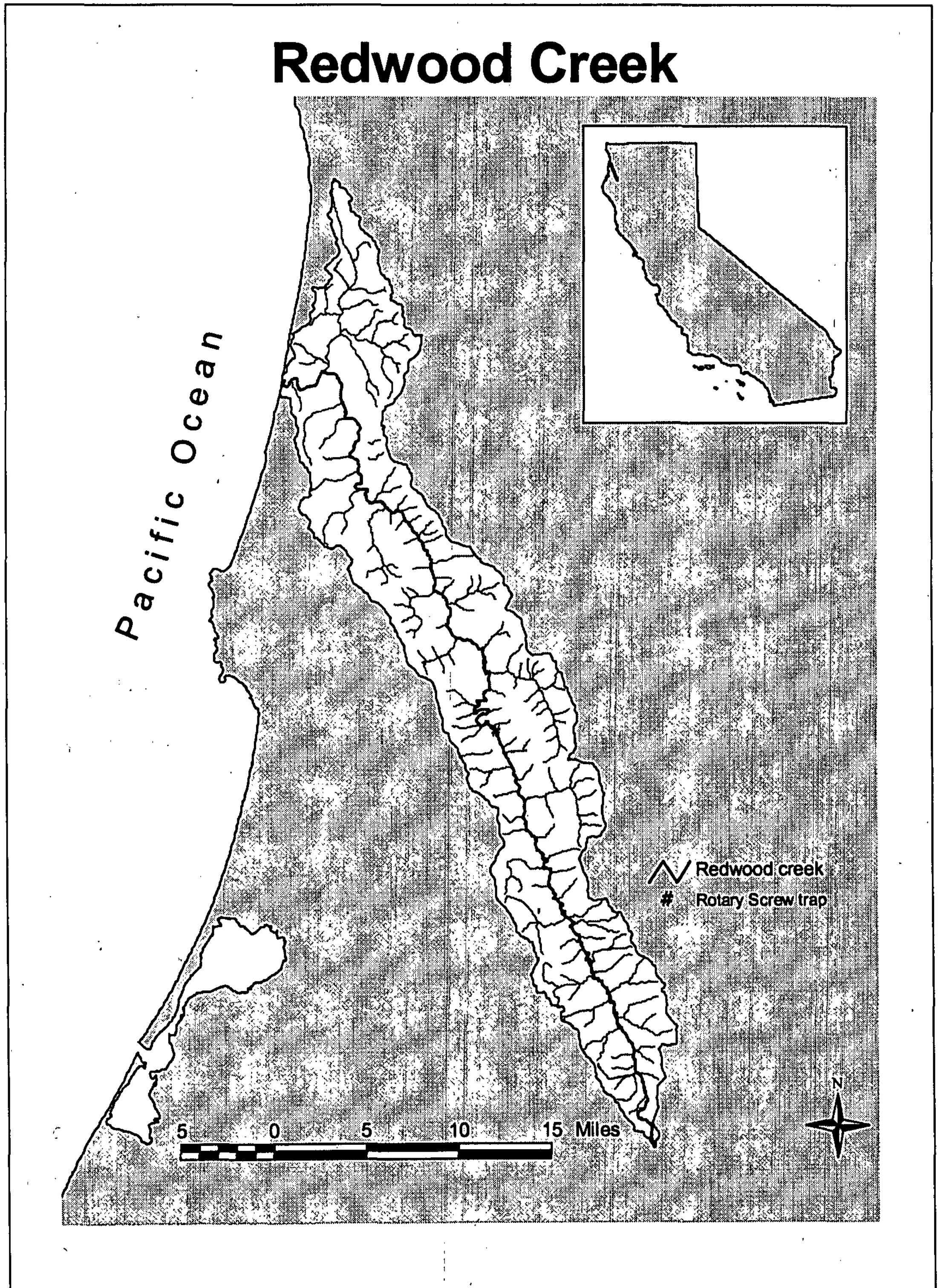

Figure 1. Redwood Creek watershed with rotary screw trap location in Redwood Valley, Humboldt County, CA. (scale is slightly inaccurate due to reproduction process; Charlotte Peters pers. comm. 2001).

ocean, and differ from inland areas (i.e. upper Redwood Creek) which experience high and low temperatures. Summers are typically cool and moist on the coast, and hot and dry inland. Ambient air temperatures in Redwood Valley often exceed 32 °C (or 90 °F) during summer months. Upper Redwood Creek experiences cold temperatures during the winter, and snowfall is common. In study year 2005, snowfall occurred as late as May. Rainfall in upper Redwood Creek is influenced by orographic effects, and can fall in considerable amounts.

A weather station (Davis Vantage Pro Weather Station) is located at the Hinz family residence in Redwood Valley, about 5.25 miles downstream of the trap site. Rainfall records cover the period from 1986 to the present to total 20 years (Redwood National Park, in house data, 2005; Vicki Ozaki pers. comm. 2005). Annual precipitation ranges from 90 cm (35.4 in.) to 238 cm (93.7 in.), and averages 177 cm (69.7 in.). Most (97%) of the rainfall in Redwood Creek occurs from October through May, with peak monthly rainfall occurring in December and January (Appendix 1). However, in some years relatively large amounts of rainfall may occur in November, February, April, and May (eg. YR 2005) as well. Rainfall in WY 2005 was about 185 cm (73 in.), and 8 cm (3.1 in.) greater than the 20 year average (Appendix 1).

The 20 year average monthly rainfall during the majority of the trapping season (April – July) totaled 26.7 cm (10.5 in.) (Table 1). Total monthly rainfall during this period of trapping in YR 2005 (60.5 cm or 23.8 in.) was considerably greater than rainfall for the historic average (by a factor of 2.3) and the average of the previous five study years (by a factor of 2.9) (Table 1). Rainfall in May 2005 was 2.2 times greater than the historic average for May; and rainfall in June 2005 was 4.8 times greater than the historic average for June (Table 1).

Table 1. Comparison of 20 year average monthly rainfall and monthly rainfall during the majority of the trapping period, Redwood Creek, Redwood Valley, Humboldt County, California.

	Rainfall* (centimeters)		
Month	Historic Average	Average of previous 5 study years (2000-04)	YR2005
Apr.	13.7	14.9	23.8
May	9.2	4.2	19.9
June	3.5	1.6	16.8
July	0.3	0.0	0.0
Total:	26.7	20.7	60.5

* Data courtesy of Redwood National Park, Vicki Ozaki pers. comm. 2005.

Stream Discharge

A USGS/CDWR gaging station (Blue Lake O'Kane, #11481500) is located about 8.4 miles upstream of the trap site on Redwood Creek. Stream flow records cover the periods of 1953 – 1958, 1972 – 1993, and 1997 – 2005 to total 34 years (Thomas Haltom pers. comm. 2005, USGS 2005). Following the pattern of rainfall, most of the high flows occur in the months of November - April, and typically peak in February; low flows usually occur from July - October (Appendix 2, USGS 2005). However, in WY 2005, peaks in average monthly flow occurred March - May, with the greatest average monthly flow occurring in April. Low flows in WY 2005 occurred October - November, and August - September. Using all years' data, mean monthly discharge in upper Redwood Creek is 232 cfs (or 6.6 m^3/sec), and ranges from 8 - 553 cfs (USGS 2005). Average monthly discharge in WY 2005 was 197 cfs (5.6 m^3/sec) and greater than the previous five year average (187 cfs) (Appendix 2, USGS 2005).

The 34 year average monthly discharge during the majority of the trapping season (April - July) equaled 138 cfs (Table 2). Average monthly discharge from April – July, 2005 (272 cfs) was much higher than the historic average (by a factor of 1.97) and the average of the previous five study years (by a factor of 2.41) (Table 2, data from USGS 2005). The probability that the average flow during April – July would exceed 272 cfs (based upon 54 years of record) equaled 5.6%.

Table 2. Comparison of 34 year average monthly discharge and average monthly discharge in upper Redwood Creek (O'Kane station) during the majority of the trapping period (USGS 2005).

	Average Discharge (cfs)		
Month	Historic	Previous 5 study years (2000-04)	YR2005
Apr.	302	250	511
May	162	153	377
June	67	38	153
July	21	12	47
Ave:	138	113	272

Overstory

The overstory in the Redwood Creek watershed is predominately second and third growth Redwood (*Sequoia sempervirens*) and Douglas Fir (*Pseudotsuga menziesii*), mixed with Big Leaf Maple (*Acer macrophyllum*), California Bay Laurel (*Umbellularia californica*), Incense Cedar (*Calocedrus decurrens*), Cottonwood (*Populus spp.*), Manzanita

(*Arctostaphylos spp.*), Oak (*Quercus spp.*), Tan Oak (*Lithocarpus densiflorus*), Pacific Madrone (*Arbutus menziesii*), and Red Alder (*Alnus rubra*).

Understory

Common understory plants include: dogwood (*Cornus nuttallii*), willow (*Salix lucida*), California hazelnut (*Corylus rostrata*), lupine (*Lupinus spp.*), blackberry (*Rubus spp.*), plantain (*Plantago coronopus*), poison oak (*Toxicodendro diversilobum*), wood rose (*Rosa gymnocarpa*), false Solomon's seal (*Smilacina amplexicaulis*), spreading dog bane (*Apocynum spp.*), wedgeleaf ceanothus (*Ceanothus spp.*), bracken fern (*Pteridium aquilinum*), blackcap raspberry (*Rubus spp.*), and elderberry (*Sambucus spp.*), among other species.

Redwood Creek History (Brief)

Redwood Creek watershed has experienced extensive logging of Redwood and other commercial tree species. By 1978, 81% of the original forest was logged, totaling 66% of the basin area (Kelsey et al. 1995). Most, if not all, of the remaining old growth Redwood is contained within Redwood National Park, which is downstream of the trap site. In conjunction with clear-cut logging, associated road building, geology types and geomorphic processes (eg debris slides and earthflows), and flood events in 1955 and 1964, large amounts of sediments were delivered into the stream channel (Madej and Ozaki 1996) with a resultant loss of stream habitat complexity (filling in of pools and flattening out of the stream channel, Marlin Stover pers. comm. 2000). Additional high flows occurred in 1972, 1975, and 1995 as well, and have helped influence the current channel morphology of Redwood Creek. Currently, Redwood Creek within the study area appears to have experienced channel incision in flood gravel deposits, scouring of pools to increase depth, riparian growth, and input of woody debris (small), which collectively increase stream complexity. However, in YR 2005 relatively large amounts of sands were deposited at the trap site and areas downstream of the trap site.

Redwood Creek has been listed as sediment and temperature-impaired under section 303(d) of the Clean Water Act (CWA 2002; SWRCB 2003; USEPA 2003).

Federal ESA Species Status

Chinook (King) salmon (*Oncorhynchus tshawytscha*), coho (Silver) salmon (*O. kisutch*), steelhead trout (*O. mykiss*), and cutthroat trout (*O. clarki clarki*) are known to inhabit Redwood Creek. This study also shows that pink salmon (*O. gorbuscha*) are present in Redwood Creek. Chinook salmon (KS) of Redwood Creek belong to the California Coastal Chinook Salmon Evolutionarily Significant Unit (ESU), and are listed as "threatened" under the Federal Endangered Species Act (Federal Register 1999a). The definition of threatened as used by National Oceanic and Atmospheric Administration (NOAA) and the National Marine Fisheries Service (NMFS) is "likely to become endangered in the foreseeable future throughout all or a significant portion of their range" (NOAA 1999). Coho salmon (CO) belong to the Southern Oregon / Northern California Coasts ESU and were classified as "threatened" (Federal Register 1997) prior to the Chinook salmon listing. Steelhead trout (SH) fall within the Northern California Steelhead ESU, and are also listed as a "threatened" species (Federal Register 2000). Coastal cutthroat trout (CT) of Redwood Creek fall within the Southern Oregon / California Coasts Coastal Cutthroat Trout ESU, and were determined "not warranted" for ESA listing (Federal Register 1999b). Despite ESU listings of Redwood Creek anadromous salmonid populations, relatively little data exists concerning abundance and population sizes, particularly for juvenile (and adult) life history stages. Historically, the most prolific species was most likely the fall/early winter-run Chinook salmon.

Purpose

The purpose of this project is to describe juvenile salmonid downstream migration in upper Redwood Creek, and to determine emigrant population sizes for wild 0+ (young-of-year) Chinook salmon (Ocean type), 1+ (between 1 and 2 years old) steelhead, 2+ (2 years old and greater) steelhead, and 1+ coho salmon smolts. The long term goal is to monitor the status and trends of out-migrating juvenile salmonid smolts in Redwood Creek in relation to watershed conditions and restoration activities in the basin; and to provide data needed for Viable Salmonid Population (VSP) Analysis. An additional goal is to document the presence or absence of juvenile coho salmon and 1+ Chinook salmon (Stream type). Specific study objectives were as follows:

1) Determine the species composition and temporal pattern of downstream migrating juvenile salmonids, and enumerate species out-migration.
2) Determine population estimates for downstream migrating 1+ steelhead trout, 2+ steelhead trout, and 0+ Chinook salmon.
3) Record fork length (mm) and weight (g) of captured fish.
4) Investigate 0+ Chinook salmon, 1+ steelhead trout, and 2+ steelhead trout travel time and growth as they migrate from the upper trap to the lower trap (or estuary) using passive integrated transponder tags (Pit Tags).
5) Collect and handle fish in a manner that minimizes mortality.
6) Statistically analyze data for significance and trends.
7) Compare data between study years.

METHODS AND MATERIALS

Trap Operations

A modified E.G. Solutions (5 foot diameter cone) rotary screw trap was deployed in upper Redwood Creek (RM 33) on March 25, 2005 at the same location as in previous study years (i.e. downstream of a moderately high gradient riffle). The trap was modified by using the larger pontoons normally equipped with the 8 foot cone so that a larger livebox could be used. The debris wheel of the E.G. solutions livebox was cut out, and aluminum was added to the livebox to increase the length nearly two-fold (L 218.4 cm x W 121.9 cm x H 55.9 cm). A framed perforated steel plate with 2 mm holes was then used to close the downstream end where the debris wheel once was located. Perforated plates with 2 mm holes were also placed in the sides (n = 2, 56 x 31 cm) and bottom (n = 1, 89 x 41 cm) of the livebox to dissipate livebox water velocities. Modifications to the livebox decreased livebox water velocities, allowed for less fish crowding during peak catches, and enabled the trap to continue trapping under higher flows as compared to the stock model.

The rotary screw trap operated continually (24 hrs/day, 7 days a week) from March 25th through August 26th except when stream flows and debris loads were too high to trap safely. The trapping season in YR 2005 was extended compared to previous trapping years because juvenile salmonids were outmigrating beyond August 5th, which is normally when out-migration has tapered off considerably.

When stream flows were too high to operate the rotary screw trap, we used a winch attached to a 4x4 truck and a cable gripper (attached to one of the main cables connected to the rotary screw trap) to move the trap to the side of the steam to raise the cone. The trap was re-set as soon as possible, and placed back into the thalweg of the stream. Every attempt was made to maintain the trap's position in the thalweg. Trapping in higher than normal flows in YR 2005 (similar to YR 2003) required operating the trap in and out of the thalweg at various times during the high flow periods. During some of the high flows within which we trapped, the trap was set partially out of the thalweg to reduce cone revolutions to less than 45 per 3 minutes (considered an upper limit for the modified version) and to reduce excessive debris loading. We also moved the trap completely out of the thalweg to determine if any fish (primarily 0+ Chinook salmon) were moving along the margin areas of the stream (few were). Additionally, we operated the trap in the thalweg during some of the high flows (eg in April and May) to make sure that we were not 'missing' fish (few fish were caught). On one high flow event on May 17th, we stayed overnight and operated the trap fully in the thalweg. We used a winch (attached to a truck) and pulled the trap into shallower water every 2.5 hours so that we could access the livebox. Trap efficiency trials were on-going throughout these events. A major benefit to the upper Redwood Creek trapping site is a relatively narrow channel width which causes the stream to rise vertically more than spread out horizontally during high rainfall and stream flow periods. The channel morphology reduces the amount of space fish could pass by the trap without being captured.

During periods of lesser stream flows, rock type weirs and weir panels were used with the rotary screw to: 1) keep the trap's cone revolutions relatively high, and 2) maintain good trap efficiencies by directing the fish into the cone area. The weir panels were set to fall down under any unexpected, high stream flows. Plastic drop cloths were used to cover the weirs in July to further increase flow into the cone area. Normally by mid to late July we remove the rotary screw trap and install a pipe trap to finish the study. However, due to the increase in stream discharge and apparent increase in summer base flow in YR 2005, we were able to complete the study using the rotary screw trap.

The YR 2005 trapping season, particularly March - May, can be characterized as working in and out of high flow events. In YR 2005, we experienced the most difficult flow conditions to trap in compared to previous study years (2000 - 2004).

Biometric Data Collection

Fishery technicians carefully removed debris (e.g. alder cones, leaves, sticks, detritus, large amounts of filamentous green algae, etc) from within the livebox nearly every night of trapping to reduce trap mortalities the following morning. The trap's livebox was emptied at 09:00 every morning by 2 - 4 technicians. Young of year fish were removed first and processed before 1+ and 2+ fish to decrease predation or injury to the smaller fish. Captured fish (0+ fish first, then 1+ and older) were placed into 5 gal. buckets and carried to the processing station. At the station, fish were placed into a 23.5 gal. ice chest modified to safely hold juvenile fish. The ice chest was adapted to continually receive fresh water from the stream using a 3,700 gph submersible bilge pump. The bilge pump connected to a flexible line (ID 4 cm or 1.6 in.) that connected to a manifold with four ports. "Y" type hose adapters were connected to each port. Garden hoses connected to the hose adapters, with one line feeding the ice chest, and four lines feeding recovery buckets for processed fish. Additional garden hoses were connected to the hose adaptors to quickly fill buckets if needed. Plumbing inside the ice chest consisted of two PVC pipes: one that served to dissipate the stream water into the ice chest, and the other to drain excess water. The water lines to the recovery buckets were elevated above the recovery buckets so that the fresh water would also provide increased aeration. The system worked very well, did not require additional battery operated aerators, and decreased total fish processing time.

Each individual fish was counted by species and age, and observed for trap efficiency trial marks. Random samples of each species at age (eg 0+ KS, 0+ SH, etc.) were netted from the ice chest for enumeration and biometric data collection.

<u>Fork Lengths/Weights</u>

Fish were anesthetized with MS-222 prior to data collection in 2 gal. dishpans. Biometric data collection included 30 measurements of fork length (mm) and wet weight (g) for random samples of 0+ Chinook salmon (0+ KS), 1+ Chinook salmon (1+ KS), 1+ and greater cutthroat trout (CT), 0+ steelhead trout, 1+ steelhead trout (1+ SH), and 2+ and greater steelhead trout (2+ SH). Although both fork lengths and weights were taken for 0+ steelhead trout (0+ SH), only FL data is reported. A 350 mm measuring board ($\pm$ 1 mm) and an Ohaus Scout ll digital scale ($\pm$ 0.1 g) were used in the study. Fork lengths were taken every day of trap operation, and fork length frequencies of 0+ and older steelhead trout and Chinook salmon were used to determine age-length relationships at various times throughout the trapping period. Scales were occasionally read to verify age class cutoffs. 0+ Chinook salmon and 1+ steelhead trout weights were taken 2 - 4 times per week, and 2+ steelhead trout weights were taken almost every day of trap operation and collection due to expected, low sample sizes. Individuals were weighed in a tared plastic pan (containing water) on the electronic scale. The scale was calibrated every day prior to data collection. After biometric data was collected, fish were placed into 5 gal. recovery buckets which received continuously pumped fresh stream water. Young of year fish were kept in separate recovery buckets from age 1+ and older fish to decrease predation or injury. When fully recovered from anesthesia, 0+ juvenile fish were transported 157 m downstream of the trap site, and aged 1 and older fish were transported 170 m downstream of the trap site and released into the river.

Developmental Stages

We visually determined developmental stages (e.g. parr, pre-smolt, smolt) for every 1+ steelhead trout, 2+ steelhead trout, and 1+ (and greater) cutthroat trout captured using the following criteria:

- Parr designated fish that had obvious parr marks present and no silvering of scales.

- Pre-smolt designated individuals with less obvious parr marks, showed some blackening of the caudal fin, and were in the process of becoming silver colored smolts. Pre-smolt was considered in-between parr and smolt.

- Smolt designated fish that were very silver in coloration (i.e. smoltification), had little to no parr marks present, and had blackish colored caudal fins. Smolts are also known to shed scales.

Discerning developmental stages is subjective; however, I attempted to minimize observer bias by individually training (and checking) each crew member and having all crew members follow the same protocol. The most difficult stages to separate were for those fish which fell between smolt and pre-smolt.

Population Estimates

The number of fish captured by the trap represented only a portion of the total fish moving downstream in that time period. Total salmonid out-migration estimates (by age and species) were determined on a weekly basis for 0+ Chinook salmon, 1+ steelhead trout, and 2+ steelhead trout using stratified mark-recapture methodology described by Carlson et al. (1998). The approximately unbiased estimate equation for a 1-site study was used to determine total population size (U_h) in a given capture and trapping efficiency period (h). Variance was computed, and the value was used to calculate 95% confidence intervals (CI) for each weekly population estimate. The weekly population estimate (U_h) does not include catches of marked releases in the "C" component (or 'u_h') of the equation, and any short term handling mortality was subtracted (Carlson et al. 1998). Trap efficiency trials were conducted two to five times a week for 0+ Chinook salmon, 1+ steelhead trout, and 2+ steelhead trout. Data was combined and run through the equation to determine the weekly estimate (for a complete description of estimation methods and model assumptions see Sparkman 2004a, study 2a5).

Partial fin clips were used to identify trap efficiency trial fish by squaring the round edge (or tip) of a given fin (caudal, pectoral) with scissors. Fish used in efficiency trials were given partial fin clips while under anesthesia (MS-222), and recovered in 5 g buckets which received fresh stream water (via the plumbing system). Clips for 2+ steelhead trout were stratified by week such that marked fish of one group (or week) would not be included in the following week(s) calculations (no out of strata captures occurred in YR 2004 and 2005). I did not stratify clips for 0+ Chinook and 1+ steelhead trout because four years of data (when I did stratify clips) showed that nearly all of the recaptures (99.4%) occurred in the correct strata. Clip types for 1+ and 2+ steelhead were kept on different time schedules to aid in identifying the correct age group of the recaptured fish; if there was any doubt or question, we would re-measure the fish, and count it for the appropriate age group. 0+ Chinook salmon and 1+ steelhead trout were given upper caudal fin clips, and 2+ steelhead trout were given upper or lower caudal fin clips. Once recovered from anesthesia, the fish were placed in mesh cages in the stream for at least 1 - 2 hrs to test for short term delayed mortality (Carlson et al. 1998). The number of efficiency trials per week for a given species at age ranged from 2 – 5. Fin clipped 0+ Chinook salmon were released in fry habitat 260 m upstream of the trap, and clipped 1+ and 2+ steelhead were released into a pool 160 m upstream of the trap. Fin clipped 0+ Chinook salmon were released upstream of the trap after the livebox was emptied (eg 1300 – 1800), and 1+ steelhead and 2+ steelhead trout were released upstream of the trap site at night. We released the fish at night either manually or by using a live cage with a battery operated lever system that opened the trap door at any given time (eg 2200). Night releases generally occurred from 2000 – 2300.

Additional Experiments

Re-migration

In YR 2004, we marked and released 223 2+ steelhead trout and 577 1+ steelhead trout with a plastic elastomer (Northwest Marine Technology, P.O. Box 427, Ben Nevis Loop Road, Shaw Island, Washington 98286 USA) to investigate travel time between the upper trap (RM 33) and lower trap (RM 4) in Redwood Creek. These marks also served to show if any marked 1+ or 2+ steelhead trout that migrated downstream in YR 2004 re-migrated back upstream of the upper trap to be caught in YR 2005 as two or three year old fish (we did this in YR 2001-02 as well). Every 1+ and 2+ steelhead trout captured in YR 2005 was examined for elastomer marks. Mark retention was assumed to be nearly 90% within 16 months (Fitzgerald et al. 2004).

Travel Time and Growth

We marked 37 2+ steelhead trout and 146 1+ steelhead trout with plastic elastomer in YR 2005 to investigate travel time from the upper trap to the lower trap (a distance of 29 miles). We applied the elastomer marks subdermally using a hypodermic needle on the underside of both lower jaws while fish were under anesthesia (MS-222). 0+ Chinook salmon were generally too small to safely mark. Marked fish were treated as batches, with a unique color combination for each week of release. Each batch of marked fish was held in the stream for 24 hours to test for any delayed mortality prior to release, and released into the stream at the downstream release site.

Plastic elastomer has limitations because individual fish cannot be uniquely identified when marks are used for batches of fish, and the mark is rather difficult to apply for fish under 85 mm (FL). Pit tags offer the ability of individual recognition by using numbers unique to each tag (and marked fish). In YR 2005 we used Pit Tags to investigate both travel time and growth of tagged fish as they migrated downstream to be later caught at the lower trap (Sparkman 2006) or estuary (David Anderson, pers. comm. 2005). We found pit tagging to be easier and faster than applying elastomer. A more thorough examination of the pit tag data and subsequent results can be found in Sparkman (In progress). Pit tags used in the study were 11.5 mm long x 2 mm wide, and weighed 0.09 g (ALLFLEX USA, Inc., PO BOX 612266, Dallas/Ft Worth Airport, Texas). Pit tags were applied to randomly selected 1+ steelhead trout (n = 147), 2+ steelhead trout (n = 46) and 0+ Chinook salmon smolts (FL $\geq$ 70 mm, n = 555) using techniques shown by Seth Ricker (CDFG, pers. comm. 2005). Fish were anesthetized with MS-222, and measured for FL (mm) and Wt (g) prior to tagging. A scalpel (sterilized with a 10:1 solution of water to Argentyne; Argent Chemical Laboratories, 8702 152nd Ave. N.E., Redmond, WA, 98052) was used to make a small incision (2 - 3 mm long) into the body cavity just posterior (about 3 - 5 mm) to a pectoral fin. The incision was dorsal to the ventral most region of the fish to help prevent the tag from exiting the incision. Tags were also sterilized with Argentyne, and then inserted by hand into the body cavity via the incision. Glue was not used to close the incision after tag placement because previous experience with tagging showed it was unnecessary (Seth Ricker, pers. comm. 2005). Pit tagged 0+ Chinook salmon were also given a small partial upper caudal fin clip to aid in recognizing a tagged fish so that technicians at the lower trap and estuary did not have scan every 0+ Chinook salmon they captured. Some of the 1+ and 2+ steelhead trout also had partial fin clips because we tagged recaptures from trap efficiency trials to increase sample size. After tag application, fish were held in a livecar in the stream for a period of 34 hrs to test for delayed mortality. 0+ Chinook salmon were kept separately from 1+ and 2+ steelhead trout. All pit tagged fish were released at night downstream of the trap site at the normal downstream release site. Field crews at the upper trap, lower trap, and estuary had hand held pit tag readers (ALLFLEX USA, Inc., PO BOX 612266, Dallas/Ft Worth Airport, Texas) so that they could scan and identify pit tag fish; and perform necessary fork length and weight measurements.

Delayed Mortality

We conducted several delayed mortality tests for captured 0+ Chinook salmon (n = 28 tests), 1+ steelhead trout (n = 31 tests), and 2+ steelhead trout (n = 41 tests) throughout the trapping period to insure that our methods were not harming fish during and after processing. Fish were held in mesh cages (live cars) in the stream during each type of test. Fin clip tests were for fish that were anesthetized and given a partial fin clip; some fin clip test fish were also measured for FL and Wt due to small sample sizes. Total sample size was 78 for 0+ Chinook salmon, 86 for 1+ steelhead trout, and 37 for 2+ steelhead trout. The duration of each test was 24 hrs for 0+ Chinook salmon, 1+ steelhead trout, and 2+ steelhead trout. Elastomer tests were for 1+ and 2+ steelhead trout that were anesthetized and given an elastomer mark (some fish were also measured for FL and Wt due to low sample size); total sample size was 146 for 1+ steelhead trout and 37 for 2+ steelhead trout. The duration of each test was 24 hrs. Pit tag tests were for fish that were anesthetized, measured for FL (mm) and Wt (g), tagged with a pit tag, and for 0+ Chinook salmon and a few 1+ and 2+ steelhead trout, given a partial upper caudal fin clip. Total sample size was 555 for 0+ Chinook salmon, 147 for 1+ steelhead trout, and 46 for 2+ steelhead trout. The duration of each test was 34 hrs (eg 7/1/05 1100 – 7/2/05 2100).

Physical Data Collection

A staff gage with increments in hundredths of a foot was used to measure the relative stream surface elevation (hydrograph) at the trap site from March 26th – August 26th, 2005. The gage was read every morning at 0900 to the nearest one-hundredth of a foot prior to biometric data collection. A graphical representation of the data (along with average daily stream discharge data from the O'Kane gaging station, USGS 2005) is given in Appendix 3.

Stream temperatures were recorded with an Optic StowAway® Temp data logger (Onset Computer Corporation, 470 MacArthur Blvd. Bourne, MA 02532) placed behind the rotary screw trap. A second probe was deployed at the same location for comparison. Both probes gave similar results (Ave. = 14.7 °C), therefore only data from one probe is reported. The probes were placed into a PVC cylinder with holes to ensure adequate ventilation and to prevent influences from direct sunlight. Probes were set to record stream temperatures (°C) every 60 minutes and recorded about 3,700 measurements per probe over the course of the study. The shallowest stream depths during which measurements were taken (in August) were about 2 - 3 feet. The maximum weekly average temperature (MWAT) and maximum weekly maximum temperature (MWMT) for YRS 2001 - 2005 were determined following methods described by Madej et al. (1995). MWAT is defined as the maximum value of a 7-day moving average of daily average stream temperatures, and MWMT is the maximum value of a 7-day moving average of daily maximum stream temperatures (Madej et al. 2005).

Statistical Analyses

Numbers Cruncher Statistical System software (NCSS 97) (Hintze 1998) was used for linear correlation, regression/ANOVA output, single factor ANOVA, chi-square, and descriptive statistics.

Linear regression was used to estimate the catch for each species at age for days when the trap was not fishing by using data before and after the missed day(s) catch. The estimated catch (except for 0+ steelhead) was then added to the known catch in a given stratum and applied to the population model for that stratum (Roper and Scarnecchia 1999).

Linear regression and correlation (for temporal component) were used to test for influences of average daily stream temperature, average daily discharge (O'Kane gage, USGS 2005), stream gage height (at trapping site) and trapping day (temporal variable) on daily catches of all juvenile salmonids combined and for each species at age. Regression and correlation models did not include any combination of the independent variables (eg average temperature, average daily discharge, gage height, and trapping day) in a given model or test because they were highly correlated with one-another (Correlation, $p = 0.000001$, r ranged from 0.72 – 0.95). Regression and correlation were also used to test for influences of average weekly stream temperature, stream discharge, gage height, and trapping week number on the weekly catches of all species combined, and for each species at age; weekly trapping efficiencies for 0+ Chinook salmon, 1+ steelhead trout, and 2+ steelhead trout were also regressed on weekly catches for a given species at age.

Regression (and correlation) was also used to test for influences of average weekly stream temperature, stream discharge, gage height, and trapping week number on population emigration by week for 0+ Chinook salmon, 1+ steelhead trout, and 2+ steelhead trout. Once again, independent variables were not combined together in the models due to high correlations (Correlation, $p = 0.000001$, r ranged from 0.84 – 0.95).

Linear correlation was used to determine if weekly trapping efficiencies for 0+ Chinook salmon, 1+ steelhead trout, and 2+ steelhead trout changed over time (weeks). Regression was used to test for influences of physical variables (average weekly gage height and average weekly stream discharge) on weekly trapping efficiencies for a given species at age. One week (stratum) for 2+ steelhead trout trap efficiency was omitted in the analysis because only two marked fish were released with one subsequent recapture; the weekly trap efficiency was considered an outlier for the regression test. As in previous tests, gage height and stream discharge were not combined together in the models due to high correlation ($p = 0.000001$, $r = 0.95$).

Linear correlation slope and equation line were used to determine if population size of a given species at age was increasing, or decreasing over the six years of study. Linear regression was used to test the relationship of peak winter flows during egg incubation in spawning redds on the subsequent population size of 0+ Chinook salmon by coding high, bedload mobilizing flows as 1 (YRS 2003 and 2005) and non-bedload mobilizing flows as 0 (YRS 2000 - 2002, and 2004) (Zar 1999). Flows considered great enough to mobilize the bedload in upper Redwood Creek (> 4,500 cfs) were identified by Redwood National Park Hydrologists and Geologists (Randy Klein, Greg Bundros, Vicki Ozaki, Mary Ann Madej, pers comm. 2003). High flows for the 2005 cohort occurred 12/08/04, when stream flow reached 6,350 cfs (USGS 2005).

I partitioned the 0+ Chinook salmon population estimate into classes of fry (newly emerged and post-emergent fry, FL < 45 mm) and fingerlings (FL > 44 mm) each week of a given year using fork lengths and weekly population estimates. The percentage of juvenile Chinook salmon per size class each week was then multiplied by the corresponding weekly population estimate (which included marked recaptures of fry and fingerlings) to estimate the population of fry and fingerlings. The FL cutoff between fry and fingerlings was determined by examining FL histograms from five years of trapping in upper Redwood Creek (FL nadir ranged from 42 – 45 mm, mean = 44 mm), from trapping Chinook salmon redds in Prairie Creek (emergent fry fork length per redd ranged from 35 – 43, and averaged 39 mm; n = 4 redds) (Sparkman 1997 and 2004b), and from information gathered in the literature (Allen and Hassler 1986, Healey 1991, Bendock 1995, Seiler et al. 2004). Allen and Hassler (1986) summarized that newly emerged Chinook salmon fry range from 35 – 44 mm FL, Healey (1991) reported that Chinook salmon fry FL's normally range from 30 – 45 mm, and Bendock (1995) and Seiler (2004) used a FL < 40 mm for fry. Therefore, the 45 mm FL cutoff for fry in Redwood Creek was similar to that used in other studies.

Descriptive statistics were used to characterize the mean FL (mm) and Wt (g) of each species at age on a study year and weekly basis. Linear correlation was used to test if average FL and Wt by season (study year) changed over time (study year). Regression was used to test for influences of a species total catch (0+SH) or population estimate (0+KS, 1+SH, 2+SH) on average FL and Wt per season for the current six years of data collection. Data for 0+ Chinook salmon in YR 2003 was omitted from analysis because so few measurements were taken due to the year class failure in 2003. Additionally, the majority of measurements were taken in June and did not include the smaller fry that normally emigrate in late March, April, and May. Removal of data did not change the test conclusion.

I determined a ' rough' estimate of growth rate in FL and Wt for 0+ Chinook salmon in YR 2005 generally following methods by Bendock (1995). I used the first weekly average in FL and Wt with a sample size $\geq$ 25 (week 4/02 - 4/08) and the last weekly average in the season (7/23 - 7/29) with a sample size $\geq$ 25. The first average was subtracted from the last average, and divided by the number of days from the first day after the first weekly average to the last day of the last weekly average. For the example above, the number of days used in the growth calculation equaled 112. The resultant growth rate is not an individual growth rate, but more of a 'group' growth rate. The calculated values were then compared to values put forth by Healey (1991) and Bendock (1995) for juvenile Chinook salmon in other streams.

Linear correlation was also used to test if the average weekly FL and Wt of each species at age increased over the study period in YR 2005 and for the previous five year average (excluding 0+ steelhead weight). The lack of data in any given week was due to: 1) differences in trap deployment time among study years, 2) no catches occurred, or 3) sample size was too low to generate a reliable average. Single factor ANOVA (or non-parametric equivalent, Kruskal-Wallis One-Way ANOVA on Ranks) was used to test for significant variation among weekly FL's and Wt's in YR 2005 with the four year average for 0+ Chinook salmon, and five year average for 0+, 1+, and 2+ steelhead trout.

Chi-square was used to test for differences in the proportions of pre-smolt and smolt designations for captured 1+ steelhead trout and 2+ steelhead trout in YR 2005 with the previous five year average. Parr stage was not included in the tests because at least one of the values in the contingency tables was less than 5, which can cause the tests to be inaccurate (NCSS 97).

Descriptive statistics were used to characterize FL, Wt, travel time (d), travel rate (mi per d), and various growth indices (Percent Change in Growth, Absolute Growth Rate, Specific Growth Rate, and Relative Growth Rate) for all pit tagged fish recaptured at the lower trap. Average growth values were also determined for recaptured pit tagged fish that showed positive (excludes negative and zero growth) and negative (excludes positive and zero growth) growth. The weight of the pit tag (0.09 g) was subtracted from the final recorded weight to obtain the true weight of the fish. Measurement uncertainties for FL and Wt were assumed to be $\pm$ 1 mm and $\pm$ 0.1 g, therefore final FL's and Wt's needed to be greater than the initial FL and Wt by this amount to constitute a real change in size.

Travel time is defined as the difference (in days) from the recapture date to initial release date, and equals the period of growth for recaptured individuals. Since pit tagged fish were released at night (eg 2100) and recaptured at some date in the morning by the lower trap (when the crew checks the trap at 0900) the earliest recorded travel time could be 0.5 days (or 12 hours). Travel rate is the travel time divided by 29 miles (the distance between the upper and lower traps). For the following equations, t_1 is the initial date, t_2 is the ending or recapture date, Y_1 is fish size at t_1, and Y_2 is the fish size at t_2 (Busacker et al. 1990).

Percent change in growth is defined as (Busacker et al. 1990):

1) $\%\text{ change in growth} = ((Y_2 - Y_1)/ Y_1) \times 100$

Absolute growth rate (AGR) is defined as (Busacker et al. 1990):

2) $\text{Absolute growth rate} = (Y_2 - Y_1)/(t_2 - t_1)$

where $t_2 - t_1$ equals the number of days from initial release (at the upper trap) to subsequent recovery at the lower trap. Thus, absolute growth rate is expressed as mm per day or g per day.

Specific growth rate (SGRsc) is defined as (Busacker et al. 1990):

3) $\text{Specific growth rate (scaled)} = [(\log_e Y_2 - \log_e Y_1)/(t_2 - t_1)] \times 100$

Specific growth rate is expressed as a scaled number (by multiplying specific growth by 100). Thus, if the specific growth rate scaled equaled 0.741 %(mm per day), the un-scaled value would equal 0.00741 mm per day.

Relative growth rate (RGR) is defined as (Busacker et al. 1990):

4) $\text{Relative Growth Rate} = (Y_2 - Y_1)/[Y_1(t_2 - t_1)]$

Relative growth rate is a growth rate that is relative to the initial size of the fish, and units for FL are in mm/mm/d and for Wt are in g/g/d. Therefore, if the relative growth rate equaled 0.003 mm/mm/d, then we would say that the fish grew 0.003 mm per mm of fish per day.

Travel time, travel rate, and growth for all recaptured pit tagged 0+ Chinook salmon smolts (n = 27) were modeled using linear regression. These parameters for 1+ and 2+ steelhead trout could not be modeled due to low recaptures. Independent variables for travel time and travel rate (dependent variables in this case) included fish size at time 1 or time 2, water temperature during a specific migration period (average of data from both traps), and stream discharge during a specific migration period (average of data from both traps). Independent variables for modeling growth (dependent variable) included travel time, travel rate, average water temperature, and average stream discharge. Stream temperature and stream discharge were not included together in any regression models because they were highly correlated ($p < 0.001$). During the travel time and growth experiments (6/3 – 8/10), average daily stream temperatures at the upper trap site ranged from 11.0 – 22.4 °C (51.8 – 72.3 °F) and average daily stream discharge ranged from 13 - 309 cfs. Average daily stream temperatures at the lower trap site ranged from 12.2 – 20.0 °C (54.0 – 68.0 °F) and average daily stream discharge ranged from 63 - 1,620 cfs. Thus, the experiments were conducted over a fairly wide range of environmental variables.

Minimum, average, and maximum stream temperatures for each day during the trapping period were determined from data collected by temperature probes. Descriptive statistics were used to determine the average stream temperature during the course of the study. Single factor ANOVA was used to test for significant variation in average monthly stream temperature among YR 2005 and the previous four year average (YRS 2001-2004). Study year 2000 was omitted from analysis because the temperature probe was not deployed over the majority of the trapping period, and encompassed only two months. Linear correlations were used to test if the average daily (24 hour) stream temperature increased or decreased over the study period (March - August) in YR 2005; the same test was applied to the previous four year average. Regression was used to examine the relationship of the daily stream gage height on average daily stream temperature for YR 2005, and the relationship of average discharge during each trapping season on average stream temperature each season (n = 5) (excluding YR 2000).

If data violated tests of statistical assumptions, data was transformed with Log (x+1) to approximate normality (Zar 1999). Power is defined as the probability of correctly rejecting the null hypothesis when it is false (Zar 1999). The level of significance (Alpha) for tests with six data points (eg. population or catch trend analysis, regressions of population size on average FL and Wt by year, etc) was set at 0.10, and for tests with more than six data points, alpha was set at 0.05.

RESULTS

The rotary screw trap operated from 3/25/05 - 8/26/05 and trapped 146 nights out of a possible 154. The trapping rate in YR 2005 was 94% compared to 97% for the previous five year average (ranged from 92 - 99%). Days missed trapping in YR 2005 occurred in March (n = 2), April (n = 2), May (n = 3), and June (n = 1).

Species Captured

Juvenile Salmonids

Species captured in YR 2005 included: juvenile Chinook salmon (*Oncorhynchus tshawytscha*), juvenile steelhead trout (*O. mykiss*), coastal cutthroat trout (*O. clarki clarki*), and juvenile pink salmon (*O. gorbuscha*). No juvenile coho salmon (*O. kisutch*) were captured for the sixth consecutive year. A total of 56,544 juvenile salmonids were captured in YR 2005 (Figure 2).

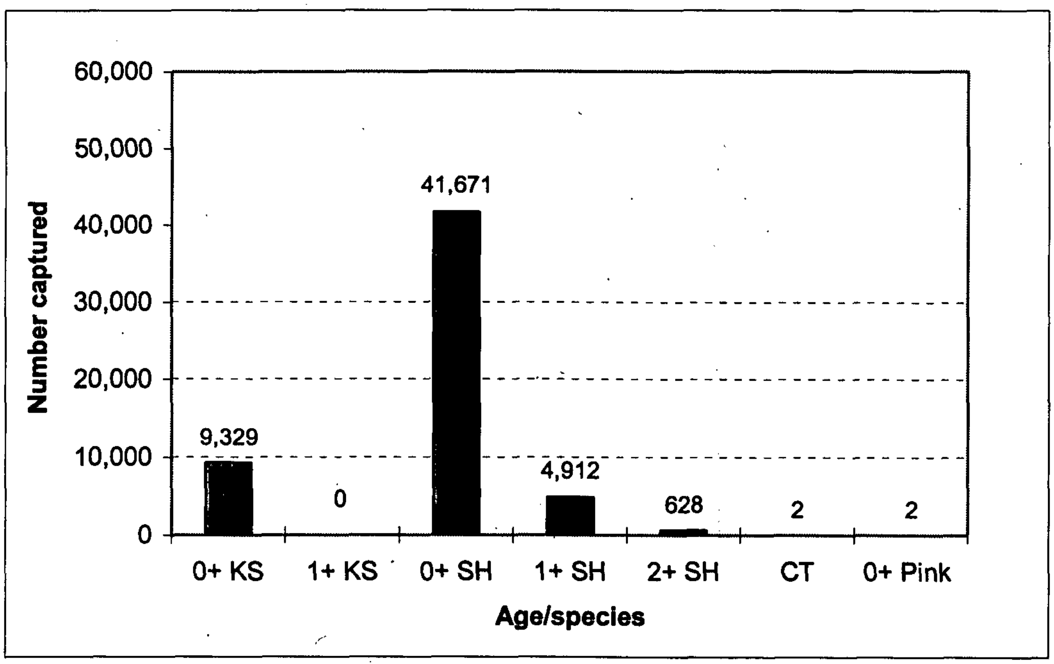

Figure 2. Total juvenile salmonid actual catches (n = 56,544) from March 26 through August 26, 2005, upper Redwood Creek, Redwood Valley, Humboldt County, CA. Numeric values above columns represent actual catches. 0+ KS = young-of-year Chinook salmon, 1+ KS = age 1 and older Chinook salmon, 0+ SH = young-of-year steelhead trout, 1+ SH = age 1 and older steelhead trout, 2+ SH = age 2 and older steelhead trout, CT = cutthroat trout, 0+ Pink = young-of-year pink salmon.

Trap catches of 0+ Chinook salmon, 0+ steelhead trout, 1+ steelhead trout, 2+ steelhead trout, and cutthroat trout in YR 2005 were much less (77%) than trap catches for the previous five year average (Table 3). The greatest reduction (93%) in catches in YR 2005 occurred with 0+ Chinook salmon.

Table 3. Comparison of juvenile salmonid trap catches in YR 2005 with the previous five year average catch, upper Redwood Creek, Humboldt County, CA.

	Actual Catches		
Age/species*	YR 2005	Previous five year average	Percent reduction in YR 2005**
0+ KS	9,329	134,880	93.1
1+ KS	0	14	-
0+ SH	41,671	102,760	59.4
1+ SH	4,912	12,583	61.0
2+ SH	628	1,121	44.0
CT	2	4	50.0
0+ Pink	2	3	33.3
Total:	56,544	251,365	77.5

* Age/species definitions are the same as in Figure 2.
** Comparison is with the previous five year average.

Miscellaneous Species

The trap caught numerous species besides juvenile anadromous salmonids in YR 2005, including: prickly sculpin (*Cottus asper*), coast range sculpin (*Cottus aleuticus*), sucker (*Catostomidae* family), three-spined stickleback (*Gasterosteus aculeatus),* brown bullhead (*Ameiurus nebulosus*), juvenile (ammocoete) lamprey and adult Pacific Lamprey (*Entosphenus tridentatus*) (Table 4). The brown bullheads likely escaped from a farm pond which drains into upper Redwood Creek.

Amphibian catches included coastal (Pacific) giant salamander (*Dicamptodon tenebrosus*), rough skinned newt (*Taricha granulosa granulosa*), yellow legged frog (*Rana muscosa*), tailed frog tadpole (*Ascaphus truei*) and American bullfrog (*Rana catesbeiana*), among other species (Table 4). Numerous aquatic and semi-aquatic invertebrates were also captured in the trap.

Table 4. Miscellaneous species captured in YR 2005 compared to the previous five year average, upper Redwood Creek, Redwood Valley, Humboldt County, CA.

	Number Captured	
Species Captured	YR 2005	Previous five year average
Prickly Sculpin	1	6
Coast Range Sculpin	13	109
Sucker	3	8
3-Spined Stickleback	92	101
Brown Bullhead	3	< 1
Adult Pac. Lamprey	9	40
Juvenile Lamprey	2,210	2,186
Possible River Lamprey*	1	3
Pac. Giant Salamander	147	105
Painted Salamander	1	1
Rough Skinned Newt	18	33
Red-Legged Frog	2	1
Yellow-Legged Frog	25	12
Tailed Frog**	4	4
American Bullfrog	0	< 1

* Has not been keyed to species.
** Includes both adult and tadpole stages.

Juvenile Salmonid Captures

Catches of 0+ Chinook salmon, 0+ steelhead trout, 1+ steelhead trout, and 2+ steelhead trout in YR 2005 were variable over time, with apparent multi-modal catch distributions for each species at age.

0+ Chinook salmon daily catches in YR 2005 (n = 9,329) ranged from 0 - 371 individuals, and averaged 65 fish per day. The previous five year daily catch ranged from 0 - 10,700 and averaged 1,096 per day. Daily 0+ Chinook salmon captures in YR 2005 expressed as a percentage of total 0+ Chinook salmon catch in YR 2005 (n = 9,329) ranged from 0.0 - 4.0%, and averaged 0.6%. The peak catch in YR 2005 occurred 5/2/05.

0+ steelhead trout daily catches in YR 2005 ranged from 0 - 2,109 individuals, and averaged 271 per day. The previous five year daily catch ranged from 0 - 6,993 individuals and averaged 799 per day. Daily 0+ steelhead captures in YR 2005 expressed as a percentage of total 0+ steelhead catch in YR 2005 (n = 41,671) ranged from 0.0 - 5.1% and averaged 0.6%. The peak catch in YR 2005 occurred 7/16/05.

1+ steelhead trout daily catches in YR 2005 ranged from 0 - 200, and averaged 32 per day. The previous five year daily catch ranged from 0 - 727 individuals and averaged 98 per day. Daily 1+ steelhead captures in YR 2005 expressed as a percentage of total 1+ steelhead catch in 2005 (n = 4,912) ranged from 0.0 - 4.1% and averaged 0.6%. The peak catch in YR 2005 occurred on 5/3/05.

2+ steelhead trout daily catches in YR 2005 ranged from 0 - 23, and averaged four individuals per day. The previous five year daily catch ranged from 0 - 45 individuals and averaged nine per day. Daily 2+ steelhead trout captures in YR 2005 expressed as a percentage of total 2+ steelhead trout catches in YR 2005 (n = 628) ranged from 0.0 - 3.7%, and average 0.6%. The peak catch in YR 2005 occurred on 4/19/05 and 4/27/05.

Days Missed Trapping

Eight days were not trapped during the course of the study due to high flow events and high debris loads in the livebox. Days missed trapping did not appear to influence the total catch or population estimate of any species at age to any large degree (Table 5).

Table 5. The estimated catch and expansion (population level) of juvenile anadromous salmonids considered to have been missed due to trap not being deployed (n = 8 d) during the emigration period of March 25 through August 26 (as a percentage of total without missed days in parentheses), upper Redwood Creek, Humboldt County, CA., 2005.

Age/spp.*	Catch	Population Level
0+ KS	88 (0.95%)	347 (0.88%)
0+ SH	311 (0.75%)	-
1+ SH	193 (4.1%)	1002 (4.0%)
2+ SH	22 (3.7%)	96 (4.3%)

* Age/species abbreviations are the same as in Figure 2.
Note: Regression methods were used to estimate the number of fish caught when the trap was not operating. The estimated catches were then added to the known catches for a given stratum (week) and used in the population estimate for that stratum (Roper and Scarnecchia 1999).

0+ Chinook Salmon

The majority of 0+ Chinook salmon catches in YR 2005 occurred in June and July (63% of total), compared with May and June (80% of total) for the previous five year average (Figure 3). The percentage of total catch in late March, April, and August 2005 were similar to the previous five year average. The percentage of total catches in July 2005 was markedly higher than July for the previous five year average.

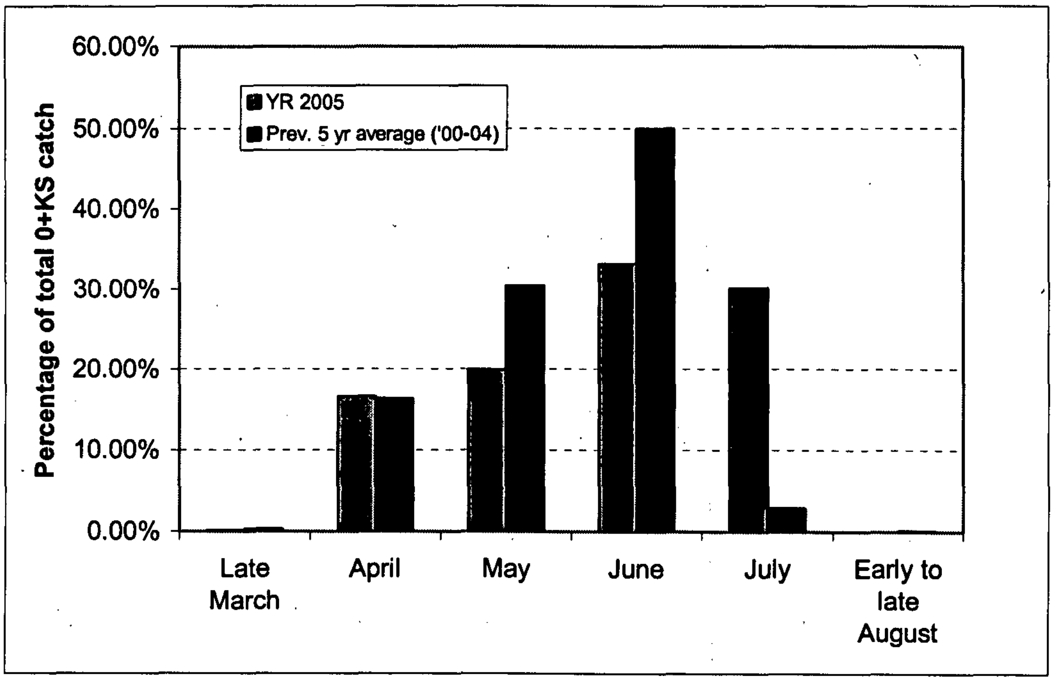

Figure 3. Comparison of the percentage of total 0+ Chinook salmon catch by month in YR 2005 with the previous five year average, upper Redwood Creek, Humboldt County, CA. Age/species abbreviation is the same as in Figure 2.

The correlation of 0+ Chinook salmon catches with study years showed a non-significant negative relationship ($p = 0.56$, $r = 0.30$, power = 0.08).

0+ Steelhead Trout

The pattern in monthly catches (as a percentage of total catch) for 0+ steelhead trout in YR 2005 was markedly different than for the previous five year average (Figure 4). The majority of catches in YR 2005 occurred in July (60%), compared to May and June (74%) for the previous five year average. In YR 2005, relatively few fish were captured in May and June (26%). The percentage of 0+ steelhead trout captured in July 2005 was nearly 3 times greater than the percentage caught in July for the previous five year average.

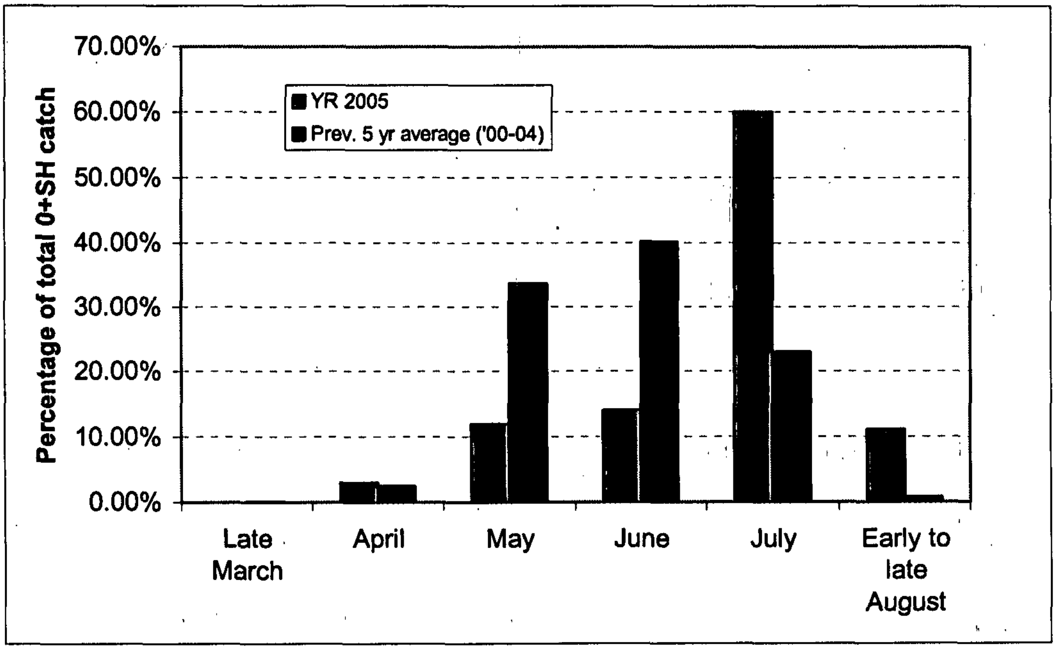

Figure 4. Comparison of the percentage of total 0+ steelhead trout catch by month in YR 2005 with the previous five year average, upper Redwood Creek, Humboldt County, CA. Age/species abbreviation is the same as in Figure 2.

The correlation of 0+ steelhead trout catches with study years showed a non-significant negative relationship ($p = 0.98$, $r = 0.20$, power = 0.05).

1+ Steelhead Trout

The majority of 1+ steelhead trout catches occurred in April and May for both YR 2005 and the previous five year average, and were equal in value (74%) on a percentage basis (Figure 5). In YR 2005, the greatest captures occurred in April, as compared to May for the previous five year average. In YR 2005, catches in May and June were reduced compared to the five year averaged values. On a percentage basis, few 1+ steelhead trout were captured in Late March and August.

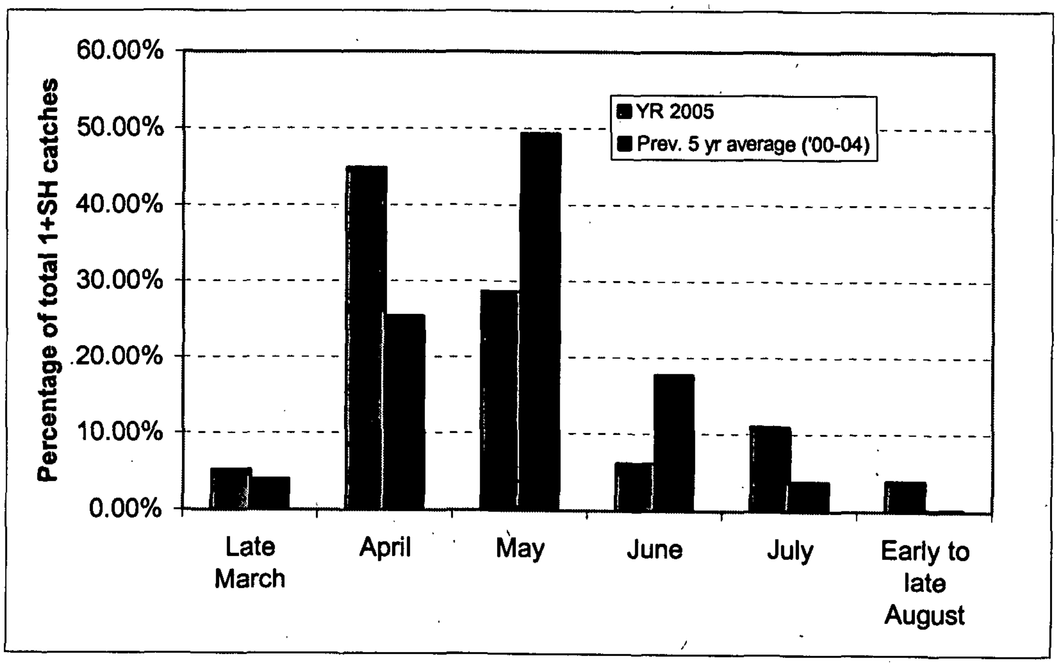

Figure 5. Comparison of the percentage of total 1+ steelhead trout catch by month in YR 2005 with the previous five year average, upper Redwood Creek, Humboldt County, CA. Age/species abbreviation is the same as in Figure 2.

The correlation of 1+ steelhead trout catches with study years showed a non-significant negative relationship ($p = 0.37$, $r = 0.45$, power = 0.12).

2+ Steelhead Trout

The majority of 2+ steelhead trout catches occurred in April and May for both YR 2005 (ie 70%) and the previous five year average (ie 69%) (Figure 6). Peak monthly catches in YR 2005 occurred in April and for the previous five year average occurred in May. More 2+ steelhead trout were captured in August, 2005 compared to the previous five year average for August.

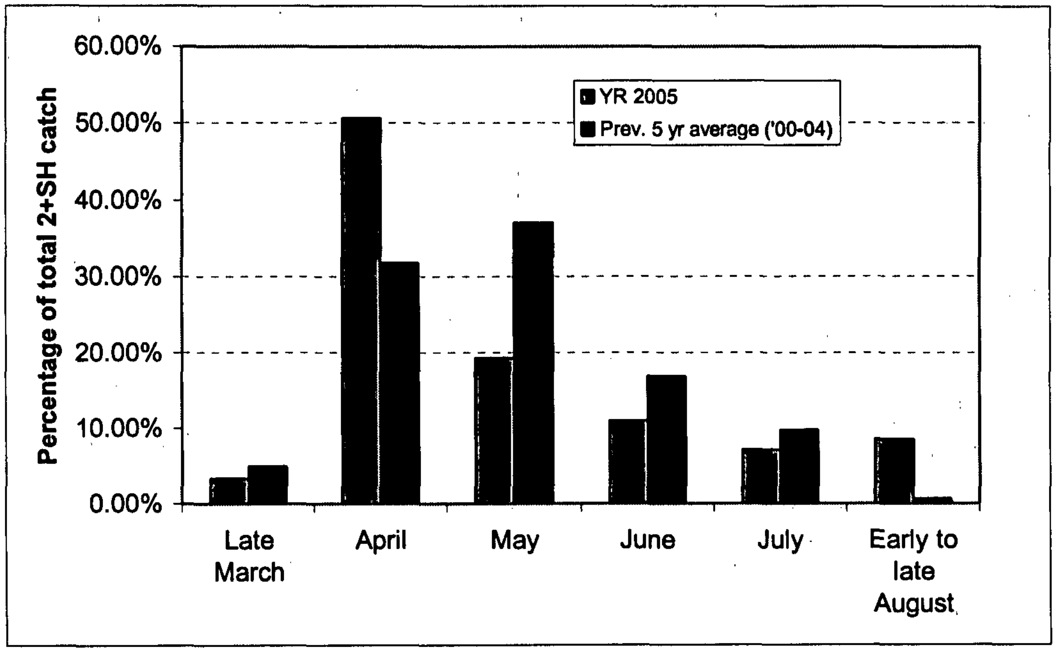

Figure 6. Comparison of the percentage of total 2+ steelhead trout catch by month in YR 2005 with the previous five year average, upper Redwood Creek, Humboldt County, CA. Age/species abbreviation is the same as in Figure 2.

The correlation of 2+ steelhead trout catches with study years showed a non-significant negative relationship ($p = 0.69$, $r = 0.21$, power = 0.06).

Linear Relations of Catch with Stream Gage Height, Stream Discharge, Stream Temperature, and Time (trapping day or trapping week number)

Linear regressions of average daily stream temperature (°C), average daily discharge (cfs), or daily gage height (feet) on daily catches of all salmonids combined, 0+ Chinook salmon, 0+ steelhead trout, 1+ steelhead trout, and 2+ steelhead trout (except for average stream temperature and week number) violated regression assumptions (even with log(x+1) transformations), and results were not valid. Average daily stream temperature on 2+ steelhead trout daily catches (log (x+1) transformation) passed regression assumption tests, and a significant (yet weak) negative relationship was detected ($p < 0.001$, $R^2 = 0.18$, negative slope, power = 1.0). Trapping day on 2+ steelhead trout catches also showed a significant negative relationship (Correlation, $p = 0.000001$, $r = 0.48$, negative slope, power = 1.0).

Although statistical tests were not warranted for most species at age, some generalizations can be made from the corresponding scatter plots (not given) of average stream temperature and stream gage height (which can also represent stream discharge, see Appendix 3) on daily catches. Slightly more 0+ Chinook salmon (56.6%) were captured during average daily (24 hr) stream temperatures of 7.1 – 14.3 °C compared to catches in stream temperatures ranging from 15.1 – 22.4 °C. The majority of 0+ steelhead trout catches (71.9%) occurred during average daily stream temperatures of 15.1 – 22.4 °C; and the majority of 1+ steelhead trout catches (84%) and 2+ steelhead trout catches (83%) occurred during average daily stream temperatures of 7.1 – 14.3 °C.

None of the peak catches of 0+ Chinook salmon occurred during peaks in the stream's gage height (although trap efficiencies for those weeks when storms occurred were sufficient). Most of the higher catches occurred during the descending limb of the hydrograph, however, on two occasions catches slightly increased during increases in gage height. 0+ steelhead trout followed a similar pattern to 0+ Chinook salmon; no peak catches occurred during peaks in the gage height, most catches occurred during the descending limb of the hydrograph, and on one occasion catches slightly increased during a small increase in gage height. 1+ steelhead trout catches decreased during peaks in the hydrograph (although trap efficiencies for those weeks when storms occurred were sufficient), and also on the descending limb of some of the peaks in the hydrograph; the peaks in 1+ steelhead catches occurred on the descending limb of other increases in gage height. Most of the 1+ steelhead trout were caught prior to June when storm events (and higher gage height readings) occurred compared to post June catches. 2+ steelhead trout followed a very similar pattern to 1+ steelhead trout.

The regressions of weekly gage height and average weekly discharge, and the correlation of trapping week number on catches of all salmonids by week or each species at age by week was not significant ($p > 0.05$, power = 0.05); however, a positive significant relationship was found for average weekly stream temperature on catches of all salmonids by week ($p < 0.05$) (Appendix 4). No significant relationships of independent variables with 0+ Chinook salmon catches were detected ($p > 0.05$). 0+ steelhead trout catches were negatively related to gage height and stream discharge, and positively related to stream temperature and week number ($p < 0.05$ for each test). 1+ steelhead trout and 2+ steelhead trout catches were each positively related to gage height and stream discharge, and negatively related to stream temperatures and week number ($p < 0.05$ for each test).

Trapping Efficiencies

0+ Chinook Salmon

We fin clipped and released 3,569 young-of-year Chinook salmon upstream of the trap site during 57 efficiency trials over the course of trapping in YR 2005. The average number used in our weekly trials (includes 2 - 5 efficiency trials) was 210, and ranged from 4 - 500 (per week).

Weekly trapping efficiencies in YR 2005 ranged from 6.2 - 75%, and averaged 32.8% (Table 6). Average weekly and seasonal (total number of recaptures/total number marked) trapping efficiencies in YR 2005 were less than efficiencies for the previous five year average (Table 6).

0+ Chinook salmon weekly trap efficiencies in YR 2005 significantly increased over time (Correlation, $p = 0.000001$, $r = 0.93$, positive slope, power = 1.0), and were negatively related to gage height (Regression, $p = 0.000004$, $R^2 = 0.77$, negative slope, power = 1.0) and stream discharge (Regression, $p = 0.0002$, $R^2 = 0.61$, negative slope, power = 0.99).

Table 6. 0+ Chinook salmon trapping efficiency in YR 2005 and the previous five year average, upper Redwood Creek, Humboldt County, CA.

	0+ Chinook salmon trap efficiency (percentage)		
	Weekly trapping efficiency		
Study Year	Range	Average	Seasonal
2005	6.2 - 75.0	32.8	33.0
2000-04	3.2 - 100.0	49.6	48.0

1+ Steelhead Trout

We fin clipped and released 1,940 1+ steelhead trout upstream of the trap site during 80 efficiency trials over the course of trapping in YR 2005. The average number used in our weekly trials (includes 2 - 5 efficiency trials) was 88, and ranged from 11 - 243 (per week).

Weekly trapping efficiencies in YR 2005 ranged from 9.2 – 36.4%, and averaged 23.4% (Table 7). Average weekly and seasonal (total number of recaptures/total number marked) trapping efficiencies in YR 2005 were less than efficiencies for the previous five year average (Table 7).

1+ steelhead trout weekly trap efficiencies in YR 2005 significantly increased over time (Correlation, $p = 0.0005$, $r = 0.66$, positive slope, power = 0.97), and were negatively related to gage height (Regression, $p = 0.004$, $R^2 = 0.35$, negative slope, power = 0.88) and stream discharge (Regression, $p = 0.006$, $R^2 = 0.32$, negative slope, power = 0.83).

1+ steelhead trout weekly trap efficiencies were not significantly different than 2+ steelhead trout weekly efficiencies (Kruskal-Wallis One-Way ANOVA on Ranks, $p = 0.65$).

Table 7. 1+ steelhead trout trapping efficiency in YR 2005 and the previous five year average, upper Redwood Creek, Humboldt County, CA.

	1+ Steelhead trout trap efficiency (percentage)		
	Weekly trapping efficiency		
Study Year	Range	Average	Seasonal
2005	9.2 - 36.4	23.4	21.1
2000-04	0.0 - 57.0	28.6	30.1

2+ Steelhead Trout

We fin clipped and released 371 2+ steelhead trout upstream of the trap site during 53 efficiency trials over the course of trapping in YR 2005. The average number used in our weekly trials (includes 2 - 5 efficiency trials) was 17, and ranged from 2 - 47 (per week).

Weekly trapping efficiencies in YR 2005 ranged from 0.0 – 50.0%, and averaged 26.2% (Table 8). Average weekly and seasonal (total number of recaptures/total number marked) trapping efficiencies in YR 2005 were greater than efficiencies for the previous five year average (Table 8).

2+ steelhead trout weekly trap efficiencies in YR 2005 significantly increased over time (Correlation, $p = 0.0007$, $r = 0.57$, positive slope, power = 0.82) and were negatively related to gage height (Regression, $p = 0.005$, $R^2 = 0.34$, negative slope, power = 0.85) and stream discharge (Regression, $p = 0.006$, $R^2 = 0.34$, negative slope, power = 0.84).

All of the fin clipped 2+ steelhead trout released upstream of the trap site were recovered in the 'correct' strata when recaptured.

Table 8. 2+ steelhead trout trapping efficiency in YR 2005 and the previous five year average, upper Redwood Creek, Humboldt County, CA.

	2+ Steelhead trout trap efficiency (percentage)		
	Weekly trapping efficiency		
Study Year	Range	Average	Seasonal
2005	0.0 - 50.0	26.2	23.5
2000-04	0.0 - 48.8	16.7	18.9

Population Estimates

0+ Chinook Salmon

The population estimate (or production) of 0+ Chinook salmon emigrating from upper Redwood Creek in YR 2005 equaled 39,614 with a 95% CI of 34,961 - 44,268. Population estimate error (or uncertainty) equaled ± 11.7%. Population emigration in YR 2005 was markedly lower than emigration in YR 2004 (N = 629,847) by 94% and the previous five year average ($N_{av5yr} = 390{,}926$) by 90%.

Correlation of time (study year) on yearly population estimates showed a non-significant negative relationship ($p = 0.49$, $r = 0.35$, power = 0.09) (Figure 7).

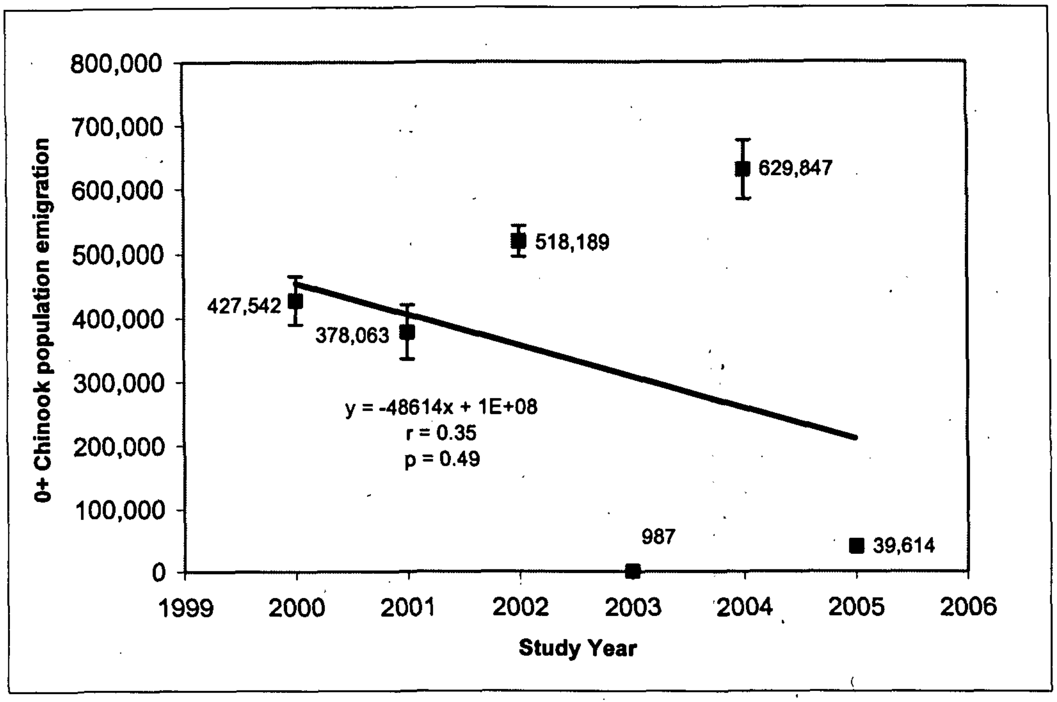

Figure 7. 0+ Chinook salmon population estimates (error bars are 95% confidence interval) in six consecutive years. Lack of 95% CI for YRS 2003 and 2005 is due to scale of Y axis. Numeric values next to box represent number of individuals. Line of best fit is a regression line, with corresponding equation, correlation value (r), and p value.

Linear regression detected a significant negative relationship with bedload mobilizing flows during egg incubation (and embryogenesis) in spawning redds and the subsequent 0+ Chinook salmon population estimate for the six study years ($p = 0.005$, $R^2 = 0.89$, slope is negative, and power = 0.98). The variation in peak stream flow (in this case, bedload mobilizing flow and non-bedload mobilizing flow) during the redd incubation period explained 89% of the variation in seasonal 0+ Chinook salmon population estimates (production).

The number of 0+ Chinook salmon (at population level) per mile, kilometer, and watershed acres upstream of the trap site in YR 2005 was about 90% less than values for the previous five year average (Table 9).

Table 9. Estimated number of 0+ Chinook salmon per stream mile, stream kilometer, and watershed acreage upstream of the trap site, YRS 2000-2005.

Study Year	0+KS/mi	0+KS/km	0+KS/acre
2000	11,555	7,186	6.58
2001	10,218	6,354	5.82
2002	14,005	8,709	7.97
2003	27	17	0.01
2004	17,023	10,586	9.69
Average:	10,566	6,570	6.01
2005	1,071	666	0.61

0+ Chinook salmon population emigration by month in YR 2005 was severely reduced compared to emigration by month for the previous five year average (Figure 8).

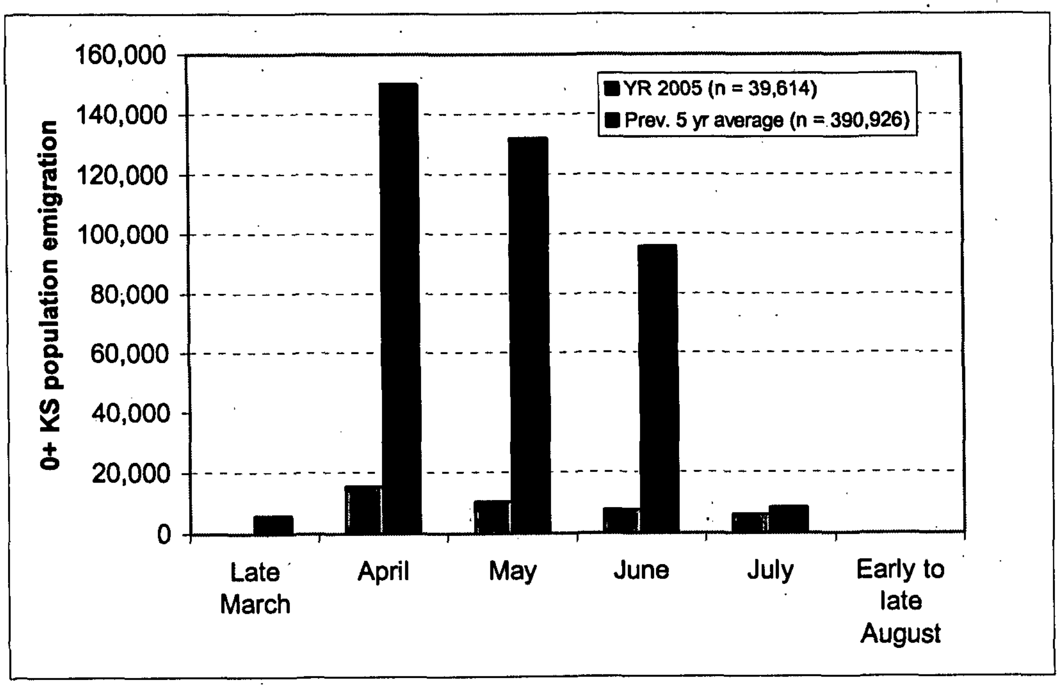

Figure 8. Comparison of 0+ Chinook salmon population emigration by month in YR 2005 with the previous five year average, upper Redwood Creek, Humboldt County, CA. Age/species abbreviation is the same as in Figure 2.

The majority of 0+ Chinook salmon population emigration occurred in April and May for both YR 2005 (66%) and the previous five year average (72%) (Figure 9). Emigration during April – June accounted for 85% of the population in YR 2005, and 96% for the previous five year average. Emigration in July 2005 was nearly seven times greater than emigration in July for the previous five year average.

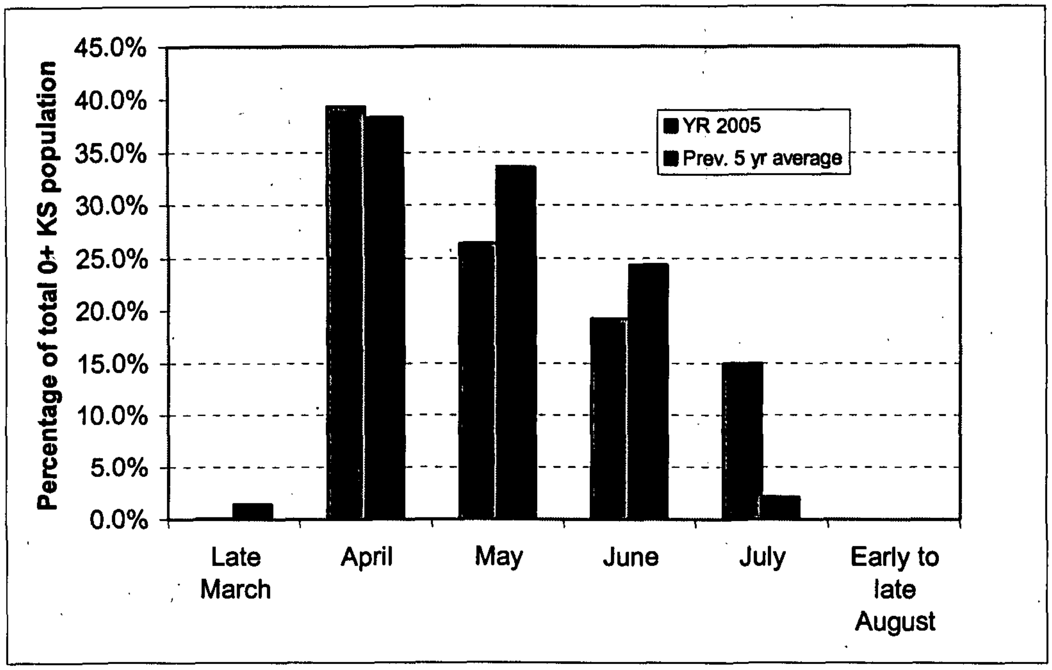

Figure 9. Comparison of the percentage of total 0+ Chinook salmon population emigration by month in YR 2005 with the previous five year average, upper Redwood Creek, Humboldt County, CA. Age/species abbreviation is the same as in Figure 2.

The peak in population emigration in YR 2005 occurred 4/23 - 4/29 (Table 10). Peak emigration occurred in late May/early June for YR 2000, May for YR 2001, June for YRS 2002 and 2003, and April for YR 2004 (Table 10).

Table 10. Date of peak weekly 0+ Chinook salmon population emigration by study year (number of individuals in parentheses).

Study Year	Date of peak in weekly out-migration (number in parentheses)
2000	5/28 - 6/03 (56,457)
2001	5/07 - 5/13 (79,848)
2002	6/04 - 6/10 (63,093)
2003	6/11 - 6/17 (316)
2004	4/09 - 4/15 (165,782)
2005	4/23 - 4/29 (9,059)

The number and percentage of 0+ Chinook salmon migrants grouped into fry or fingerling categories varied among study years (Table 11). In YR 2005, 58% of the migrants were estimated as fry, and 42% were estimated as fingerlings. The previous five year average (N_{av5yr} = 390,926) consisted of 53% fry and 47% fingerlings. A statistically higher proportion of fry and a lesser proportion of fingerlings were present in YR 2005 compared to the previous five year average (Chi-square, $p = 0.000001$). The percentage of fry over study years was not influenced by emigrant population size, size of emigrants (FL, Wt), stream temperature, or stream discharge (Regression, $p > 0.10$ for all tests).

Table 11. Comparison of the production of 0+ Chinook salmon partitioned into fry and fingerling categories for each study year (percentage of total for each year in parentheses), upper Redwood Creek, Humboldt County, CA.

	0+ Chinook salmon production as:	
Study Year	Fry (FL < 45mm)	Fingerling (FL > 44 mm)
2000	139,316 (33)	288,226 (67)
2001	226,351 (60)	151,712 (40)
2002	245,024 (47)	273,165 (53)
2003	8 (1)	979 (99)
2004	434,400 (69)	195,447 (31)
5 yr ave.	209,020 (53)	181,906 (47)
YR 2005	22,957 (58)	16,657 (42)

0+ Chinook salmon fry and fingerling migrants showed differences in abundance and migration timing in YR 2005 compared to the previous five year average (Figure 10). For the previous five year average, fry migration generally occurred near the onset of trapping (except in YR 2001, juvenile Chinook salmon did not emigrate until 4/16), peaked in mid April, and gradually diminished to low values by early June; fingerling migration began in mid to late April, reached peaks in late May - June 10, and gradually decreased to low values by late July (Figure 10). In YR 2005, fry migration was low in the beginning of trapping (first three weeks), reached a peak value during late April through May 6th, and quickly decreased to low values by May 20th; fingerling migration began in early April in very low numbers (n = 3), reached a smaller peak May 28 - June 3 and a larger peak late June/early July; and descended to low values near the end of July (Figure 10).

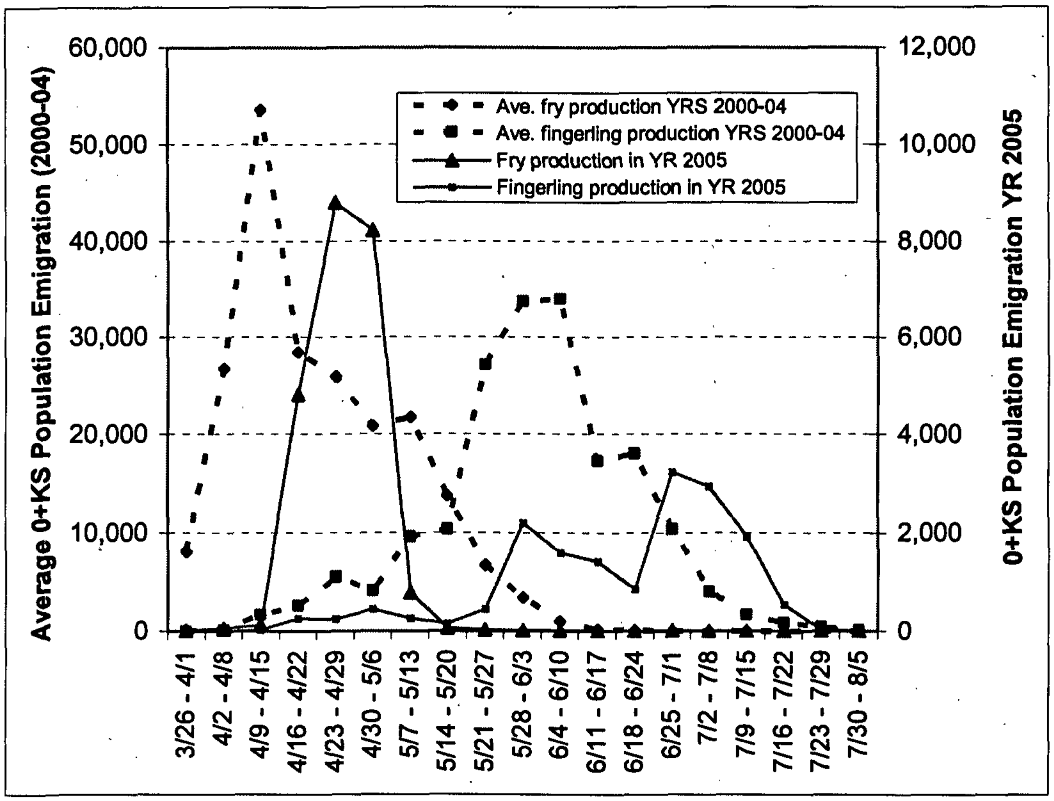

Figure 10. Comparison of estimated 0+ Chinook salmon fry and fingerling abundance and migration timing in YR 2005 (uses second "Y" axis) with previous five year average, upper Redwood Creek, Humboldt County, CA. Age/species abbreviation is the same as in Figure 2.

1+ Steelhead Trout

The population estimate (or production) of 1+ steelhead trout emigrating from upper Redwood Creek in YR 2005 equaled 26,176 with a 95% CI of 22,726 – 29,625. Population estimate error (or uncertainty) equaled ± 13.2%. Population emigration in YR 2005 was lower than emigration in YR 2004 (N = 41,434) by 37% and the previous five year average (N_{av5yr} = 43,762) by 40%.

Correlation of time (study year) on yearly population estimates showed a significant negative relationship (p = 0.07, r = 0.77, power = 0.46) (Figure 11).

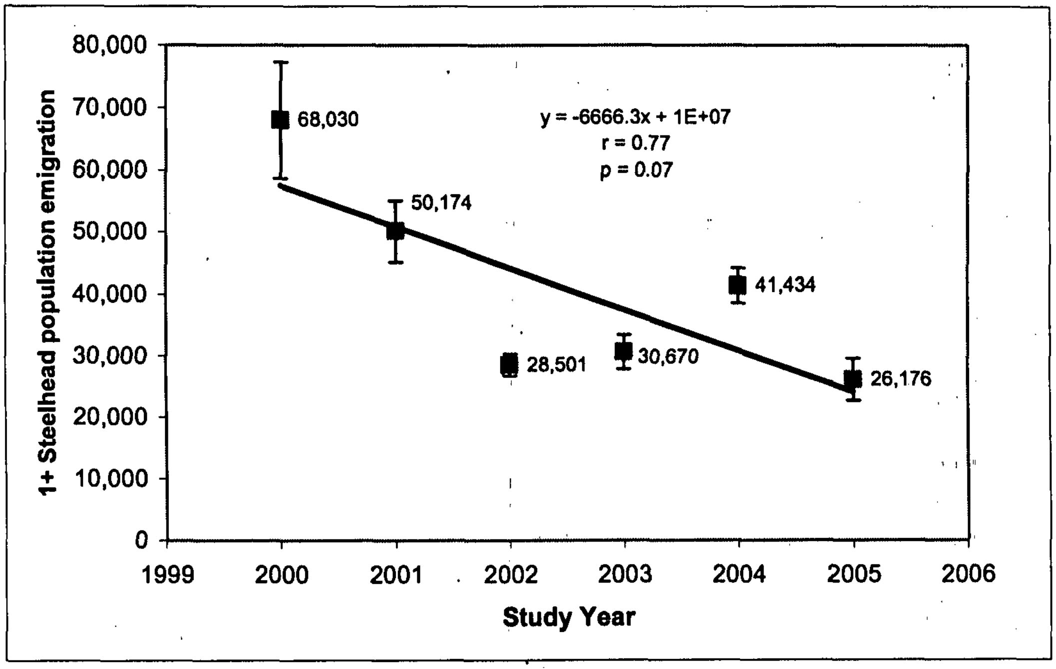

Figure 11. 1+ steelhead trout population estimates (error bars are 95% confidence interval) in six consecutive years. Numeric values next to box represent number of individuals. Line of best fit is a regression line, with corresponding equation, correlation value (r), and p value.

The number of 1+ steelhead trout (at population level) per mile, kilometer, and watershed acreage upstream of the trap site in YR 2005 was about 40% less than values for the previous five year average (Table 12). Highest values occurred in YR 2000 and lowest values occurred in YR 2005.

Table 12. Estimated number of 1+ steelhead trout per stream mile, stream kilometer, and watershed acreage upstream of the trap site, YRS 2000-05.

Study Year	1+SH/mi	1+SH/km	1+SH/acre
2000	1,839	1,143	1.05
2001	1,356	843	0.77
2002	770	479	0.44
2003	829	515	0.47
2004	1,120	696	0.64
Average:	1,183	735	0.67
2005	707	440	0.40

1+ steelhead trout monthly population emigration peaked in April (N = 15,285 or 58% of total) in YR 2005 and May (N_{av} = 20,092 or 46% of total) for the previous five year average (Figure 12). In YR 2005 20,592 individuals (or 79% of total) emigrated in April and May, compared to 40,613 (or 92% of total) migrants that emigrated in April - June for the previous five year average. Emigration in May 2005 (N = 5,307) was about four times less than the previous five year average for May (N_{av} = 20,092; and emigration in June 2005 (N = 1,384) was about eight times less than the previous five year average for June (N_{av} = 10,793). Emigration in August 2005 (N = 721) was about 12 times higher than the five year average for August (N_{av} = 60).

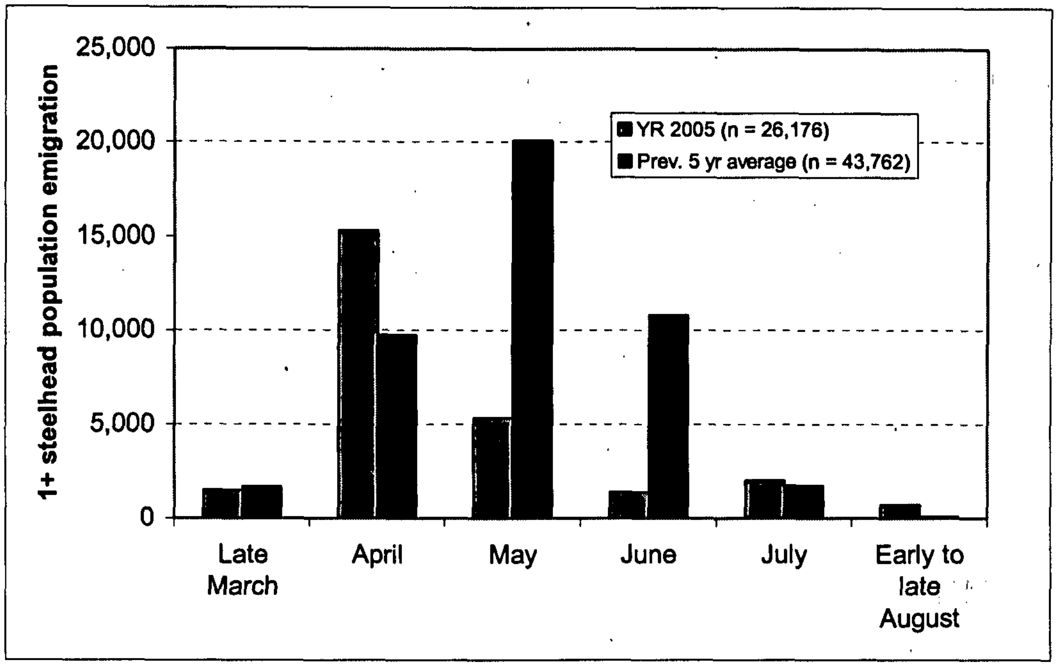

Figure 12. Comparison of 1+ steelhead trout population emigration by month in YR 2005 with the previous five year average, upper Redwood Creek, Humboldt County, CA.

The peak in 1+ steelhead trout weekly emigration in YR 2005 occurred at the same time as in YR 2001, and earlier than other study years (Table 13). Peaks occurred in April (YRS 2001 and 2005) and May (YRS 2000, 2002 - 2004).

Table 13. Date of peak weekly 1+ steelhead trout population emigration by study year (number of individuals in parentheses).

Study Year	Date of peak in weekly out-migration (number in parentheses)
2000	5/07 - 5/13 (16,244)
2001	4/23 - 4/29 (6,963)
2002	5/14 - 5/20 (4,180)
2003	5/14 - 5/20 (4,483)
2004	5/14 - 5/20 (6,659)
2005	4/23 - 4/29 (4,834)

2+ Steelhead Trout

Two weeks (or strata) had zero recaptures (primarily due to low sample sizes for marked fish) and the seasonal trap efficiency was inserted into those weeks.

The population estimate (or production) of 2+ steelhead trout emigrating from upper Redwood Creek in YR 2005 equaled 2,364 with a 95% CI of 1,933 - 2,796. Population estimate error (or uncertainty) equaled $\pm$ 18.2%. Population emigration in YR 2005 was lower than emigration in YR 2004 (N = 5,778) by 59% and the previous five year average (N_{av5yr} = 6,667) by 64%.

Correlation of time (study year) on yearly population estimates showed a non-significant negative relationship ($p = 0.28$, $r = 0.52$, power = 0.16) (Figure 13).

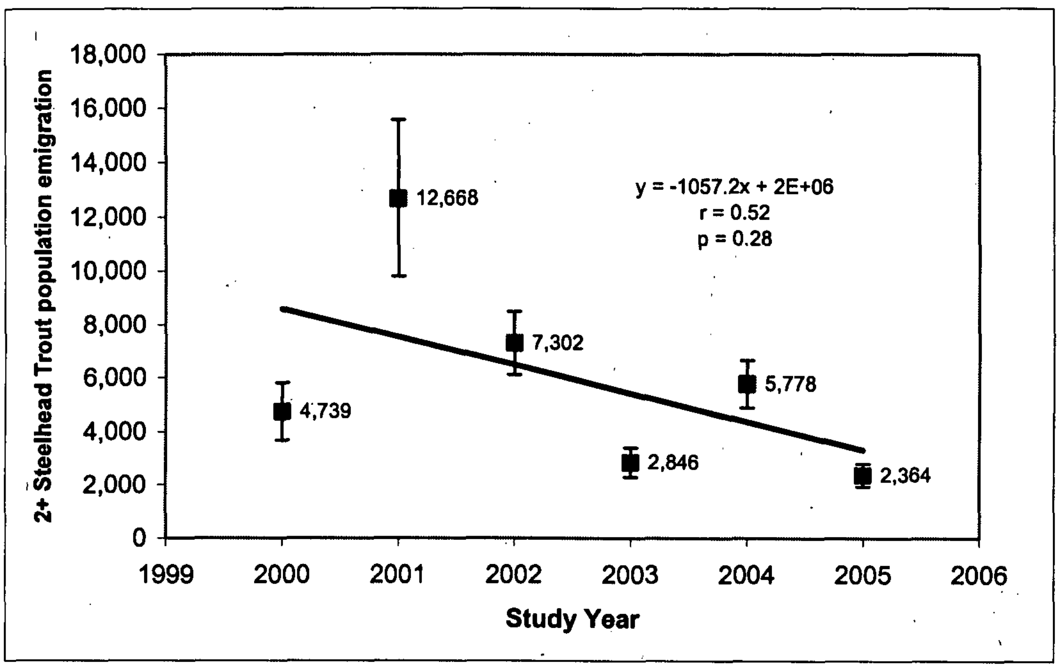

Figure 13. 2+ steelhead trout population emigration (error bars are 95% confidence interval) in six consecutive years. Numeric values next to box represent number of individuals. Line of best fit is a regression line with corresponding equation, correlation value (r), and p value.

The number of 2+ steelhead trout (at population level) per mile, kilometer, and watershed acreage upstream of the trap site in YR 2005 was 60 - 64% less than values for the previous five year average (Table 14). Highest values occurred in YR 2001 and lowest values occurred in YR 2005.

Table 14. Estimated number of 2+ steelhead trout per stream mile, stream kilometer, and watershed acreage upstream of the trap site, YRS 2000-2005.

Study Year	2+SH/mi	2+SH/km	2+SH/acre
2000	128	80	0.07
2001	342	213	0.19
2002	197	123	0.11
2003	77	48	0.04
2004	156	97	0.09
Average:	180	112	0.10
2005	64	40	0.04

2+ steelhead trout monthly population emigration in YR 2005 was less than each month of the previous five year average except for August (Figure 14). The highest emigration in YR 2005 occurred in April (55.2% of total) compared to May (34% of total) for the previously averaged data. The percentage emigrating April - June in YR 2005 (84%) was similar to the previous five year average for those months (88%).

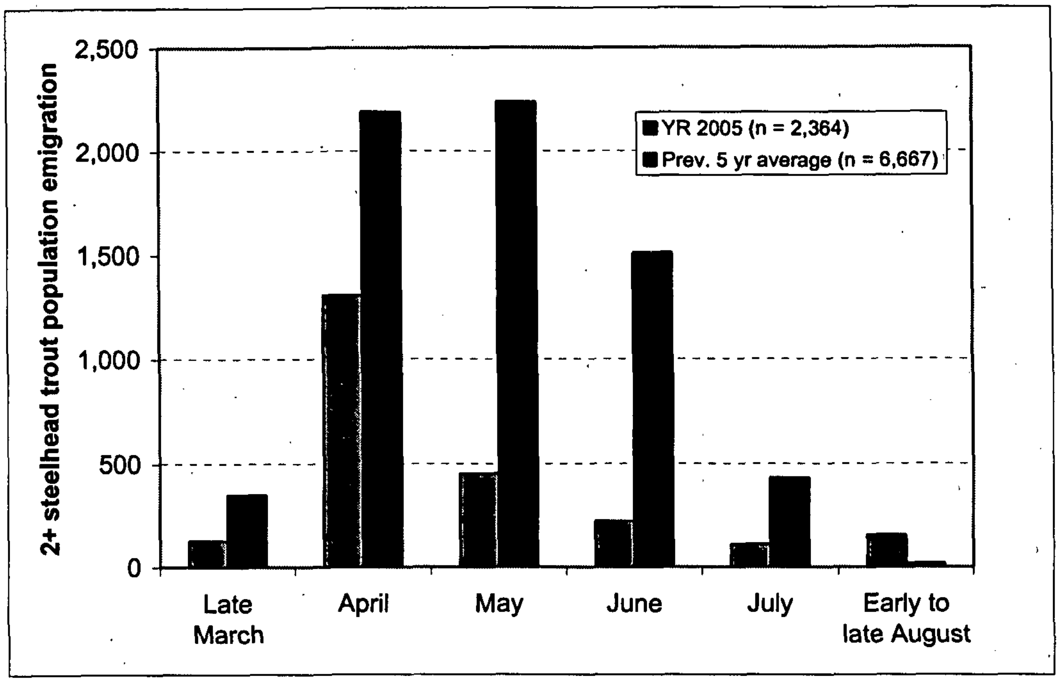

Figure 14. Comparison of 2+ steelhead trout population emigration by month in YR 2005 with the previous five year average, upper Redwood Creek, Humboldt County, CA.

Peaks in 2+ steelhead trout emigration occurred during April (YRS 2000, 2002 and 2005) or May (YRS 2001, 2003, and 2004) (Table 15).

Table 15. Date of peak weekly 2+ steelhead trout population emigration by study year (number of individuals in parentheses).

Study Year	Date of peak in weekly out-migration (number in parentheses)
2000	4/09 - 4/15 (1,094)
2001	5/28 - 6/03 (1,463)
2002	4/23 - 4/29 (1,061)
2003	5/14 - 5/20 (363)
2004	5/14 - 5/20 (645)
2005	4/16 - 4/22 (380)

Linear Relations of weekly population emigration for 0+ Chinook salmon, 1+ steelhead trout, and 2+ steelhead trout with Stream Gage Height, Stream Discharge, Stream Temperature, and Time (trapping week number)

0+ Chinook salmon weekly population emigration was positively related to the stream gage height and stream discharge ($p < 0.05$ for each test), and negatively related to stream temperature and week number ($p < 0.05$ for each test) (Appendix 5). Models with gage height or stream discharge each explained 30% of the variation in population emigration over time (Appendix 5).

1+ steelhead trout weekly population emigration was positively related to the stream gage height and stream discharge ($p < 0.05$ for both tests), and negatively related to stream temperature and week number ($p < 0.05$ for both tests) (Appendix 5). Models with gage height or stream discharge explained 37 and 32%, respectfully, of the variation in population emigration (Appendix 5). Stream temperature explained slightly more of the variation ($R^2 = 0.39$). The correlation of week number with emigration ($r = 0.72$, or $r^2 = 0.52$) determined that 52% of the variation in emigration can be associated with trapping week number.

2+ steelhead trout weekly population emigration was also positively related to the stream gage height and stream discharge ($p < 0.05$ for both tests), and negatively related to stream temperature and week number ($p < 0.05$ for both tests) (Appendix 5). Models with gage height or stream discharge explained 32 and 36%, respectfully, of the variation in population emigration (Appendix 5). Stream temperature explained slightly more of the variation ($R^2 = 0.44$; or 44%). The correlation of week number with emigration ($r = 0.73$, or $r^2 = 0.53$) determined that 53% of the variation (in emigration) can be associated with week number.

Age Composition of Juvenile Steelhead Trout

The following percentages represent maximum values for 1+ and 2+ steelhead trout because their population estimates were compared to catches of 0+ steelhead trout (ie the actual catches of 0+ steelhead trout are less than expected 0+ steelhead trout population out-migration). Far more 0+ steelhead trout migrated downstream than either 1+ or 2+ steelhead trout on a percentage basis (Table 16). In YR 2005, the ratio of 0+ steelhead trout to 1+ steelhead trout to 2+ steelhead trout equaled 18:11:1 compared to the previous five year average ratio of 15:7:1. The ratio of 1+ steelhead trout to 2+ steelhead trout was 11:1 in YR 2005, and 7:1 for the previous five year average.

Table 16. Comparison of 0+ steelhead trout, 1+ steelhead trout, and 2+ steelhead trout percent composition of total juvenile steelhead trout downstream migration in YR 2005 and the previous five year average, upper Redwood Creek, Humboldt County, CA.

	Percent composition of total juvenile steelhead trout out-migration		
Study Year	0+ steelhead*	1+ steelhead	2+ steelhead
2005	59.3	37.3	3.4
Prev. 5 yr ave.	67.0	28.6	4.4
All years combined	66.4	29.3	4.3

* Uses actual catches instead of population estimate.

Fork Lengths and Weights

0+ Chinook Salmon

We measured (FL mm) 2,489 and weighed (g) 1,751 0+ Chinook salmon in YR 2005 (Table 17). Excluding YR 2003, average FL and Wt in YR 2005 was greater than the average for each previous study year, and the average of previous four study years (excludes YR 2003).

Average FL and Wt did not significantly change over study years 2000 - 2002, 2004 and 2005 (Correlation: FL, $p = 0.56$, $r = 0.36$, slope is positive, power = 0.08; Wt, $p = 0.37$, $r = 0.52$, power = 0.12). Linear regression detected a significant negative relationship of population estimate on average FL ($p = 0.03$, $R^2 = 0.83$, power = 0.72) and average Wt ($p = 0.02$, $R^2 = 0.88$, power = 0.86), which suggests a density-dependent relationship.

Table 17. 0+ Chinook salmon population estimates, and average fork length (mm) and weight (g) for study YRS 2000 - 2005, upper Redwood Creek, Humblodt County, CA.

	0+ Chinook Salmon						
		Fork Length (mm)			Weight (g)		
Study Year	(N)*	n	Ave.	SEM	n	Ave.	SEM
2000	427,542	3,661	55.5	0.2	913	2.03	0.04
2001	378,063	2,719	51.9	0.2	778	1.73	0.04
2002	518,189	3,517	52.4	0.2	1,545	1.70	0.03
2003	987	573	67.3	0.3	499	3.43	0.05
2004	629,847	3,571	50.8	0.2	1,593	1.61	0.03
4 yr ave.**			52.7			1.77	
2005	39,614	2,489	60.4	0.3	1,751	3.09	0.05

* "N" denotes emigrant population size; "n" denotes sample size for FL and Wt.
** Average for FL and Wt does not include YR 2003.

Average weekly FL (mm) significantly increased over time (weeks) in YR 2005 and for the four year average (Correlation, $p = 0.000001$, $r = 0.99$, power = 1.0 for each test) (Figure 15). The increases in average FL over time show growth was taking place, and from 4/09/05 – 7/29/05 0+ Chinook salmon grew 0.41 mm/d.

Kruskal-Wallis One-Way ANOVA on Ranks showed that the median weekly FL in YR 2005 (60.2 mm) was not significantly different than the median weekly FL of the four year average (52.6 mm) ($p = 0.35$).

Average weekly Wt (g) significantly increased over time (weeks) in YR 2005 and for the four year average (Correlation, $p = 0.000001$, $r = 0.97$ and 0.98, power = 1.0) (Figure 16). The increases in average Wt over time show growth was taking place, and from 4/09/05 – 7/29/05 0+ Chinook salmon grew 0.05 g/d.

The average weekly Wt (g) (2.70 g) in YR 2005 was not significantly different than the average weekly Wt (1.77 g) for the previous four year average (excludes YR 2003) (ANOVA, $p > 0.05$, power = 0.40).

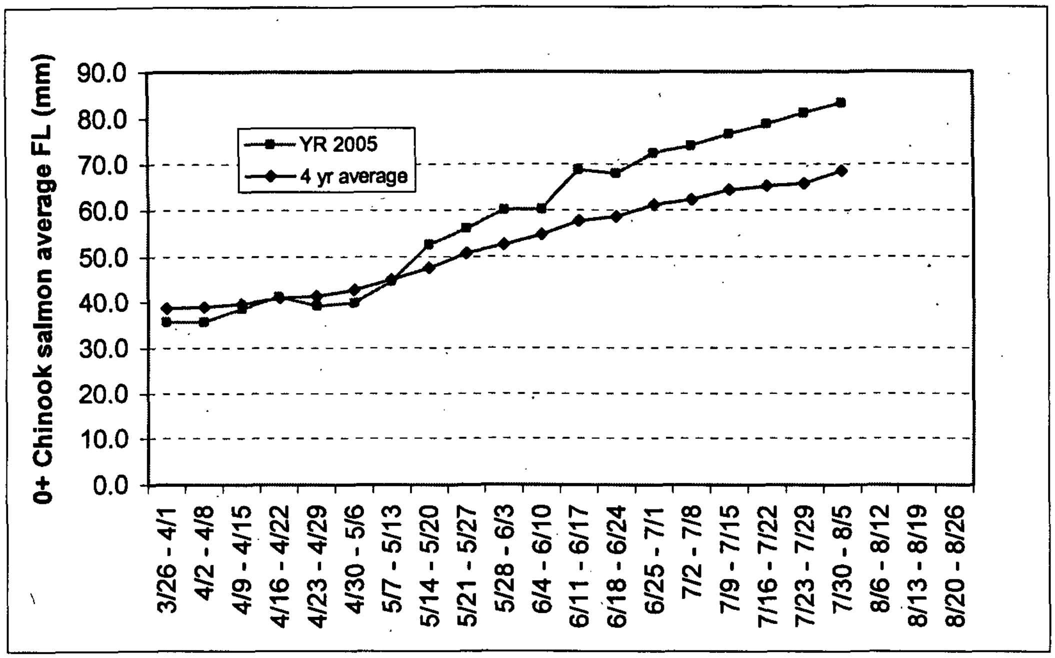

Figure 15. 0+ Chinook salmon average weekly fork lengths (mm) in YR 2005 and the average of four years, upper Redwood Creek, Humboldt County, CA.

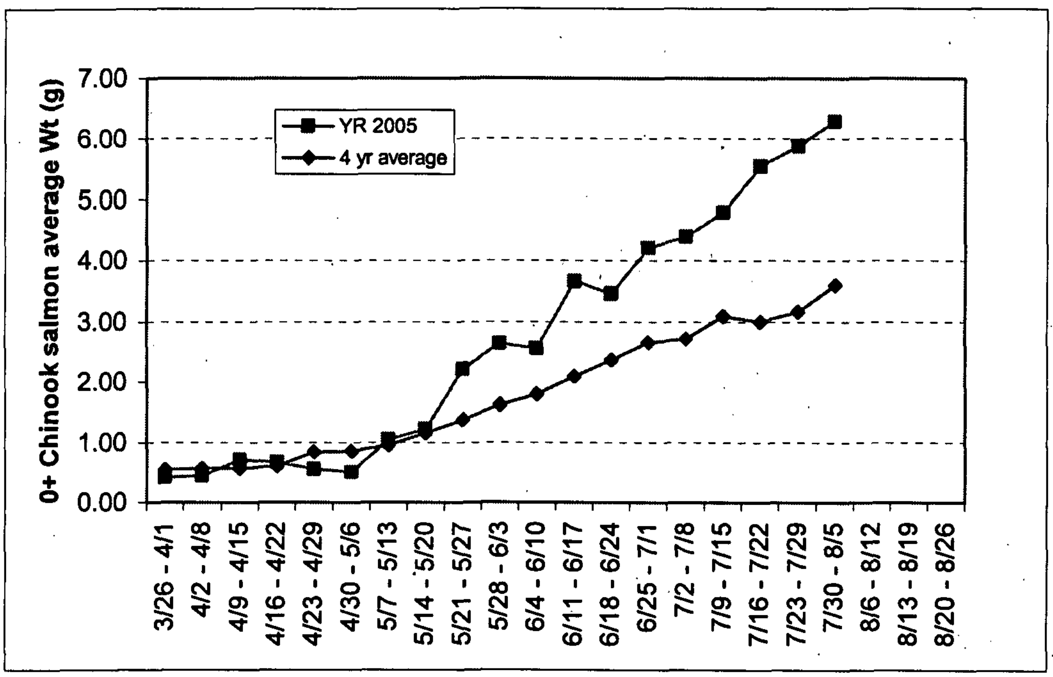

Figure 16. 0+ Chinook salmon average weekly weights (g) in YR 2005 and the average of four years, upper Redwood Creek, Humboldt County, CA.

0+ Steelhead Trout

We measured (FL mm) 3,661 0+ steelhead trout in YR 2005 (Table 18). Average FL in YR 2005 was greater than previous study years (Table 18).

Table 18. 0+ steelhead trout total catch and average fork length (mm) for study years 2000 - 2005, upper Redwood Creek, Humboldt County, CA.

	0+ Steelhead Trout						
		Fork Length (mm)			Weight (g)		
Study Year	(Catch)	n	Ave.	SEM	n	Ave.	SEM
2000	55,126	2,669	40.9	0.2	-	-	-
2001	102,408	1,136	39.0	0.3	-	-	-
2002	124,426	3,228	38.7	0.2	-	-	-
2003	102,954	3,338	38.5	0.2	-	-	-
2004	128,885	3,615	37.5	0.2	-	-	-
5 yr ave.			38.9			-	
2005	41,671	3,661	42.3	0.2			

Average FL did not significantly change over the six study years (Correlation, $p = 0.90$, $r = 0.07$, slope is positive, power = 0.05). Linear regression detected a significant negative relationship of seasonal catch on average FL by season ($p = 0.002$, $R^2 = 0.93$, power = 1.0), which suggests a density-dependent relationship.

Average weekly FL (mm) significantly increased over time (weeks) in YR 2005 (Correlation, $p = 0.000001$, $r = 0.92$, power = 1.0) and for the previous five year average (Correlation, $p = 0.000001$, $r = 0.98$, power = 1.0) (Figure 17). The increases in average weekly FL over time show growth was taking place.

Kruskal-Wallis One-Way ANOVA on Ranks showed that the median weekly FL in YR 2005 (32.2 mm) was not significantly different than the median weekly FL of the five year average (35.4 mm) ($p = 0.53$).

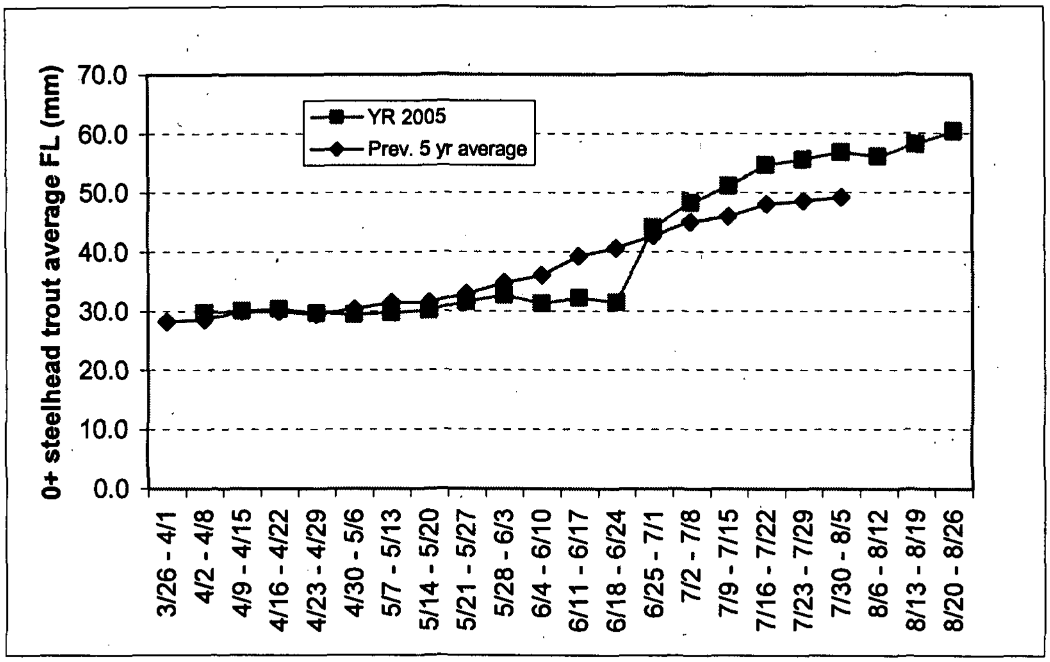

Figure 17. 0+ steelhead trout average weekly fork lengths (mm) in YR 2005 and the previous five year average, upper Redwood Creek, Humboldt County, CA.

<u>1+ Steelhead Trout</u>

We measured (FL mm) 2,473 and weighed (g) 1,592 1+ steelhead trout in YR 2005 (Table 19). Average FL and Wt in YR 2005 was nearly equal to the average of the previous five study years (Table 19).

Average FL and Wt did not significantly change over study years 2000 - 2005 (Correlation: FL, p = 0.12, r = 0.70, slope is negative, power = 0.33; Wt, p = 0.29, r = 0.52, slope is negative, power = 0.16). Linear regression detected a significant positive relationship of population estimate on average FL (p = 0.07, R^2 = 0.61, power = 0.48), and a non-significant positive relationship for average Wt (p = 0.29, R^2 = 0.27, power = 0.16).

Table 19. 1+ steelhead trout population estimates, and average fork length (mm) and weight (g) for study years 2000 - 2005, upper Redwood Creek, Humboldt County, CA.

		1+ Steelhead Trout					
		Fork Length (mm)			Weight (g)		
Study Year	(N)*	n	Ave.	SEM	n	Ave.	SEM
2000	68,030	2,721	92.4	0.2	1,455	8.29	0.09
2001	50,174	2,761	91.9	0.3	908	9.27	0.11
2002	28,501	3,049	86.7	0.3	1,356	7.79	0.14
2003	30,670	3,064	84.8	0.3	1,633	7.14	0.09
2004	41,434	3,191	85.7	0.3	1,441	7.57	0.10
5 yr ave.			88.3			8.01	
2005	26,176	2,473	88.1	0.2	1,592	8.02	0.09

* "N" denotes emigrant population size; "n" denotes sample size for FL and Wt.

1+ steelhead trout average weekly FL (mm) did not significantly change over time (weeks) in YR 2005 (Correlation, p = 0.13, r = 0.33, slope is positive, power = 0.33). The average FL (mm) by week for the previous five year average positively changed over time (Correlation, p = 0.008, r = 0.59, slope is positive, power = 0.80) (Figure 18).

As expected, single factor ANOVA showed that the average weekly FL in YR 2005 (88.6 mm) was not significantly different than the average weekly FL for the previous five year average (88.4 mm) (p = 0.92).

1+ steelhead trout average weekly Wt (g) significantly decreased over time (weeks) in YR 2005 (Correlation, p = 0.04, r = 0.44, slope is negative, power = 0.56) and for the five year average, average Wt (g) significantly increased over time (Correlation, p = 0.001, r = 0.68, slope is positive, power = 0.95) (Figure 19).

Similar to FL comparisons, single factor ANOVA showed that the average weekly Wt in YR 2005 (8.24 g) was not significantly different than the average weekly Wt for the previous five year average (8.38 g) (p = 0.75, power = 0.06).

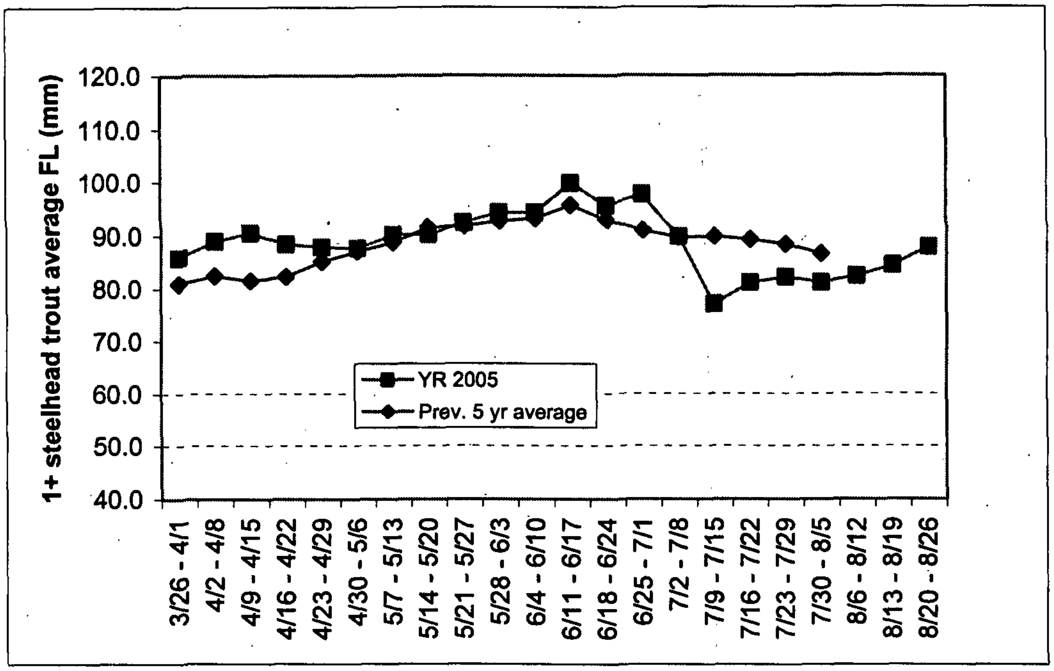

Figure 18. 1+ steelhead trout average weekly fork lengths (mm) in YR 2005 and the previous five year average, upper Redwood Creek, Humboldt County, CA.

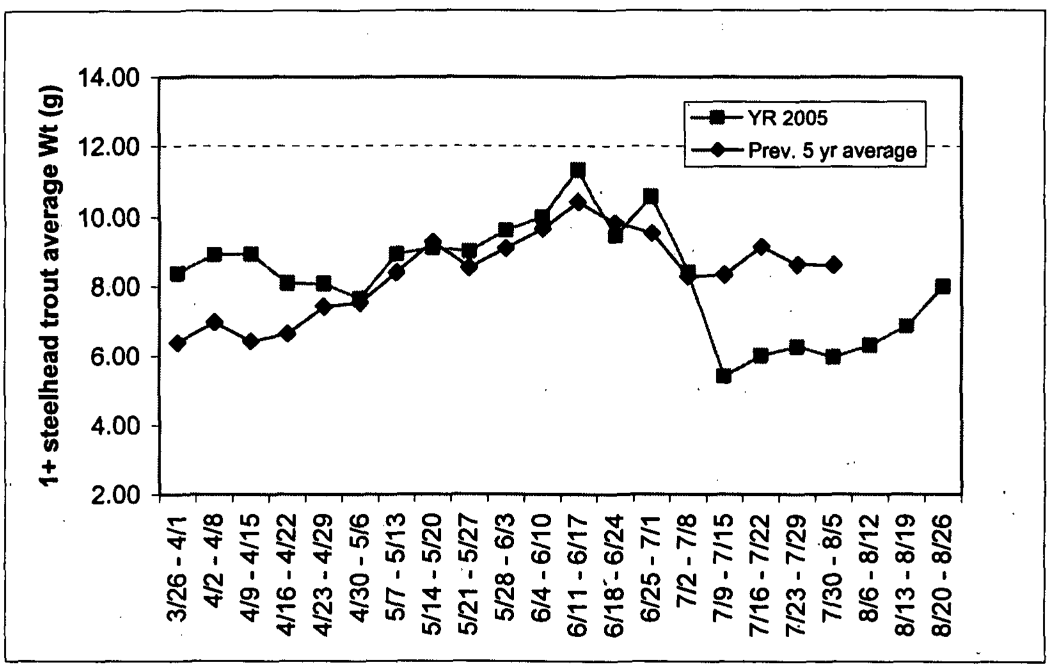

Figure 19. 1+ steelhead trout average weekly weights (g) in YR 2005 and the previous five year average, upper Redwood Creek, Humboldt County, CA.

2+ Steelhead Trout

We measured (FL mm) 594 and weighed (g) 592 2+ steelhead trout in YR 2005 (Table 20). Average FL and Wt in YR 2005 was nearly equal to the previous five year average (Table 20). Average FL and Wt over study years 2000 - 2005 did not significantly change (Correlation: FL, $p = 0.15$, slope is negative, $r = 0.67$, power = 0.28; Wt, $p = 0.18$, $r = 0.63$, power = 0.24). Linear regression detected a non-significant relationship of population estimate on average FL ($p = 0.95$, $R^2 = 0.00$, slope is positive, power = 0.05) and average Wt ($p = 0.95$, $R^2 = 0.00$, slope is negative, power = 0.05).

Table 20. 2+ steelhead trout population estimates, and average fork length (mm) and weight (g) for study years 2000 - 2005, upper Redwood Creek, Humboldt County, CA.

	2+ Steelhead Trout						
		Fork Length (mm)			Weight (g)		
Study Year	(N)*	n	Ave.	SEM	n	Ave.	SEM
2000	4,739	710	164.4	0.6	480	49.12	0.61
2001	12,668	1,316	151.2	0.5	1,225	39.17	0.43
2002	7,302	1,528	147.5	0.6	1,463	37.87	0.51
2003	2,846	625	144.0	0.9	583	35.15	0.71
2004	5,778	1,277	144.1	0.7	1,244	35.44	0.47
5 yr ave.			150.2			39.35	
2005	2,364	594	150.5	0.2	592	39.90	0.91

* "N" denotes emigrant population size; "n" denotes sample size for FL and Wt.

2+ steelhead trout average weekly FL (mm) did not significantly change over time (weeks) in YR 2005 (Correlation, $p = 0.07$, $r = 0.39$, slope is positive, power = 0.43). Average FL (mm) by week for the previous five year average significantly decreased over time (Correlation, $p = 0.04$, $r = 0.49$, slope is negative, power = 0.59) (Figure 20). Median weekly FL in YR 2005 (142.4 mm) was not significantly different than the median weekly FL for the previous five year average (150.0 mm) (Kruskal-Wallis One-Way ANOVA on Ranks, $p = 0.07$).

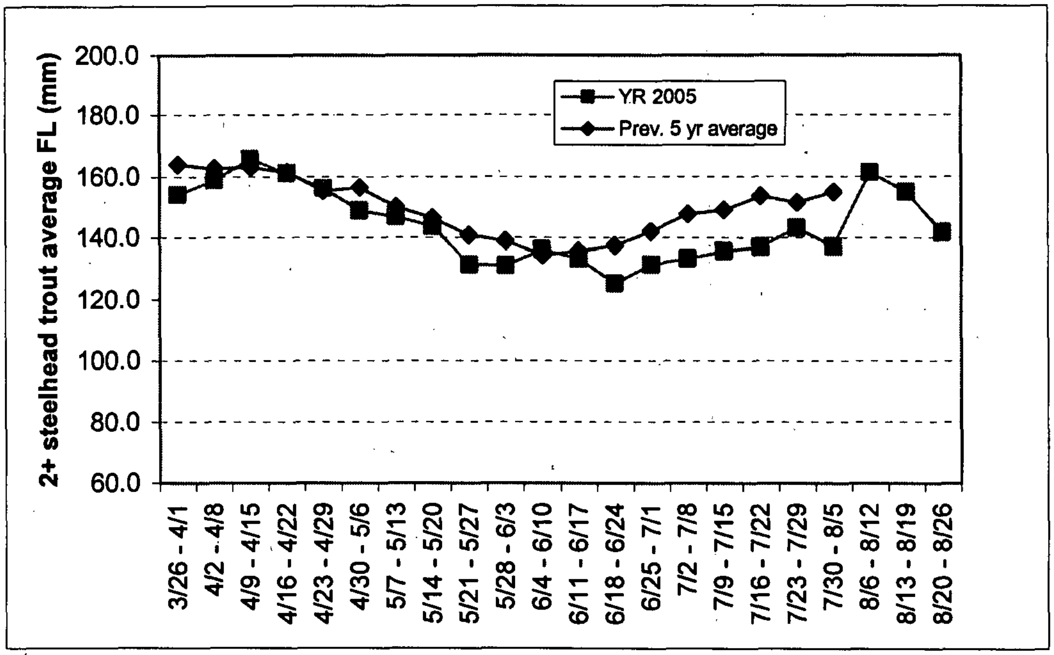

Figure 20. 2+ steelhead trout average weekly fork lengths (mm) in YR 2005 and the previous five year average, upper Redwood Creek, Humboldt County, CA.

2+ steelhead trout average weekly Wt (g) did not significantly change over time (weeks) in YR 2005 (Correlation, $p = 0.09$, $r = 0.37$, slope is negative, power = 0.39); and for the previous five year average, average Wt (g) significantly decreased over time (Correlation, $p = 0.03$, $r = 0.50$, slope is negative, power = 0.61) (Figure 21).

Single factor ANOVA determined that the average weekly Wt in YR 2005 (35.25 g) was not significantly different than the average weekly Wt for the previous five year average (38.97 g) ($p = 0.15$, power = 0.30).

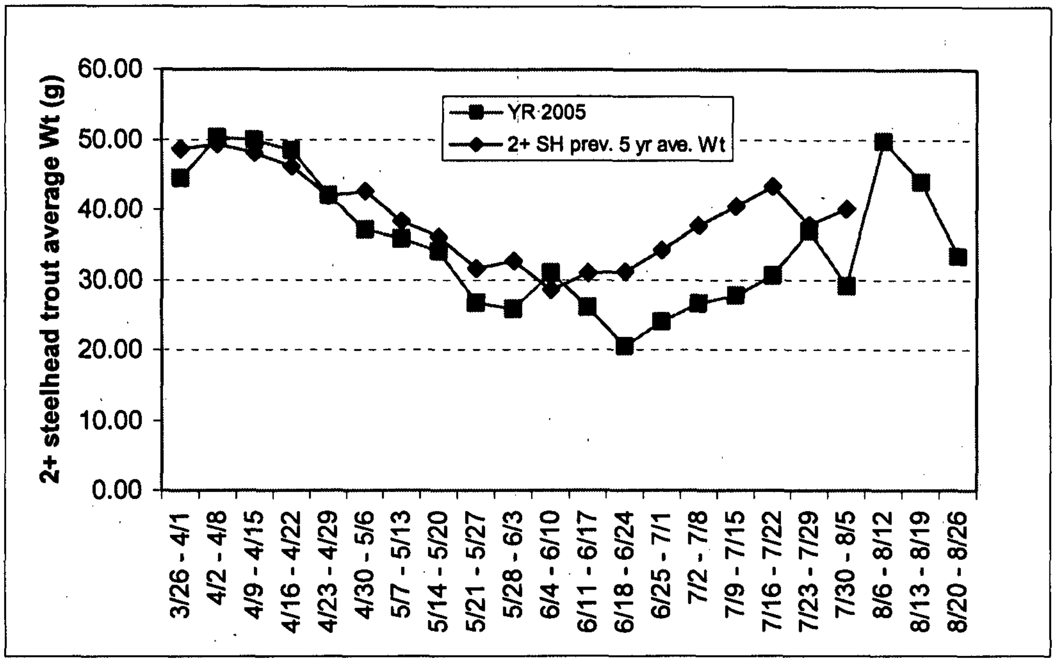

Figure 21. 2+ steelhead trout average weekly weights (g) in YR 2005 and the previous five year average, upper Redwood Creek, Humboldt County, CA.

Developmental Stages

1+ and 2+ Steelhead Trout

There was an obvious non-random distribution of parr, pre-smolt, and smolt designations (developmental stages) for 1+ and 2+ steelhead trout captured in YR 2005 and for the previous five year average (Table 21). Contingency tests (2x2) showed that there were significant differences in the proportions of pre-smolt and smolt designations for 1+ steelhead trout and 2+ steelhead trout in YR 2005 with the previous five year average (Chi-square, $p < 0.000001$; power = 1.00 for each test). For both tests (1+SH and 2+SH) there were comparatively more smolt designations in YR 2005. Using data by year (not given), the percentage of 1+ steelhead trout smolts in a given study year was not related to population size or size of fish (FL, Wt) (Regression, $p > 0.10$); however, smolt percentages were positively related to stream discharge (Regression, $p = 0.06$, $R^2 = 0.63$, power = 0.50, n = 6) and negatively related to stream temperature (Regression, $p = 0.03$, $R^2 = 0.82$, power = 0.70, n = 6). For 2+ steelhead trout, the percentage of smolts in a given year was inversely related to population size (Regression, $p = 0.07$, $R^2 = 0.59$, power = 0.45, n = 6), and inversely related to stream temperature (Regression, $p = 0.09$, $R^2 = 0.65$, power = 0.37, n = 6). No relationships were found with average fish size or average stream discharge ($p > 0.10$). The combined percentage of pre-smolts and smolts for 1+ steelhead trout and 2+ steelhead trout in YR 2005 and for the previous five year average was nearly 100% (Table 21).

Table 21. Developmental stages of captured 1+ and 2+ steelhead trout in YR 2005 and the previous five year average, upper Redwood Creek, Humboldt County, CA.

	Developmental Stage (as percentage of total catch)					
	1+ Steelhead Trout			2+ Steelhead Trout		
Year	Parr	Pre-smolt	Smolt	Parr	Pre-smolt	Smolt
2005	< 0.1	13.6	86.4	0.0	0.6	99.4
5 yr ave.*	4.4	70.2	25.4	0.1	28.6	71.3

* Study years 2000 – 2004.

Additional Experiments

Re-migration

We did not recapture any of the 1+ and 2+ steelhead trout marked with elastomer (n = 800) in YR 2004 in YR 2005. To date (including elastomer marked releases in YR 2001, n = 374), we have found no evidence of 1+ and 2+ steelhead trout re-migrating upstream of the trap site to be caught moving downstream the following year.

Travel Time and Growth

0+ Chinook Salmon

We recaptured 27 pit tagged 0+ Chinook salmon smolts released from the upper trap site at the lower trap (Sparkman 2006). Initial fork lengths of recaptured fish ranged from 70 - 90 mm and averaged 80 mm (Appendix 6). Time to travel the 29 miles between traps ranged from 1.5 - 19.5 d and averaged 7.5 d (median = 5.5 d). Travel time was not significantly related to FL or Wt at time 1 or time 2, stream temperature, or stream discharge (Regression, $p > 0.05$ for all tests, n = 27).

Travel rate ranged from 1.5 - 19.3 mi/d (2.4 – 31.1 km/d) and averaged 8.2 mi/d (13.2 km/d) (median = 5.3 mi/d or 8.5 km/d). Travel rate was weakly related to FL at time 1 (Regression, $p = 0.01$, $R^2 = 0.24$, slope is positive, power = 0.76, n = 27) and Wt at time 1 (Regression, $p = 0.006$, $R^2 = 0.27$, slope is positive, power = 0.83); no significant relationships were found with stream temperature, stream discharge or fish size at time 2 (Regression, $p > 0.05$ for each test).

Multiple fish released from the same release group were recaptured at the lower trap on the same day (n = 5 recaptures). In contrast, most fish that were released at the same time (as a group) were recaptured on varying dates, and travel time for recaptured individuals (n = 5) for the 7/21/05 release group ranged from 4.5 - 19.5 days (Appendix 6). The size of recaptured pit tagged 0+ Chinook salmon at time 2 (recapture day) was positively related to initial size at release (Regression, FL: p = 0.000001, R^2 = 0.67, power = 1.0; Wt: p = 0.00001, R^2 = 0.62, power = 1.0).

Fourteen (52%) of the 27 recaptured 0+ Chinook salmon showed positive growth in FL and Wt, five (18%) showed a decrease in Wt, and none of the recaptures showed a decrease in FL. Thirteen individuals (48%) showed no change in FL and eight individuals did not experience a change in Wt (30%) (Appendix 7). On average, the 0+ Chinook salmon experienced a positive percent change in size of 3.6% for FL and 9.6% for Wt (Appendix 8). The 0+ Chinook salmon showed, on average, positive growth in FL for absolute growth rate (Ave. = 0.22 mm/d), relative growth rate (Ave. = 0.003 mm/mm/d), and specific growth rate scaled [Ave. = 0.279 %(mm/d)] (Appendix 8). The 0+ Chinook salmon averaged an absolute growth rate in Wt of 0.00 g/d, a relative growth rate of 0.001 g/g/d and a specific growth rate scaled of 0.003 %(g/d) (Appendix 8).

The relationship of travel time on various FL and Wt growth indices was significant and positive (Appendix 9). Travel time explained more of the variation in growth than any other variable tested (Appendix 9 and Figure 22).

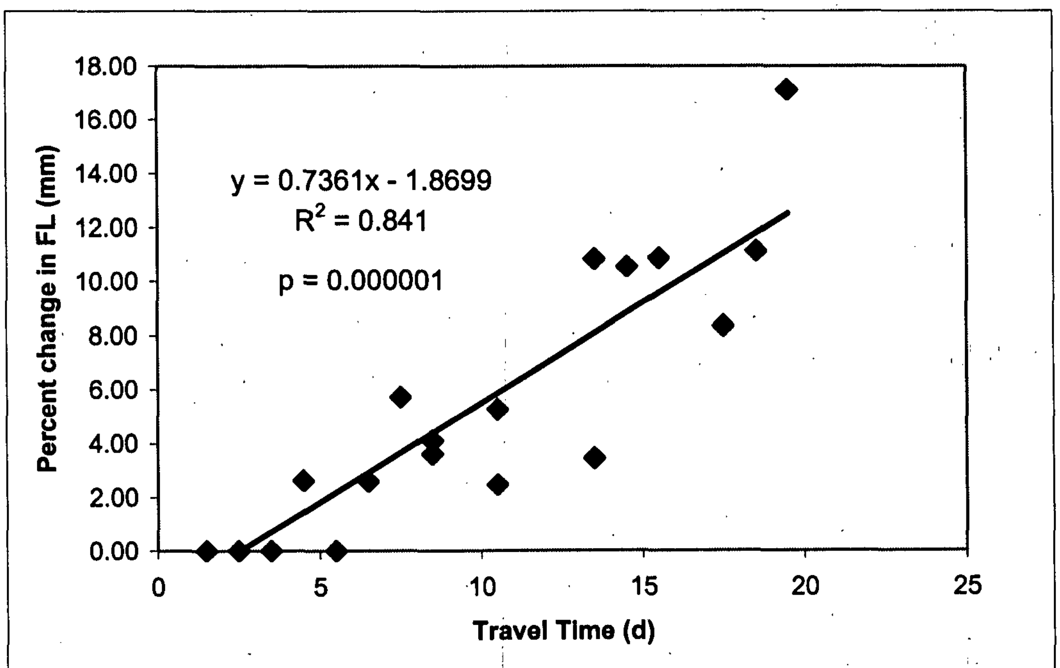

Figure 22. Linear regression of travel time (d) on percent change in FL (mm) for pit tagged 0+ Chinook salmon recaptured at the lower trap in Redwood Creek, Humboldt County, CA. 2005. Although 27 data points were used in the regression, only 18 are visible due to symbol overlap.

Separate growth statistics were determined for recaptured pit tagged 0+ Chinook salmon individuals showing either positive (n = 14) or negative growth (n = 5) (Table 22). On average, the pit tagged Chinook salmon absolute growth rate equaled 0.428 mm per day for FL, and 0.094 g per day for Wt (Table 22).

Table 22. Growth statistics for recaptured pit tagged 0+ Chinook salmon that showed positive (n = 14) or negative (n = 5) growth, Redwood Creek, Humboldt County, CA., 2005.

	Positive Growth							
	% Change in:		AGR*		SGRsc*		RGR*	
	FL	WT	FL	WT	FL	WT	FL	WT
Min.	2.47	4.20	0.190	0.020	0.232	0.312	0.002	0.003
Max.	17.11	46.04	0.670	0.270	0.810	3.177	0.009	0.033
Ave.	**7.04**	**20.75**	**0.428**	**0.094**	**0.538**	**1.546**	**0.006**	**0.017**
SD	4.46	16.03	0.142	0.063	0.182	0.744	0.002	0.009
	Negative Growth							
	% Change in:		AGR		SGRsc		RGR	
	FL	WT	FL	WT	FL	WT	FL	WT
Min.	-	-5.09	-	-0.190	-	-3.481	-	-0.034
Max.	-	-7.66	-	-0.390	-	-5.315	-	-0.051
Ave.	**-**	**-6.26**	**-**	**-0.286**	**-**	**-4.312**	**-**	**-0.042**
SD	-	0.95	-	0.076	-	0.677	-	0.006

* AGR = absolute growth rate (FL mm/d; Wt g/d), SGR = specific growth rate scaled [FL %(mm/d); Wt %(g/d)], RGR = relative growth rate (FL mm/mm/d; Wt g/g/d).

1+ and 2+ Steelhead Trout

We recaptured one 2+ steelhead trout marked with elastomer and a partial upper caudal fin clip, and three 1+ steelhead trout marked with elastomer in YR 2005 at the lower trap in YR 2005 (Table 23) (Sparkman 2006). The 2+ steelhead trout was not a re-migrating fish (1+SH) from YR 2004 because the partial fin clip was fresh, and showed no signs of regeneration. We also captured two pit tagged 1+ steelhead trout at the lower trap which were released at the upper trap (Table 23). Travel time for the single 2+ steelhead trout was 7 d, as compared to the average travel time for 1+ steelhead trout of 12 d (n = 5, SD = 13.3). The range in travel time for 1+ steelhead trout was 2 - 35 d, and the range in travel rate was 0.8 - 14.5 miles per day (Table 23).

One of the recaptured pit tagged steelhead trout showed growth during the 29 mile migration (initial size = 71 mm). This fish experienced a percent change in FL and Wt of 7.0 and 39.7%, an absolute growth rate of 0.43 mm/d and 0.11 g/d, a specific growth rate (scaled) of 0.257 %(mm/d) and 1.262 %(g/d), and a relative growth rate of 0.006 mm/mm/d and 0.035 g/g/d.

Table 23. Travel time (d) and travel rate (mi/d) results for 2+ steelhead trout and 1+ steelhead trout released at the upper trap site and recaptured at the lower trap (distance of 29 miles) in Redwood Creek, Humboldt County, CA., 2005.

Travel Time Experiments						
Age/species	Initial FL mm	Mark or Tag type	Date Released*	Date Recaptured**	Travel time (d)	Travel rate (mi/d)
2+ SH	-	Elastomer	5/28/05	6/04/05	7.0	4.1
	-					
1+ SH	-	Elastomer	4/28/05	4/30/05	2.0	14.5
1+ SH	-	Elastomer	4/28/05	6/02/05	35.0	0.8
1+ SH	-	Elastomer	5/05/05	5/15/05	10.0	2.9
1+ SH	89	Pit Tag	6/02/05	6/06/05	3.5	8.3
1+ SH	71	Pit Tag	7/14/05	7/26/05	11.5	2.5

* Released at upper trap (RM 33). Elastomer fish were released in the morning, pit tag fish were released at night.

** Recapture at lower trap (RM 4).

Delayed Mortality

0+ Chinook Salmon

A total of 28 delayed mortality experiments were conducted with 0+ Chinook salmon (n = 633) in YR 2005 (Appendix 10). The single fish that died during a partial fin clipping test occurred during a storm event and subsequent increase in stream discharge. A total of 555 0+ Chinook salmon were given pit tags (along with FL and Wt measurements, and a small partial upper caudal fin clip) and held for a 34 hour period prior to release. None of the pit tag fish died during the experiments.

1+ Steelhead Trout

A total of 31 delayed mortality experiments were conducted with 1+ steelhead trout (n = 379) in YR 2005 (Appendix 11). Aside from two immediate mortalities from injecting elastomer, no delayed mortalities attributable to fin clipping, pit tagging, or applying elastomer occurred over a 24 or 34 hour period (Appendix 11).

2+ Steelhead Trout

A total of 41 delayed mortality experiments were conducted with 2+ steelhead trout (n = 120) in YR 2005 (Appendix 12). No mortalities attributable to fin clipping, pit tagging, or applying elastomer occurred over a 24 or 34 hour period.

Trapping Mortality

The mortality of fish that were captured in the traps and subsequently handled was closely monitored over the course of the trapping period. The trap mortality (which includes handling mortality) for a given age/species in YR 2005 ranged from 0.00 - 0.75%, and using all data, was 0.65% of the total captured and handled (Table 24). This level of trap mortality is very low, and considered negligible.

Juvenile salmonid trapping mortality in YR 2005 (0.65%) fell within the range for study years 2000 - 2004, and was slightly higher than the average for the previous five years by 0.20% (Table 25).

Table 24. Trapping mortality for juvenile salmonids captured in YR 2005, upper Redwood Creek, Humboldt County, CA.

	Trap Mortality in YR 2005		
Age/spp.	No. captured	No. of mortalities	Percent mortality
0+ Chinook	9,329	52	0.56
0+ Steelhead	41,671	312	0.75
1+ Steelhead	4,912	5	0.10
2+ Steelhead	628	1	0.16
Cutthroat trout	2	0	0.00
Overall:	56,542	368	0.65

Table 25. Comparison of trapping mortality of juvenile salmonids in six consecutive study years, upper Redwood Creek, Humboldt County, CA.

	Trap Mortality		
Study Year	No. captured	No. of mortalities	Percent mortality
2000	191,761	934	0.49
2001	239,262	1,631	0.68
2002	361,433	1,480	0.41
2003	111,514	362	0.32
2004	352,860	1,192	0.34
2005	56,544	368	0.65
Average (2000-04)			0.45

Stream Temperatures

The average daily (24 hr period) stream temperature from 3/26/05 – 8/26/05 was 14.56 °C (or 58.2 °F) (95% CI = 13.80 – 15.32 °C), with daily averages ranging from 7.10 – 22.40 °C (44.8 – 72.3 °F). In 2005, the average daily stream temperature exceeded 20 °C (68 F) for 40 d (26%) out of 154 d of record. The average daily stream temperature in YR 2005 from 3/26/05 – 8/05/05 (truncated to compare with other study years) was 13.54 °C (56.4 °F) (Table 26). Average stream temperature during the trapping period in YR 2005 was lower than other study years (Table 26).

The average stream temperature during the majority of the trapping period for YRS 2001 – 2005 was inversely related to the average discharge during the trapping period (Regression, $p = 0.03$, $R^2 = 0.82$, slope is negative, power = 0.71).

Average monthly stream temperatures during the majority of the trapping season (April – July) in YR 2005 ranged from 9.2 – 19.4 °C (48.6 – 66.9 °F) (Table 27). Highest stream temperatures occurred in the later part of the trapping season (June, July, early August) each study year. No significant difference in average monthly steam temperature (°C) among study years was detected (ANOVA, $p = 0.93$, power = 0.08).

Table 26. Stream temperatures (°C) (standard deviation in parentheses) during the trapping period in YR 2005 and previous four years, upper Redwood Creek, Humboldt County, CA.

	Stream Temperature					
	Celsius			Fahrenheit		
Study Year	Ave.	Min.	Max.	Ave.	Min.	Max.
2001	16.3 (4.4)	5.7	28.2	61.3 (7.9)	42.3	82.8
2002	15.8 (4.4)	6.7	27.5	60.4 (8.0)	44.1	81.5
2003	14.7 (5.3)	6.1	28.4	58.4 (9.5)	43.0	83.1
2004	15.8 (4.6)	6.7	28.8	60.5 (8.2)	44.1	83.8
4 Yr. Ave*	15.6 (4.7)	5.7	28.8	60.1 (8.5)	42.3	83.8
2005**	13.5 (4.3)	6.2	25.8	56.4 (7.8)	43.2	78.4

* YR 2000 excluded due to incomplete coverage during trapping period.
** Data truncated for comparison.

Table 27. Average stream temperature (°C) by month (°F in parentheses) in study years 2001 - 2005, upper Redwood Creek, Humboldt County, CA.

	Average stream temperature in Celsius (°F in parentheses)				
Month	YR 2001	YR 2002	YR 2003	YR 2004	YR 2005
April	9.4 (48.9)	10.7 (51.3)	8.5 (47.3)	10.6 (51.1)	9.2 (48.6)
May	15.1 (59.2)	13.1 (55.6)	11.2 (52.2)	13.8 (56.8)	11.6 (52.9)
June	17.5 (63.5)	18.0 (64.4)	17.2 (63.0)	17.7 (63.9)	13.4 (56.1)
July	20.9 (69.6)	21.3 (70.3)	21.1 (70.0)	21.6 (70.9)	19.4 (66.9)

The MWAT during the trapping period in YR 2005 at the trap site was 21.9 °C (71.4 °F) and occurred on 8/05/05 (Table 28). MWMT in YR 2005 was 25.7 °C (78.3 °F) and also occurred on 8/05/05 (Table 28).

Table 28. Maximum weekly average temperature (MWAT) and maximum weekly maximum temperature (MWMT) for stream temperatures °C (°F in parentheses) at the trap site in upper Redwood Creek, Humboldt County, CA., study years 2001 – 2005.

	MWAT**		MWMT***	
Study Year	Date of occurrence	°C (°F)	Date of occurrence	°C (°F)
2000	-	-	-	-
2001	7/25/01	21.8 (71.2)	7/25/01	27.9 (82.2)
2002	7/29/02	21.9 (71.4)	7/27/02	26.4 (79.5)
2003	7/29/03	23.1 (73.6)	7/29/03	27.4 (81.3)
2004	7/25/04	23.3 (73.9)	7/25/04	28.2 (82.8)
2005*	8/05/05	21.9 (71.4)	8/05/05	25.7 (78.3)

* Data truncated to 8/05/05 for comparison with other years.
** MWAT is the maximum value of a 7-day moving average of daily average stream temperatures.
*** MWMT is the maximum value of a 7-day moving average of daily maximum stream temperatures.

The average stream temperature increased over the study period in YR 2005 (Correlation, $p = 0.000001$, $r = 0.95$, slope is positive, power = 1.0) (Figure 23).

Similar to past study years, average daily stream temperature in YR 2005 was significantly related to the stream gage height at the trapping site (Regression, $p = 0.000001$, $R^2 = 0.83$, slope is negative, power = 1.0).

The minimum stream temperature in YR 2005 (not truncated) was 6.25 °C (43.2 °F) and occurred on 4/14/05; the maximum stream temperature was 26.3 °C (79.3 °F) and occurred on 8/07/05 (Figure 23).

The previous four year average stream temperature also increased over time (Correlation, $p = 0.00001$, $r = 0.98$, slope is positive, power = 1.0) (Figure 24). Median daily stream temperature in YR 2005 (13.3 °C) was not significantly different than the median (16.0 °C) for the previous four year average (Kruskall-Wallis One Way ANOVA on Ranks, $p = 0.15$).

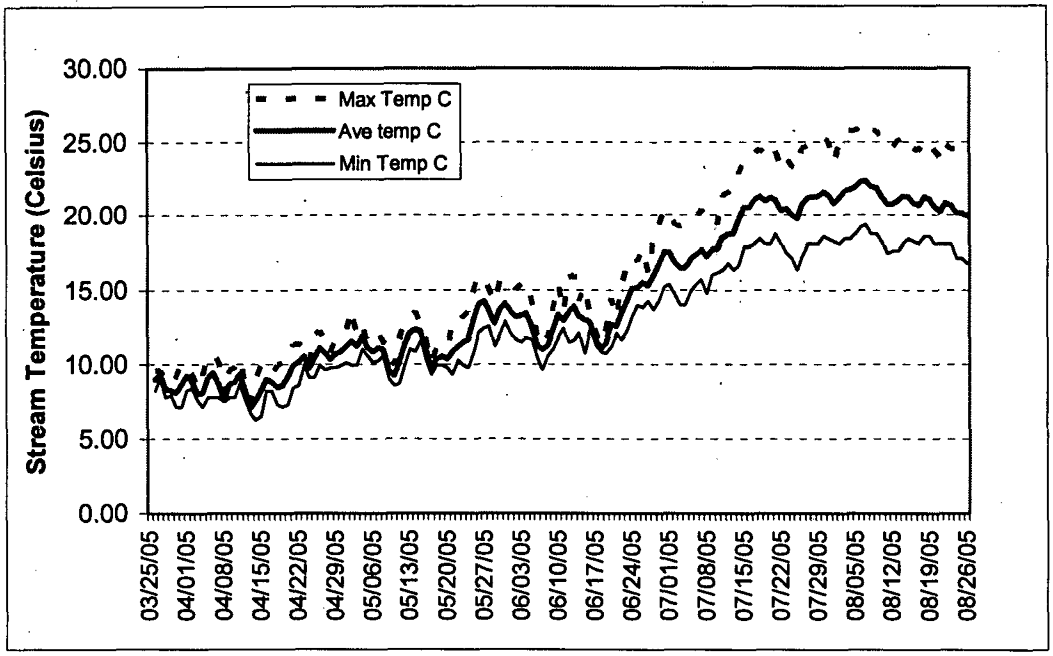

Figure 23. Average, minimum, and maximum stream temperatures (°C) at trapping site, upper Redwood Creek, Humboldt County, CA., 2005.

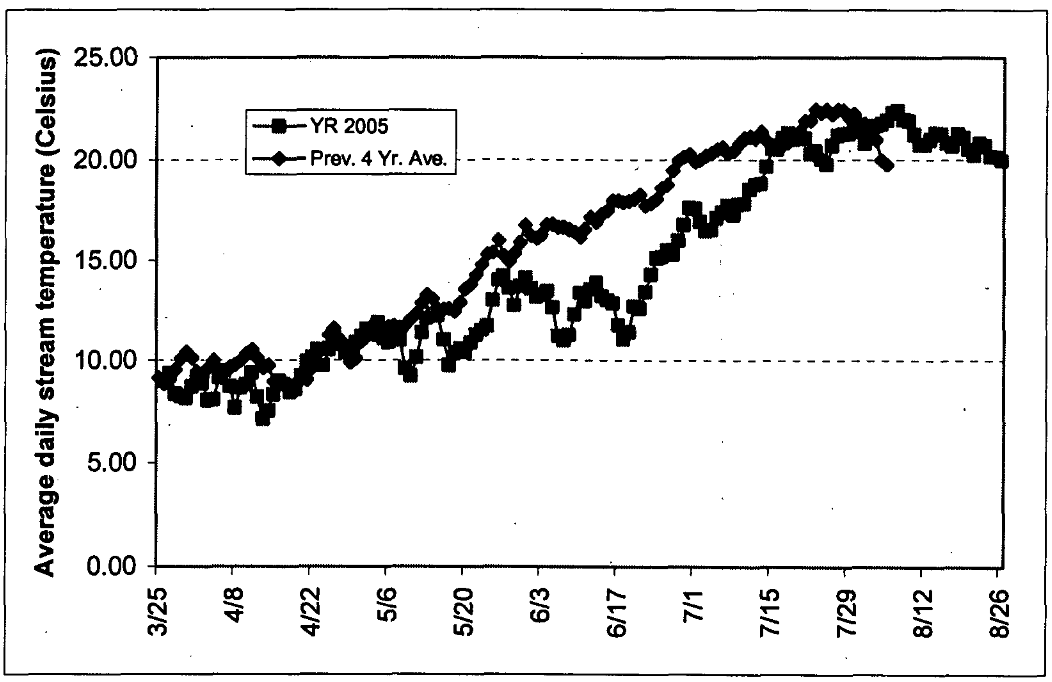

Figure 24. Comparison of the average daily stream temperature (°C) in YR 2005 with the previous four year average, upper Redwood Creek, Humboldt County, CA.

DISCUSSION

The main goal of our downstream migration study in upper Redwood Creek is to estimate and monitor the production of Chinook salmon, steelhead trout, and coho salmon (if present) in a reliable, long-term manner. Redwood Creek is a difficult, if not impossible stream to monitor for adult salmon and steelhead populations on a long term basis using traditional techniques (weirs and spawning ground surveys). However, "quantifying juvenile anadromous salmonid populations as they migrate seaward is the most direct assessment of stock performance in freshwater" (Seiler et al. 2004). In addition, studies in various streams have found that smolt numbers can relate to stream habitat quality, watershed condition, restoration activities, the number of parents that produced the cohort, and future adult populations.

The sixth consecutive year of trapping in upper Redwood Creek was a wet year, with average precipitation and stream flow during the trapping period greater than historic and recent averages. Precipitation during the trapping period (60.5 cm) was 2.3 times greater than the historic average, and 2.9 times greater than the previous five year average. In contrast with YR 2003 (also a wet year) when large amounts of rain fell in April, rainfall during the trapping period in YR 2005 fell in relatively large amounts during April, May, and June. In response, the average stream flow in which we operated the trap was about 2 times greater than the historic average, 2.4 times greater than the previous five year average, and slightly greater than the average for YR 2003. The increase in stream flow in YR 2005 led to cooler stream temperatures which in turn lowered the average stream temperature compared to other study years. High stream flow in YR 2005 also appeared to increase the summer base flow. The current six study years within which we have collected juvenile salmonid data encompass good variability in the stream environment, as evidenced by the range in physical variables (rainfall, stream flow, stream temperature).

Although conditions for trapping in YR 2005 were the most difficult of all prior seasons, we were able to operate the trap and run multiple efficiency trials over a range of trapping conditions to produce a reliable catch and population estimate for each species at age. The eight days we missed trapping were spread out over time with trappable days before and after a given event, which facilitated estimation techniques using linear regression. The estimates for catch and subsequent expansions to the population level, based on the missed trapping days, were negligible for each species at age; the greatest impact on a population estimate was estimated at 4.3%, and the adjusted point value easily fell within the 95% confidence interval of the un-adjusted point estimate. Thus, this season's trapping resulted in very good estimates of wild Chinook salmon and steelhead trout emigration (production) from areas upstream of the trapping site.

0+ Chinook Salmon

0+ Chinook salmon (ocean-type) emigrating from upper Redwood Creek have dominated the trap's catch for four out of six years. Low catches occurred in YRS 2003 and 2005, and the total catch in YR 2005 was 93% less than the average catch for the previous five years. 0+ Chinook salmon emigration at the population level was variable over the six consecutive years of study; the two lowest population estimates (YRS 2003 and 2005) followed years with the highest population estimate (YR 2002, N = 518,189; YR 2004, N = 629,847). The reduction in emigration in YR 2005 (90% reduction from previous five year average, 94% reduction of YR 2004 estimate) could be due to: 1) change in adult spawner distribution in the watershed, 2) simple decrease in the total number of spawners upstream of the trap site, 3) high bedload mobilizing flows in early December which scoured or jostled redd gravels, or 4) a combination of factors 1, 2, and 3.

If adult salmon returning to Redwood Creek changed their spawning distribution such that most spawned downstream of the trap site, we would naturally see a sharp decrease in the production of juvenile Chinook salmon from upper Redwood Creek. Since we currently do not count adults or have an index of adult escapement, I cannot say for certain that a major change in the spawning distribution did not occur, and was not reflected by low juvenile emigration from upper Redwood Creek in YR 2005. The emigrant population passing the rotary screw trap in lower Redwood Creek in YR 2005 (N = 127,350) does not give much supportive evidence because it too was greatly reduced (by 77%) compared to emigration in YR 2004 (Sparkman 2006). Data from the lower trap was able to show: 1) the severe decrease in 0+ Chinook salmon numbers was not limited to upper Redwood Creek, and included the entire Redwood Creek watershed upstream of where Prairie Creek enters Redwood Creek, and 2) production of 0+ Chinook salmon in YR 2005 was greater in areas downstream of the upper trap site. Unfortunately, peaks in stream flow measured in lower Redwood Creek in December 2004 were also high enough to mobilize the bedload and redd gravels (Madej pers. comm. 2005). Thus, a drastic change in the adult spawner distribution in the watershed (favoring spawning in areas downstream of the upper trap) could have been masked by scouring of spawning redds.

A very low number of adults returning to areas upstream of the trap site would also result in a noticeable reduction in juvenile production. Unfortunately, stream flows during the months when adults returned in YRS 2002 and 2004 were high enough to obscure adult observations; and the high flows would also wash an unknown percentage of the carcasses downstream, thus giving the appearance that few fish returned to spawn in upper Redwood Creek. However, I cannot say for certain that few fish did or did not return to spawning areas upstream of the trap site in YRS 2002 and 2004 because we do not currently count adults.

At least some adult Chinook salmon were present in upper Redwood Creek in mid November 2004 because a female (with a male nearby) was observed in the initial act of redd construction. After the mouth of Redwood Creek opened to the ocean on October 23rd, adult fish were able to migrate upstream into upper Redwood Creek with the given stream flow (peak flow was 340 cfs). Returning adult salmon could not enter Redwood Creek from November 21 – 27 and November 29 – December 7 because the mouth was closed from the ocean (memo, Dave Anderson pers. com. 2005). Stream flows before, during, and after mouth closures in November appear to be great enough for adult fish to enter upper Redwood Creek (minimum flow was 16 cfs). Stream flows in upper Redwood Creek during most, if not all of December were also great enough for adult passage. The high flows observed after December 7, 2004 would have easily allowed adults to migrate far upstream in the watershed. The returning adult Chinook salmon in 2004 probably did not radically change their spawning distribution because flows during the migration and spawning period seem adequate for upstream passage.

Although we do not know how many adult Chinook salmon were present upstream of the trap site in the 2004/05 spawning season, we do know that for each severely reduced population estimate (YRS 2003 and 2005), high flows capable of mobilizing bedload and scouring or jostling redd gravels occurred when Chinook salmon redds were present. The idea of a negative relationship of high winter flows (> 4,500 cfs) on subsequent juvenile Chinook salmon production in upper Redwood Creek was first put forward as a hypothesis to explain the cohort crash in YR 2003 (Don Chapman pers. comm. 2003, Sparkman 2004a, study 2a5). Several investigators have shown that the scour of redds due to high stream flows or floods can often cause severe decreases in the production of juvenile salmonids (Gangmark and Bakkala 1960, McNeil 1966, Holtby and Healey 1986, Montgomery et al. 1996, Devries 1997, Schuett-Hames et al. 2000, Seiler et al. 2002, and Don Chapman pers. comm. 2003, Greene et al. 2005); and that estimates of mortality attributable to high flows and redd scour can reach 90% (Schuett-Hames et al. 2000). Greene et al. (2005) were able to show that the flood recurrence interval during Chinook salmon intragravel development was the second most important variable in their models used to predict the return rate of adult Chinook salmon. They further report that "large flow events may be a key factor in regulating Chinook salmon populations in the Skagit River basin, Washington" (Greene et al. 2005). In the 2005 five-year summary report, linear regression showed that 84% of the variation in the population size over study years 2000 – 2004 could be attributable to peak winter stream flow that can mobilize bedload (including redds) and jostle gravels (Sparkman 2005, study 2i4). One of the main caveats at the time was that we needed another high flow event after the Chinook salmon had deposited eggs in spawning redds. On December 8, 2004 the stream flow in upper Redwood Creek reached 6,350 cfs and stayed near this level for about three hours, thereby providing another high flow data point to test our hypothesis. This year, utilizing six data points, linear regression detected a significant negative relationship with bedload mobilizing flow and the subsequent production of 0+ Chinook salmon juveniles ($p = 0.005$, $R^2 = 0.89$, power = 0.98, $n = 6$). The variation in peak stream flow (in this case bedload mobilizing flows and non-bedload mobilizing flows) during the egg incubation period in redds explained 89% of the variation in the seasonal 0+ Chinook salmon population estimate over the six year period. These high, potentially damaging stream flows in upper Redwood Creek are not uncommon because the recurrence interval is estimated to be around 3.1 years (Randy Klein, pers. comm. 2003). There might be an upper threshold to discharges in upper Redwood Creek above which redd survival can be expected to be severely reduced; the highest flows occurring when eggs were in redds with good emigrant production the following spring/summer (YR 2004) equaled 4,400 cfs (occurred during December 2003).

An alternative explanation that the 0+ Chinook salmon simply remained upstream of the trap site in YR 2003 and YR 2005 is not likely because few juvenile Chinook salmon hold over for another year to out-migrate. This study shows that less than 0.004% of the total juvenile Chinook salmon production over-summer and over-winter to emigrate as 1+ Chinook salmon the following spring. Additionally, no 0+ Chinook salmon in upper Redwood Creek held over from YR 2003 to be later captured as one-year-olds in YR 2004.

Percent emigration by month in YR 2005 was similar to the previous five year average, with April, May, and June accounting for the majority of out-migration. In contrast, emigration (on a percentage basis) in July 2005 was nearly seven times greater than July for the previous five year average. Weekly population emigration in YR 2005 was positively related (albeit weakly, $R^2 = 30\%$) to stream gage height and stream discharge; and negatively related to average stream temperature and week number. Thus, more 0+ Chinook salmon were emigrating earlier in the season when stream temperatures were lower and stream discharge was higher compared to later in the season. During periods of peak stream flow within which we trapped, we found that emigration substantially decreased. It is likely the 0+ Chinook salmon found refuge during these high stream flow events.

The 0+ Chinook salmon (ocean-type) migrants in upper Redwood Creek exhibit two different juvenile life histories (fry and fingerling) based on size and time of downstream migration. The fry are migrating shortly after emergence from spawning redds, and therefore are much smaller than the fingerlings which have reared in the stream for a longer period of time. In YR 2005, for example, the average FL for fry equaled 39.0 mm, compared to 68.8 mm for fingerlings. The emigration of 0+ Chinook salmon fry begins near the onset of trapping (in some years can be weeks later), peaks in mid April, and tapers off to very low values by early June. Factors that can influence the temporal component to fry migration are: 1) time of adult spawning, 2) how far upstream of the trap the adults spawned, 3) time from egg deposition to fry emergence from redds, and 4) travel rate, among other factors. Fingerling migration in upper Redwood Creek begins in very low numbers in April, peaks in late May/early June, and tapers to low values by mid to late July. In YR 2005, fry emigration was severely reduced in number and the period of emigration was compressed compared with the previous five year average. Fingerling migration in YR 2005 was also severely reduced in number; however, the period of emigration was extended compared to the previous five year average.

Large numbers of Chinook salmon fry emigrate soon after redd emergence in upper Redwood Creek, with percentages ranging from 1 – 69% of the Chinook salmon emigrant population per study year. The percentage of juvenile Chinook salmon migrating as fry in YR 2005 (58% of total) was higher than the percentage migrating as fingerlings (42%); and statistically higher than the percentage migrating as fry for the previous five year average (53% of total emigration). Other streams experience large migrations of Chinook salmon fry as well (Allen and Hassler 1986, Healey 1991, Taylor and Bradford 1993, Thedinga et al. 1994, Bendock 1995, Roelofs and Klatte 1996, Seiler et al. 2004, Greene et al. 2005, among others). Healey (1991) reported that it is common for Chinook salmon fry to migrate downstream soon after emergence, and cited at least five studies which documented this dispersal. Bendock (1995) reported 'large' numbers of post emergent fry were captured from the beginning of trapping in Deep Creek, Alaska, and Seiler et al. (2004) stated that about 53% (or 386,315 individuals) of the total juvenile Chinook salmon production (upstream of the trap site) migrated as fry in the Green River, WA. Unwin (1985) reported that 91 - 98% of the juvenile Chinook salmon emigrants were newly emerged fry in the Glenariffe stream, New Zealand; and Solazzi et al. (2003) show that Chinook salmon fry emigration in various Oregon streams can be substantial, numbering near one million individuals in the North Fork Nehalem River in YR 2002. Dalton (1999) determined that 93 - 98% of emigrating juvenile Chinook salmon migrated as fry in the Little North Fork Wilson River, Oregon, and similar percentages were found in the Little South Fork Kilchis River, Oregon. In contrast, Roper and Scarnecchia (1999) found only 10% of the juvenile Chinook salmon production emigrated at lengths < 50 mm FL in the South Umpqua River basin, Oregon.

The reasons why Chinook salmon fry migrate soon after emergence (or remain in the stream to grow into fingerlings) are elusive, difficult to prove, and generally unknown (Healey 1991). Healey (1991) covers the topic in much detail, and cites findings from authors who attributed (or speculated) fry dispersal to: 1) passive migration, 2) flow increases, 3) social interactions within species, 4) limits to rearing area (carrying capacity), 5) interactions with other species, and 6) genetics. In contrast, Healey (1991) also cites authors who reported no relationship between the number (or percentage) of fry and stream discharge, stream temperature, and rearing capacity. To summarize, Healey (1991) states that: 1) fry migration is a normal dispersal mechanism that helps re-distribute fry within the river, 2) estuaries can provide important rearing areas for fry, 3) fry are not 'lost' or surplus production, and 4) genotype may play an important role in fry migration.

Analysis was done on six years of data using linear regressions of average stream flow (surrogate for habitat space), average temperature, and seasonal 0+ Chinook population estimate on the percentage of emigrating fry each year in upper Redwood Creek. None of the regression models were significant, and in fact, the regressions were highly non-significant ($p > 0.70$); therefore, no relationships between measured habitat variables or juvenile Chinook salmon population size on the percentage of fry in any given year were detected (ie no density-dependent relationship existed). The mechanism for fry dispersal in upper Redwood Creek, based upon our data, appears to be largely genetic.

Passive migration probably does not play an important role in fry dispersal in upper Redwood Creek based upon our low trap catches during a range of high flow events, numerous mark/recapture trials, and a long migration period. The fry we use in our mark/recapture trials are released 250+ m upstream of the trap site, in fry habitat (very low velocity, stream margin area with overhanging trees and woody debris) that is about 20 m from the river's current. Un-marked fry are occasionally observed in small numbers at the release site so there is plenty of space for the marked fry. The marked fry have to physically move about 20 m to the river current to migrate downstream, and most if not all of the recaptures (> 98%) are caught the next morning following release.

Therefore, if the marked fry were passively moving, they would have stayed in the low velocity fry habitat which would have delayed their migration. With ample space to rear and reside, the migrating fry also indicate that space was not a cue to migrate. With respect to space or habitat availability and fry movement, Prairie Creek offers another example. Prairie Creek is known as a relatively pristine stream, with old growth forests, cool stream temperatures and high degrees of habitat complexity; yet, each year, regardless of the number of adults (and egg deposition) and subsequent juvenile production, Chinook salmon fry are captured in traps every year as they migrate downstream (Roelofs and Klatte 1996; Roelofs and Sparkman 1999, Walt Duffy pers. com. 2005).

The long period of fry migration from upper Redwood Creek is evidenced by trap catches that extend from the beginning of trapping (late March) to early June. Thus if the fry were passively migrating we would probably not catch any at the upper trap well after the high flow events (usually in March and April). The fry leaving upper Redwood Creek are also moving far downstream because for two consecutive years the lower trap in Redwood Creek (RM 4) has captured fry with fresh partial upper caudal fin clips (efficiency trial fish from upper trap). The lower trap also catches fingerlings with regenerating fin clips and fingerlings with fresh fin clips; the fingerlings with regenerating fin clips indicate that they were fin clipped as fry, and this in turn shows that some fry are growing into fingerlings as they migrate downstream. Fishery crews sampling in the estuary during June and July also observe these fin clipped fish (both fry and fingerlings) from upper Redwood Creek (Dave Anderson pers. com. 2005), which corroborates Healey's (1991) and Allen and Hassler's (1986) assertion that estuaries are important places for fry to rear. The fry in upper Redwood Creek appear to be actively (volitionally) moving downstream. Fry dispersal is a normal component of diversity in the juvenile life history of ocean-type Chinook salmon found in upper Redwood Creek.

Healey (1991) also points out that fry are not surplus or lost production that will never augment future adult populations; therefore, fry should be part of a juvenile Chinook salmon emigrant population estimate. Chinook salmon fry in upper Redwood Creek often appear smolt-like (very silvery, parr marks nearly absent or obscured to some degree by silver colored scales) and can undergo smoltification while migrating downstream from upstream spawning or rearing areas (Allen and Hassler 1986, Quinn 2005). In addition, Myers el al. (1998) summarize that ocean-type Chinook salmon fry can migrate immediately to the ocean in sizes ranging from 30 – 45 mm FL. Healey (1980), Carl and Healey (1984), Allen and Hassler (1986), and Healey (1991) also report that Chinook salmon fry can immediately migrate downstream to the estuary and ocean. Although fry to adult survival is probably less than that of fingerlings, some of the fry do survive to adulthood (Unwin 1997) and thus make a contribution to the adult population (Healey 1991). Supportive evidence of fry to adult survival is hard to find in the literature probably because most long lasting marks or tags are too big for wild fry, with the exception of coded wire tags (1/2 tags) and otolith marking.

Although more fry emigrated in YR 2005 compared to fingerlings, the average FL and Wt in YR 2005 was greater than other study years; however, differences were not statistically significant. YR 2003 was not included in analysis because so few measurements were taken due to the cohort failure (N = 987, n = 573 for FL); and exclusion did not change any test conclusion. The larger average size in YR 2005 will most likely not compensate for the severe reduction in population emigration in YR 2005. One explanation for not compensating the low numbers with increased survival due to a larger average size (FL or Wt) for the 2005 cohort is found by looking at the percentage of migrants in the fry and fingerling categories each year. Although study years 2000 - 2002, and 2004 had an average FL or Wt less than in YR 2005, far more fingerlings were present in those years compared to YR 2005. The number of fingerlings emigrating in YR 2005 was so low compared to previous years (excluding YR 2003) that far fewer adults are expected to return, regardless of the average FL and Wt in YR 2005.

Linear regression detected a significant negative relationship of yearly population emigration on average FL or Wt which may indicate a density-dependent relationship; with higher emigration we see a decrease in the average FL or Wt. The overall percentage of fry or fingerlings in a given population estimate was not related to the average seasonal FL or Wt (Regression, $p > 0.67$ for both tests, $R^2 = 0.06$, n = 6, power = 0.06). The density-dependent relationship suggests that rearing space or carrying capacity (and food availability) upstream of the trap site is limiting the average size of Chinook salmon juveniles at higher population abundances. However, the current carrying capacity is expected to be much less than the carrying capacity of the past because Redwood Creek has changed over time, and is currently listed as sediment and temperature impaired. The juvenile Chinook salmon population abundance we have measured over the past six years has a high probability of being far less than abundance during pre-disturbance (or impairment) periods. If habitat is limiting the size of smolts at high abundances, successful watershed restoration in the upper basin should allow for the juvenile Chinook salmon to gain a larger size than currently observed, even if the emigrant population is relatively large.

Although a negative relationship of average size with population abundance was detected for 0+ Chinook salmon, the average weekly FL and Wt for any given year increased over the study period. Average weekly FL and Wt in YR 2005 followed a similar pattern over time; starting out low and relatively stable for the first 6 weeks, then increasing through the end of the study period. The rather sharp increase in FL and Wt by week in YR 2005 was attributable to the increasing percentage of fingerlings in the catch over time compared to fry (Regression: FL, $p = 0.00001$, $R^2 = 0.83$, slope is positive, power = 1.0; Wt, $p = 0.00001$, $R^2 = 0.71$, slope is positive, power = 1.0). Unwin (1985) reported a similar finding in his trapping studies in New Zealand. The relationships of weekly FL and Wt in YR 2005 with the previous four year average were numerically similar for the first 7- 8 weeks, thereafter average weekly FL's and Wt's in YR 2005 were greater than the four year average. These increases in weekly FL's and Wt's indicate growth was taking place within the study periods. The rough or group estimate for growth rate from 4/09/05 - 7/29/05 equaled 0.41 mm/d for FL and 0.05 g/d for Wt. A growth rate of 0.41 mm/d falls within the range of juvenile Chinook salmon growth rates (range = 0.21 – 0.64 mm/d) measured in other streams (Healey 1991, Bendock 1995). Healey (1991) reported that growth of juvenile Chinook salmon migrants in the Sacramento River, CA equaled 0.33 mm/d during a particular study, and Bendock (1995) determined growth to equal 0.64 mm/d in Deep Creek, Alaska. In accord with Healey (1991), these group growth estimates should be viewed cautiously because we do not know exactly how long fry and fingerlings have been residing in the stream after emerging from redds. Although these growth rate estimates are for groups of fish and do not necessarily represent individual growth rates, they do take into account a variety of fish sizes and should be meaningful.

The estimates of travel time (in days) for recaptured pit tagged 0+ Chinook salmon smolts (n = 27) should be viewed as a maximum because the lower trap caught these fish sometime prior to when the crew checks and empties the livebox at 0900. For example, if a pit tagged fish was captured at 0200 and the crew emptied the trap's livebox at 0900, then travel time would be off by 7 hours. Travel time may also be positively biased if the juveniles resided in the stream during daylight hours and primarily migrated downstream at night (likely scenario). In contrast to travel time, travel rate should be viewed as a minimum for similar reasons; the individual's rate would be higher than what was observed if they were captured prior to checking the trap's livebox, and higher if they primarily migrated at night. Nevertheless, our experiments gave insight into individual juvenile Chinook salmon migration and growth between the two trap sites, which in turn may reflect stream habitat conditions, the salmon stock in Redwood Creek, or variable cohort behavior.

The travel time for 0+ Chinook salmon smolts to migrate 29 miles downstream ranged from 1.5 - 19.5 d, and averaged 7.5 d. On average, 0+ Chinook salmon moved downstream to the lower trap in fewer days than 2+ steelhead trout (n = 7, range = 2 to 35 d, ave. = 13 d) and 1+ steelhead trout (n = 9, range = 2 to 32 d, ave. = 15 d) in YR 2004 (Sparkman 2004b, study 2i3). The travel time for 0+ Chinook salmon fingerlings to reach the lower trap was not significantly related to: 1) the size of the migrant at time 1 or time 2, 2) stream temperature, or 3) stream discharge. The recapture of pit tagged 0+ Chinook salmon per release group in YR 2005 was variable. For one release group (6/30/05), five individuals were captured on the same day at the lower trap which suggests these fish traveled together as a group. In contrast, for five separate release groups, multiple recaptures from the same release group were captured on different days at the lower trap. For example, five individuals from the 7/21 release group were recaptured at the lower trap anywhere from 4.5 – 19.5 d after release from the upper trap; these fish did not travel as a group.

Travel rate ranged from 1.5 - 19.3 miles per day (2.4 – 31.1 km/d), and averaged 8.2 miles per day (13.2 km/d). Travel rate (mi/d) was weakly related to the size (FL or Wt) at time 1 (initial release), such that with a greater initial size we observed a higher travel rate. Similar to travel time, travel rate was not related to stream discharge, stream temperature, or fish size at time 2 ($p > 0.05$). Healey (1991) gives results from a study in the Rogue River, Oregon in which travel rate of spring Chinook salmon fingerlings was positively related to fish size and stream discharge in one year, and negatively related to stream discharge in the following year. Quinn (2005) reported that the rate at which 0+ Chinook salmon traveled downstream in the Columbia River was positively related to size. The upper range in travel rate (31.1 km/d) for Chinook salmon fingerlings in Redwood Creek was higher than that observed in the upper Rogue River (24.0 km/d) (Healey 1991); and the average travel rate from upper Redwood Creek (13.2 km/d) was also higher than the average (1.6 km/d) put forward by Allen and Hassler (1986). Unfortunately, there appears to be a lack of data in the literature to compare individual travel time and travel rate with data collected on juvenile Chinook salmon in Redwood Creek. Many of the studies using pit tags with juvenile Chinook salmon are within the Columbia River system, which for the most part is not comparable to Redwood Creek; Redwood Creek is much smaller in size, does not have impoundments, and the stream flow is unregulated, among other differences.

Individual growth was expressed using a variety of indices and equations to facilitate comparisons with information found in the literature. The majority of studies appear to report growth using one index or another which makes comparisons difficult if that growth index is not used in a given study. Compounding the problem of comparing data is the difficulty in finding studies that determined individual growth rates for 0+ Chinook salmon fingerlings, and in un-regulated river systems (upstream of estuaries).

In YR 2005, 52% of the 27 recaptured 0+ Chinook salmon fingerling smolts showed positive growth in FL and Wt, 18% showed a decrease in Wt, 48% showed no change in FL and 30% did not show a change in Wt. Absolute growth rate (FL) ranged from 0 - 0.67 mm/d, and averaged 0.22 mm/d. The average value (0.22 mm/d) is comparable to the group growth rate for Chinook salmon fingerlings in the Nitinat River (0.21 mm/d) and about 2/3 less than the group growth rate determined in the Cowichan River (0.62 mm/d), British Columbia (Healey 1991). The average value for recaptured pit tagged fingerlings (0.22 mm/d) in Redwood Creek was about 46% less than that calculated for fry and fingerlings in YR 2005 using the average weekly FL data (0.41 mm/d). However, the latter estimate is a group estimate, includes fry (which may have a higher absolute growth rate than fingerlings) and probably is not influenced by zero growth like the average for the individual growth rates were. For example, the absolute growth rate for Chinook salmon juveniles in Redwood Creek showing only positive growth ranged from 0.19 - 0.67 mm/d and averaged 0.428 mm/d, which is very close to the group estimate previously calculated (0.41 mm/d).

Eighteen percent (n = 5) of the recaptured pit tagged Chinook salmon lost weight (absolute growth rate in g/d) from time of release to time of recapture (range = -0.19 to - 0.39 g/d, average = -0.29 g/d). Closer examination of data for these fish reveal that four out of the five were released as a group on 6/30 and recaptured 1.5 d later; the fifth fish also had a travel time of 1.5 d. With such a short travel time, it is conceivable that these fish might have had more food in their stomachs when released than when recaptured, which could explain the apparent weight loss (loss of 0.3 – 0.6 g per fish). Alternative explanations that could apply are: 1) these fish simply spent more time traveling downstream and less time foraging for food and feeding, thereby losing weight, or 2) crews at the upper or lower trap made measurement errors. The probability that the scale malfunctioned was slight because field crews calibrated the scale each day prior to use.

The growth (positive, negative, or zero) of the 27 recaptured pit tagged 0+ Chinook salmon was successfully modeled using linear regression. The best model for any growth index included travel time as the independent variable (p ranged from 0.002 – 0.000001, R^2 ranged from 0.32 – 0.84, slope is positive for all tests); no significant relationships were detected using stream discharge or stream temperature even though the range in values for each was fairly wide. Percent change in FL was positively related to travel time, and travel time explained 84% of the variation in growth; likewise, absolute growth rate (FL) was positively related to travel time, which explained 69% of the variation in growth. Thus, fish that took longer to reach the lower trap gained more length or weight than fish that traveled the distance in a shorter amount of time. This in turn suggests fish that took a longer amount of time to migrate downstream had more time to forage for food, feed, and convert the food to growth. Beamer et al. (2004) found that the growth of juvenile ocean-type Chinook salmon (in Skagit Bay) was positively related to the amount of time that the juveniles spent in the delta.

The final size of recaptured pit tagged Chinook salmon fingerlings was positively related to the size at initial release (FL; $p < 0.0001$, $R^2 = 0.67$, power =1.0). Sixty-seven percent of the variation in the final FL was explained by the initial FL. Larger fish released at the upper trap site were, on average, larger at recapture than smaller fish released at the trap site and subsequently recaptured; likewise, smaller fish at time 1 were, on average, usually the smaller fish at time 2. The importance of this relationship is that fish size at the upper trap (initial size) had a large impact on fish size at the lower trap (final size); the larger fish at the lower trap were more likely to have been the larger fish at the upper trap.

1+ Chinook Salmon

1+ juvenile Chinook salmon (stream-type) in Redwood Creek represent the third juvenile Chinook salmon life history, and appear to be in very low abundance. Yearly catches ranged from 0 – 29 individuals and in YRS 2000, 2004 and 2005 zero were captured. Stream-type Chinook salmon are easily differentiated from ocean-type by size at time of downstream migration. For example, the average FL in May 2003 was 124 mm for 1+ Chinook salmon and 58 mm for 0+ Chinook juveniles. The total number of 1+ Chinook salmon juveniles captured over six study years equaled 68 individuals, or 0.01% of the total juvenile Chinook salmon catch. *A priori* I expected to catch 1+ Chinook salmon in YR 2005 because our highest emigration occurred in YR 2004; I thought at least some of the juvenile Chinook salmon would over-summer and residualize upstream of the trap site for a year prior to seaward migration. Maximum stream temperatures (eg. up to 28.7 °C or 83.7 °F) during late summer in YR 2004 may have inhibited or prevented 1+ Chinook salmon from rearing in upper Redwood Creek. However, the 1+ Chinook salmon captured in YRS 2001 and 2002 over-summered with stream temperatures reaching 27 - 28 °C (81 – 82 °F) at the trapping site. The lack of 1+ Chinook salmon catches at the upper trap in YR 2005 was in contrast to the capture of 11 individuals at the lower trap in YR 2005 (Sparkman 2006).

When present, 1+ Chinook salmon from upper Redwood Creek are more likely to be progeny of fall/winter-run Chinook salmon adults than from spring-run adults (Stream type) because few if any spring-run Chinook salmon are observed during spring and summer snorkel surveys in Redwood Creek (Dave Anderson, pers. comm. 2004). For example, in 21 years of adult summer steelhead snorkel dives, adult spring Chinook salmon were only observed in one year (1988) and in very low numbers (< 7 individuals) (Dave Anderson, pers. comm. 2005). Additionally, stream flows during late spring/summer months can become so low that adult upstream passage into upper Redwood Creek can become problematic. High average stream temperatures (eg > 20 °C) may also prevent any adult spring-run Chinook salmon migration into upper Redwood Creek, or inhibit their ability to over-summer in pools. Thus, the spring run of Chinook salmon adults is probably not responsible for the production of yearling Chinook salmon juveniles in Redwood Creek. Bendock (1995) also found both stream-type and ocean-type juvenile Chinook salmon in an Alaskan stream which only has one adult Chinook salmon race; and Conner et al. (2005) reported that fall Chinook salmon in the Snake River produced juveniles exhibiting an ocean-type or stream-type juvenile life history.

The 1+ Chinook salmon life history pattern may be important for increased ocean survival of Chinook salmon juveniles, and general species diversity (Don Chapman pers. comm. 2003, Sparkman 2005, study 2i4).

0+ Steelhead Trout

Considerable numbers of young-of-year steelhead trout migrate downstream from upper Redwood Creek during spring and summer months; over six consecutive study years we have captured 555,470 individuals. The total catch of 0+ steelhead trout migrating downstream in YR 2005 was the lowest of all trapping seasons. Trap catches in YR 2005 (n = 41,671) were markedly lower than catches in YR 2004 (n = 128,885) and the previous five year average (Ave. = 102,760). In each previous study year we also observed numerous 0+ steelhead trout in stream margin areas and in areas influenced by sub-gravel (seep) water. In contrast, we saw far fewer 0+ steelhead trout in margin areas and far less using thermal refugia areas in YR 2005.

Relatively high catches of young-of-year steelhead trout by downstream migrant traps in small and large streams is not uncommon (USFWS 2001, Rowe 2003, Johnson 2004, Don Chapman pers. comm. 2004, Sparkman 2005). Young-of-year steelhead trout downstream migration in upper Redwood Creek is considered to be stream re-distribution (both passive and active) because juvenile steelhead trout normally smolt and enter the ocean at age two, with lesser numbers out-migrating at ages 1 and age 3.

The number of 0+ steelhead trout that can remain upstream of the trap site is some function of a fish's disposition to out-migrate (or not out-migrate) and habitat carrying capacity. Meehan and Bjornn (1991) comment that juvenile steelhead trout have a variety of migration patterns that can vary with local conditions, and that the trigger for out-migration can be genetic or environmental. Habitat carrying capacity is generally thought to be related to environmental (hydrology, geomorphology, stream depth and discharge, stream temperatures, cover, sedimentation, etc) and biological variables (food availability, predation, salmonid behavior), and any interactions between the two (Murphy and Meehan 1991). A limitation with the view of habitat carrying capacity's affect on migration is that it fails to explain why juvenile fish emigrate at low densities or low population levels.

The decrease we observed in YR 2005 could be due to a variety of factors: 1) changes in the number of adult steelhead spawning above the trap site, 2) change in redd gravel conditions, 3) increase in carrying capacity of stream habitat upstream of trap site due to above average stream flow and cooler stream temperatures, 4) decrease in the percentage of the total population that passively or actively migrates downstream, or 5) some combination of factors 1 - 4. The potential variable of trapping efficiency among study years would not account for the decrease we observed in YR 2005 because the trap was operated in the same manner as in other study years (time of placement, use of weir panels, etc).

Changes in adult spawner distribution in the watershed could have occurred but seem unlikely because winter and early spring stream flows were adequate for upstream passage. In addition, flows were very high near the time of spawning such that adult steelhead could have migrated to the end of anadromy. With respect to adults, the probability that fewer adults were present upstream of the trap site seems more plausible than a large scale change in spawner distribution in the watershed.

Adult steelhead in upper Redwood Creek generally spawn February - April, and in YR 2005 we did observe adult steelhead on redds upstream of the trap site, with the latest observation occurring in April. High flows on April 8, 2005 reached 2,430 cfs and may have impacted redd survival (scouring of redds, jostling of redd gravels); however, on March 26, 2003 we had flows up to 3,520 cfs and captured far more individuals (n = 102,954) in that trapping season compared to catches in YR 2005.

A change in the percentage of total juvenile steelhead production in upper Redwood Creek that migrates downstream may account for some of the decrease in catches we observed in YR 2005. For example, Johnson's data (2004) showed that the percentage of young-of-year steelhead trout fry that out-migrated compared to total post emergent fry production (out-migrants and over-summer fry and parr) over a 12 year period in the upper mainstem of Lobster Creek, Oregon varied considerably from year to year, and ranged from 20 to 85%; a similar relationship was found in East Fork Lobster Creek utilizing 13 years of data. Thus, it is possible that we had 'good' production of young-of-year steelhead trout upstream of the trap site, and the fry and parr did not migrate downstream in any great percentage of the total production. If this were true, and over-summer and over-winter conditions were not harsh or cause high mortality, then we should see a large increase in the number of 1+ steelhead trout emigrating in YR 2006.

Young-of-year steelhead trout were caught in low numbers (n= 3) on the first day following trap deployment (March 26, 2005). Catches of less than 11 individuals per day occurred into the middle of April, and thereafter daily catches were generally greater than 40 per day until the end of August. The pattern of migration in YR 2005 was markedly different than other study years (including the wet year in 2003). For the previous five year average, catches by month increased until June (peak month) and then decreased to the end of the study period; May and June were the two most important months and accounted for 74% of the total catch. In contrast, catches by month in YR 2005 were low from late March through June, peaked in July, and then decreased in August; July was the most important month and accounted for 60% of total catch. Total catches in August (normally a time of reduced migration and catches) in YR 2005 were close in value to the number captured in May and June of YR 2005. On a percentage basis, far more 0+ steelhead trout were captured in August in YR 2005 than August for the previous five year average. During YR 2005, 0+ steelhead trout migration appeared to be skewed towards the end of the trapping period, instead of being predominately in the middle as shown by the previous five year average.

The average FL in YR 2005 was higher than other study years, and about 3 mm's greater than the average of the previous five years. The average FL did not significantly change over study years, thus the differences in FL among study years were slight. Average FL by year was negatively related to the total 0+ steelhead catch by year and indicates a density-dependent relationship; with higher catches we observed a lower average FL. Similar to Chinook salmon juveniles, the density-dependent relationship may indicate that rearing space (and food availability) upstream of the trap site is limiting the average size of 0+ steelhead trout migrants at higher abundances. Although a negative relationship of average size with total catch was detected, the average weekly FL for any given year increased during the study period. This increase in weekly size shows that growth occurred, and may indicate that habitat conditions and the availability of prey items were sufficient for growth. Average weekly FL in YR 2005 followed a similar pattern over time with the previous five year average for the first 10 weeks (3/26 – 6/3); thereafter, average FL in YR 2005 was less than the previous five year average from 6/4 – 6/24, and higher than the five year average from 7/2 through the end of the study. The rather sharp increase in FL by week in YR 2005 from 6/25 – 7/1 was probably influenced by the increasing percentage of parr in the catch compared to fry.

During periods of high stream temperatures (eg July and August) we frequently observe young-of-year steelhead trout in upper Redwood Creek utilizing stream areas influenced by groundwater seeps in very high numbers relative to those seen in non-influenced seep areas (Sparkman and Willits, In progress). However, in YR 2005 we observed few 0+ steelhead in the groundwater refugia areas (maximum observation was 15 fish) compared to last year (maximum observation was 400 fish). Reasons for the decrease could be attributed to low 0+ steelhead trout emigration and cooler stream temperatures in YR 2005.

I doubt that a large majority of the 0+ steelhead population that out-migrates prior to late summer low-flow periods can be viewed as surplus or lost production, which will not augment future adult steelhead populations. Meehan and Bjornn (1991) state that some steelhead populations normally out-migrate soon after emergence from redds to occupy other rearing areas (we observe this as well in Redwood Creek). In streams that are temperature impaired (many in Humboldt County, CA are: including Redwood Creek; see CWA List, 2002), out-migration prior to times when streams or sections of streams reach high (or maximum) temperatures (July/August) or dry up can be viewed as an advantageous life history strategy.

1+ Steelhead Trout

Fairly large numbers of 1+ steelhead trout emigrate from upper Redwood Creek during the spring/summer emigration period. Population emigration from YRS 2000 – 2004 ranged from 28,501 – 68,030 and averaged 43,762 individuals. Population emigration in YR 2005 was the lowest of all study years: 37% less than emigration in YR 2004 and 40% less than emigration for the previous five year average. Linear correlation detected a significant negative trend in 1+ steelhead trout population size over time ($p < 0.10$), which indicates that fewer 1+ steelhead trout were emigrating each year compared to previous years. Linear regression was used in the five year summary report to show that the number of 1+ steelhead trout in year (x+1) was inversely related to the number of 0+ steelhead trout emigrating the previous year (x) ($n = 4$). Based upon the regression model, the expected 1+ steelhead trout population size in YR 2005 was estimated to be 28,251 individuals or about 7.3% more than what was actually determined using mark/recapture techniques. The range of the 95% CI for the population estimate in YR 2005 (22,726 – 29,625) encompasses the regression estimated value. Thus, the regression model appears to accurately estimate 1+ steelhead trout emigrant population size with the given data.

Aside from being numerically less than previous study years, the pattern of population emigration in YR 2005 was markedly different than for the previous five year average. Monthly emigration in YR 2005 was skewed towards the beginning of the trapping period compared to being predominately in the middle as shown by the previous five year average. The most important month for 1+ steelhead trout emigration in YR 2005 was April, compared to May for the previous five year average. 1+ steelhead trout emigration in May and June 2005 was much less (by 78%) than May and June for the previous five year average. Emigration in late March and July were nearly equal among comparisons, and emigration in August 2005 was 12 times higher than emigration in August for the previous five year average. Weekly population emigration in YR 2005 was positively related to gage height (although weakly, $R^2 = 0.37$) and stream discharge, and negatively related to average stream temperature and week number. Thus, more 1+ steelhead trout emigrated earlier in the trapping season when stream discharge was higher and stream temperature was lower compared to later in the season. Similar to 0+ Chinook salmon, 1+ steelhead trout emigration during peaks in stream flow appeared to substantially decrease; it is likely the 1+ steelhead trout found refugia during these high flow events.

The average size of 1+ steelhead trout in YR 2005 (FL = 88.1 mm, Wt = 8.01 g) was greater than the averages for YRS 2002 – 2004 and less than the averages for YRS 2000 and 2001; however, differences were not statistically significant. The FL of 1+ steelhead trout over the six study years was positively related to the population size; with a higher population, we observed a greater FL. This is in contrast to the normal viewpoint of density-dependent relationships in which higher fish densities result in smaller fish sizes. The regression indicates that if stream conditions are favorable for survival, they are also favorable for growth. The weekly FL in YR 2005 did not significantly change over time which differed from the significant positive increase over time for the previous five year average. The general trend over time (weeks) for both lines was similar in that both reached highest values near the middle of June, with decreases in average FL in the following weeks. However, in YR 2005 average FL's starting July 16 - 22 began to slowly increase until the end of the season, compared with the five year average where average FL's decreased to the end of the season. The weekly Wt in YR 2005 significantly decreased over time which contrasts the significant positive increase in Wt over time for the previous five year average. The decrease in fish size over time in YR 2005 is not unusual because larger smolts frequently migrate earlier in the emigration period compared to smaller smolts (Quinn 2005).

Information in the literature indicates that steelhead smolting at age 1 is not uncommon, particularly in streams that are south of British Columbia (Quinn 2005, Busby et al. 1996). The percentage of 1+ steelhead trout migrants showing smolt characteristics in YR 2005 (86%) was much greater than for YR 2004 (41% were smolts) and the previous five year average (25% were smolts). These differences are likely to be real because between-observer variation was minimized in three different ways: 1) each crew member used the same protocol, 2) each crew member was thoroughly trained and tested, and 3) some of the crew members had worked on this study for the previous three years. Regressions of 1+ steelhead trout population size or average FL or Wt on the percentage of 1+ steelhead trout showing smolt characteristics each year were non-significant; thus for the data tested (n = 6), abundance and fish size did not have any influence on the seasonal percentage of smolt designations. However, stream flows and stream temperatures during the study period influenced the percentage of 1+ steelhead trout showing smolt characteristics. Using an alpha of 0.10 due to low sample sizes, regression detected a significant positive relationship of stream flow and the percentage of smolts ($p = 0.06$, $R^2 = 0.63$, power = 0.50, $n = 6$) over the six study years; with higher flows in a given study year, we observed more 1+ steelhead trout as smolts. The relationship between average stream temperature and the percentage of smolts was significantly negative (Regression, $p = 0.03$, $R^2 = 0.82$, power = 0.70, $n = 5$); thus, with colder stream temperatures more of the 1+ steelhead trout migrants were in a smolt stage.

1+ steelhead trout are actively emigrating from upper Redwood Creek because the lower trap in Redwood Creek (RM 4) has consistently captured efficiency trial fish and elastomer marked fish released from the upper trap site in both years of operation. The recapture of pit tagged 1+ steelhead trout in lower Redwood Creek in YR 2005 also indicates emigration from the upper basin. In addition, 1+ steelhead trout from upper Redwood Creek have been observed in the estuary of Redwood Creek every year since the beginning of this study (Dave Anderson, pers. comm. 2004). We have not observed re-migration of 1+ steelhead trout into upper Redwood Creek based upon elastomer marked releases in YR 2001 (n = 374) and YR 2004 (n = 577). These tests confirmed that the elastomer marked fish did not migrate back upstream to rear for another year and emigrate as 2 year-old steelhead trout smolts. Elastomer mark retention was assumed to be adequate for the studies because Fitzgerald et al. (2004) assessed elastomer mark retention in Atlantic salmon smolts and found that tag retention in the lower jaw was > 90% for the first 16 months.

Each study year the population of 1+ steelhead trout emigrating from upper Redwood Creek was far larger than 2+ steelhead trout population emigration. The ratio of 1+ to 2+ steelhead trout in YRS 2000-2004 ranged from 4:1 to 14:1 and averaged 7:1; in YR 2005 the ratio was 11:1. 1+ steelhead trout downstream migration is not unique to Redwood Creek, and other downstream migration studies have routinely documented 1+ steelhead trout emigration (USFWS 2001; Ward et al. 2002; Johnson 2004; among many others). Based upon studies in other streams, the number of returning adult steelhead trout that went to the ocean as one-year-old smolts is relatively low, and usually less than 23% (Pautzke and Meigs 1941; Maher and Larkin 1955; Busby et al. 1996, McCubbing 2002). Based upon a limited number of scale samples (n = 10) from adult steelhead trout in Redwood Creek, 30% of the adults entered the ocean as one-year-old juveniles. The reason(s) for the relative large number of 1+ steelhead trout emigrating from upper Redwood Creek and from the basin of Redwood Creek (Sparkman, 2004b, study 2i3), warrants further investigation.

2+ Steelhead Trout

In several studies investigating steelhead life histories, the majority of the returning adult steelhead spent two or more years as juveniles in freshwater prior to ocean entry (Pautzke and Meigs 1941; Maher and Larkin 1955; Busby et al. 1996, Smith and Ward 2000; McCubbing 2002). For example, Pautzke and Meigs (1941) reported that 84% of returning adult steelhead in the Green River had spent two or more years as juveniles in freshwater. Maher and Larkin (1955) found that 98% of the adult steelhead they examined had spent two or more years in freshwater prior to entering the ocean, and McCubbing (2002) reported 92% of steelhead adults in a British Columbia stream had spent two or more years as juveniles in freshwater. If this applies to steelhead trout in Redwood Creek, then 2+ steelhead trout are the most important (and most direct) group of juvenile steelhead trout that contribute to future adult steelhead trout populations. The paradox for the 2+ steelhead trout smolt is that it is the least numerous juvenile steelhead trout that emigrates from upper Redwood Creek.

2+ steelhead trout population emigration from upper Redwood Creek from YRS 2000 – 2004 ranged from 2,846 – 12,668, and averaged 6,667 individuals. Similar to 1+ steelhead trout, the 2+ steelhead trout emigrant population in YR 2005 was the lowest of all study years; 59% less than emigration in YR 2004 and 64% less than emigration for the previous five year average. The pattern or trend in population size over the six study years was negative, yet non-significant.

The pattern of population emigration in YR 2005 was markedly different than other study years. Similar to 1+ steelhead trout, 2+ steelhead trout emigration by month in YR 2005 was skewed towards the beginning of the trapping period compared to being predominately in the middle as shown by the previous five year average. The most important month for 2+ steelhead trout emigration in YR 2005 was April, compared to April and May for the previous five year average. Emigration in April – July in YR 2005 was much less than those months for the previous five year average, with reductions per month ranging from 40 – 85%. The greatest reduction in emigration in YR 2005 occurred in May (85% reduction). 2+ steelhead trout population emigration in August 2005 was considerably higher (by a factor of eight) than emigration in August for the previous five year average. Weekly population emigration in YR 2005 was positively related to gage height (although weakly, $R^2 = 0.32$) and stream discharge, and negatively related to average stream temperature and week number. Thus, more 2+ steelhead trout emigrated earlier in the trapping season when stream discharge was higher and stream temperatures were lower compared to later in the season. Similar to 0+ Chinook salmon and 1+ steelhead trout, 2+ steelhead trout emigration during peaks in stream flow appeared to substantially decrease; it is likely the 2+ steelhead trout found refugia during these high flow events.

The average size of 2+ steelhead trout in YR 2005 (FL = 150.5 mm, Wt = 39.90 g) was greater than the averages for YRS 2002 – 2004 and less than the averages for YRS 2000 and 2001; however, differences were not statistically significant. Unlike 1+ steelhead trout, the FL (and Wt) of 2+ steelhead trout over the six study years was not related to emigrant population size. The weekly FL in YR 2005 did not significantly change over time which differed from the significant negative decrease in FL by week for the previous five year average. The general FL trend over time (weeks) for both lines showed some similarity in that both reached highest values near the beginning of trapping, with decreases in average FL in the following weeks until the middle of June; thereafter FL's increased to the end of the study. The relationship of Wt in YR 2005 with time (year and week) followed the same general pattern as FL. Both median weekly FL and average weekly Wt in YR 2005 were not significantly different than the previous five year average. Thus, the size of 2+ steelhead smolts in YR 2005 was not markedly different than the previous five year average. The decrease in average FL and Wt by week during study year 2005 is not unusual because larger smolts frequently migrate earlier in the emigration period compared to smaller smolts (Quinn 2005). 2+ steelhead trout smolts in the nearby Mad River, Humboldt County, California also emigrated at a larger size in the beginning of the migration period (Sparkman 2002).

The percentage of 2+ steelhead trout emigrants showing smolt characteristics in YR 2005 (99.4%) was greater than YR 2004 (84%) and the previous five year average (75%). The number of parr designations was very low each year (6 yr average = 0.08%, ranged from 0.0 – 0.2% each year), and indicates that very few 2+ steelhead trout emigrate in a stream-resident form. The regression of 2+ steelhead trout population size on the percentage of 2+ steelhead trout showing smolt characteristics each year was significantly negative; thus, with a decreasing population size there was a higher percentage of smolts in the population. Average fish size (FL, Wt) by year or average stream discharge during each trapping period had no influence on the percentage of 2+ steelhead trout showing smolt characteristics (unlike 1+ steelhead trout). The relationship between average stream temperature during the trapping period and the percentage of smolts was significantly negative (Regression, $p = 0.09$, $R^2 = 0.65$, power = 0.37, $n = 5$); thus, with colder stream temperatures more of the 2+ steelhead trout migrants were in a smolt stage. Quinn (2005) reported that stream temperatures play an important role in smoltification.

2+ steelhead trout are actively emigrating from upper Redwood Creek because the lower trap in Redwood Creek (RM 4) has consistently captured efficiency trial fish and elastomer marked fish released from the upper trap site in both years of operation. In addition, 2+ steelhead trout from upper Redwood Creek have been observed in the estuary of Redwood Creek every year since the beginning of this study (Dave Anderson, pers. comm. 2004). We have not observed re-migration of 2+ steelhead trout into upper Redwood Creek based upon elastomer marked releases in YR 2001 (n = 8) and YR 2004 (n = 223). These tests confirmed that the elastomer marked fish did not migrate back upstream to rear for another year and emigrate as 3 year-old steelhead trout smolts. The very low number of 3+ steelhead trout smolts (expanded) observed in the previous five years of study (0.4% of 2+ steelhead trout population) provides more evidence that the 2+ steelhead trout are migrating to the ocean, and not just re-distributing in the stream to over-winter a third season.

Although there seems to be few studies that specifically look at steelhead smolt to adult survival, steelhead life history studies in a British Columbia stream (Keogh River) show there is a positive linear relationship between out-migrating 2+ smolts and returning adult steelhead (Ward and Slaney 1988; Ward 2000, Ward et al. 2002). Ward (2000) cites other authors who report similar positive linear relationships between smolts and adults along the British Columbia coast as well (eg Smith and Ward 2000). Survival from smolt to adult can be variable, and may range from an average of 15% (during 1976-1989) to an average 3.5% (during 1990-1995) (Ward 2000). Ward and Slaney (1988), reporting on data from the Keogh River for 1978 – 1982 cohorts, determined survival from smolt to adult ranged from 7% to 26%, and averaged 16%. Meehan and Bjornn (1991) reported steelhead smolt to returning adult survival can be a relative high ranging from 10 – 20% in streams that are coastal to a low survival of 2% in streams where steelhead must overcome dams and travel long distances to reach spawning grounds. It is difficult to make specific inferences about 2+ steelhead smolt to adult survival for upper Redwood Creek steelhead based upon successful studies in the literature because of differences in latitude/longitude, geography, ocean conditions (physical and biological), estuaries, and trap locations in the watershed. However, the belief that the number of 2+ smolts relate to future adults (and watershed conditions) is hard to dismiss or invalidate.

With respect to younger juvenile stages (0+ and 1+), the 2+ steelhead smolt is the best candidate for assessing steelhead status, trends, and abundance when information on adult steelhead is unavailable or un-attainable. 2+ steelhead trout have overcome the numerous components of stream survival that younger steelhead (0+ and 1+) have not yet completely faced (over-summer, over-winter, etc), and 2+ steelhead smolts are also the most direct recruit to adult steelhead populations. Along these same lines, Ward et al. (2003) reported that the 2+ steelhead smolt was a more reliable response variable with respect to stream restoration than late summer juvenile densities because of being less variable.

0+ Pink Salmon

Pink salmon in California are recognized as a "Species of Special Concern", and California is recognized as the most southern border for the species (CDFG 1995). Although not in large numbers, pink salmon have been historically observed in the San Lorenzo River, Sacramento River and tributaries, Klamath River, Garcia River, Ten Mile River, Lagunitas River, Russian River, American River, Mad River, and once in Prairie Creek, which is tributary to Redwood Creek at RM 3.7. Pink salmon were observed spawning in the Garcia River in 1937, and the Russian River in 1955 (CDFG 1995). More recently, adult pink salmon were seen spawning in the Garcia River in 2003 (Scott Monday pers. comm. 2004) and in Lost Man Creek (tributary to Prairie Creek) in 2004 (Baker Holden, pers. comm. 2005).

I know of no historic records or anecdotal information documenting pink salmon presence in Redwood Creek prior to our downstream migration trapping efforts. The pink salmon in Redwood Creek are in very low numbers, and prior to study year 2005, were only caught in even numbered years (e.g. YR 2000, YR 2002, and YR 2004). The two individuals caught in YR 2005 may indicate that pink salmon are now spawning upstream of the trap site in even and odd numbered years.

It is hard to say if the parents of the juvenile pink salmon were stays or remnants of a historic run because so little information exists about adult salmon in Redwood Creek. According to the Habitat Conservation Planning Branch (HCPB) of CDFG, pink salmon are considered to be "probably extinct" in California (CDFG 1995). However, the HCPB does state that "more efforts need to be conducted to prove (or disprove) that reproducing populations exist anywhere in California" (CDFG 1995). Based upon our trapping data from upper Redwood Creek, it appears that pink salmon are present and reproducing, albeit in low numbers.

Coho Salmon

We have not seen any juvenile coho salmon in six consecutive study years. We look at every individual fish we catch; thus, it seems highly probable that the trapping effort would catch some juveniles if they were present above the trap site. Additionally, juvenile coho salmon (eg parr and smolts) are fairly easy to identify from juvenile steelhead trout and Chinook salmon. Therefore, the trap data shows that coho salmon are not successfully returning to spawn upstream of the trap site. Historic records of coho salmon in areas above the trap site, though anecdotal, do warrant mentioning. Bill Chezum (long time resident in Redwood Valley, pers. comm. 2001) observed schools of adult coho salmon in areas upstream of the current trap site while growing up in Redwood Valley. He particularly mentioned seeing coho in the 1940's and early 1950's. Every year he watched the fish swim past him in schools during their spawning run, and around the time of the 1955 flood event, the coho seemingly disappeared. Marlin Stover (pers. comm. 2000), who is also a long time resident in Redwood Valley, corroborates Bill Chezum's observations of adult coho in upper Redwood Creek. Minor Creek, a tributary to Redwood Creek upstream of the trap site, supposedly supported runs of coho salmon. Lacks Creek, a tributary to Redwood Creek downstream of the trap site by about 9 miles, supports coho salmon (Bill Jong, pers. comm. 2003; CDFG 1953); and Prairie Creek (tributary to Redwood Creek at about RM 3.7) supports a fairly stable population of coho salmon. The last reported sighting of juvenile coho salmon upstream of the trap site occurred in 1997 (Tom Weseloh, pers. comm. 2003).

Even if the historic run of coho salmon from upper Redwood Creek is extirpated, I am surprised that we have not seen juvenile coho salmon because a few adults should at least stray into upper Redwood Creek from a tributary or mainstem area downstream of the trap site. Madej et al. (2005, draft) report that stream temperatures upstream of the trap site are probably too high for successful juvenile coho salmon rearing. Stream temperature data collected at the trap site supports their findings, however, adult coho salmon that could stray or migrate into upper Redwood Creek would not face these high stream temperatures. The lack of coho salmon in upper Redwood Creek is worthy of additional study.

Cutthroat Trout

A low number of cutthroat trout were captured in all six study years (< 9 individuals each year, total = 24), and only two individuals were captured in YR 2005. All cutthroat trout that were captured were in a smolt stage. An unknown number or percentage of cutthroat trout will residualize in the stream for varying years, and not out-migrate to the estuary and ocean; thus the low trap catches may not necessarily reflect a low population size in upper Redwood Creek. However, if there were large numbers present, we would probably catch much more than we do, as they re-distribute or migrate downstream. For example, juvenile salmonid trapping efforts in Prairie Creek consistently capture cutthroat trout during spring/early summer as they migrate downstream (Roelofs and Klatte 1996; Roelofs and Sparkman 1999, Walt Duffy, pers. comm. 2003).

We did not consider any of the young-of-year steelhead trout to be progeny of cutthroat trout because few aged 1 and older cutthroat trout were captured in any given year (average 4 per year). Upper Redwood Creek has far more older juvenile steelhead trout (1+ and 2+) than cutthroat trout as evidenced by trap catches. In the six study years, the ratio of 1+ and 2+ steelhead trout combined catches to cutthroat trout catches each year ranged from 1,534:1 to 7,881:1, and using all data equaled 3,366:1. Ratios would be even higher if juvenile steelhead trout population data were used instead of catch data. It seems very unlikely that low numbers of cutthroat trout could produce a significant portion of the juvenile trout captures. Therefore, we considered the percentage of 0+ cutthroat trout included in the 0+ steelhead trout catch to be low and negligible.

We used three characteristics to identify coastal cutthroat trout: upper maxillary that extends past the posterior portion of the eye, slash marks on the lower jaws, and hyoid teeth; spotting is also usually more abundant on coastal cutthroat trout. Hybrid juveniles, the product of mating between steelhead trout and cutthroat trout, are commonly noted to be missing one or two of these characters. We have observed less than four individuals in the six years that could have been hybrid juveniles. Thus, out of 74,063 1+ and 2+ steelhead trout catches, only 0.00005% appeared to show hybrid characteristics. Based upon visual identification, the number of potential hybrids (age 1 and greater) is extremely rare in upper Redwood Creek.

Stream Temperatures

The average stream temperature in a given trapping period ranged from 13.5 to 16.3 °C (56.4 to 61.3 °F), with the lowest values occurring in the wettest water years (WY 2003 and 2005), and the highest occurring in the driest water year (WY 2001). Stream temperatures each study year were inversely related to stream discharge during the trapping period, thus with higher flows we observed cooler stream temperatures. Daily stream gage height (a surrogate for daily discharge) was also inversely related to daily stream temperatures; with a higher gage height (due to higher flows) we observed decreases in daily stream temperature. Conversely, stream temperatures increased with decreasing stream (or water) depth. The large influence of discharge (or gage height) on stream temperature in upper Redwood Creek was evidenced by a relatively high R^2 of 0.82, which indicates that 82% of the variation in stream temperature can be explained by the variation in stream discharge or gage height. Of course there are other variables that can also affect stream temperature that were not tested (e.g. riparian canopy cover over the stream, air temperature, and streambed sediments, among others). Variation due to temperature gage placement was minimized by placing the probes in the same place each year.

Stream temperatures in YR 2005 followed the same general trend as previous study years; temperatures were lowest in April and gradually increased to maximum values in July. Daily stream temperatures during the trapping period in YR 2005 and the previous four year average followed the same general trend of increasing over the course of the study and decreasing at the end of the study. Although there was some variation in average monthly and daily stream temperatures in YR 2005 with the previous four year average,. differences were not significant.

Stream temperatures measured at the trap site appear to influence the degree of smolting for 1+ steelhead trout and 2+ steelhead trout; with colder temperatures, more of the juvenile steelhead emigrants were classified as smolts. Quinn (2005) reports that both photo period and steam temperature play important roles in smoltification by providing an external stimulus for the endocrine system, which drives the internal physiological changes necessary for smoltification. Stream temperatures also appeared to influence the migration of juvenile salmonids from upper Redwood Cr in YR 2005. The migration of 0+ Chinook salmon, 1+ steelhead trout, and 2+ steelhead trout populations was inversely related to stream temperatures; however, catches of 0+ steelhead trout were positively related to stream temperatures. Migration prior to times of increasingly higher stream temperatures could be a favorable life history strategy because high stream temperatures can cause stress and mortality, among other negative outcomes. The increase in migration of 0+ steelhead trout with increasing stream temperatures may, in part, indicate that rearing space or habitat conditions were not very favorable. In general, emigration prior to times when streams or sections of streams reach high or maximum temperatures (July/August) can be viewed as an advantageous life history strategy, and one that juvenile salmonids in upper Redwood Creek appear to employ.

CONCLUSIONS

The migration of juvenile salmonids from upper Redwood Creek in YR 2005 was the lowest of the six current study years. 0+ Chinook salmon experienced the greatest reduction (90%) in population size, which could be attributable to high winter flows which either scoured or jostled redd gravels in early December. 1+ steelhead trout population emigration in YR 2005 was reduced by 40%, 2+ steelhead trout emigration was reduced by 64%, and the catches of 0+ steelhead trout in YR 2005 was 59% less than the average catch in previous study years. All juvenile salmonids showed a negative preliminary trend over the six years of study; however, statistical significance was only found for 1+ steelhead trout. The number of 1+ steelhead trout in a given year was inversely related to the catches of 0+ steelhead trout the previous year. The predicted number of 1+ steelhead trout in YR 2005 was 7% more than the mark/recapture estimate for YR 2005. The pattern of population migration for 0+ Chinook salmon, 1+ steelhead trout, and 2+ steelhead trout in YR 2005 was skewed towards the beginning of the trapping season, with peak emigration occurring in April for each species at age. This pattern was similar to the pattern of the previous five year average for 0+ Chinook salmon and dissimilar to the migration pattern for 1+ and 2+ steelhead trout, which is normally in the middle of the trapping period.

The population of 0+ Chinook salmon emigrants in YR 2005 consisted of both fry and fingerlings, with more fry emigrating than fingerlings. No relationships between the percentage of fry and population size, stream temperature, or stream discharge were detected. The percentage of fry in a given study year did not influence the average emigrant size by year, however, the percentage of fry in a given week influenced the average size by week in YR 2005. The size of emigrating juvenile Chinook salmon and 0+ steelhead trout in YR 2005 was greater than previous study years; the size of 1+ and 2+ steelhead trout in YR 2005 was greater than YRS 2002-2004, and less than YRS 2000 and 2001. A density-dependent relationship of emigrant numbers and size was detected for 0+ Chinook salmon and 0+ steelhead trout over the six years of study; with higher numbers emigrating, the average size of the emigrants decreased. A positive relationship between emigrant numbers and size was detected for 1+ steelhead trout. This may indicate that stream conditions favorable for survival were also favorable for growth. No such relationships were detected for 2+ steelhead trout.

Twenty-seven pit tagged 0+ Chinook salmon fingerlings from upper Redwood Creek were recaptured 29 miles downstream at the second trap in lower Redwood Creek. Travel time ranged from 1.5 – 19.5 d, and averaged 7.5 d. Travel rate ranged from 1.5 – 19.3 mi/d, and averaged 8.2 mi/d. The recapture of pit tagged 0+ Chinook salmon per release group was variable. Individuals from the same release group were recaptured on the same day and in contrast, multiple recaptures from the same release group could be on different days. The greatest range in travel time for multiple recaptures from a single release group was 15 days. Fifty-two percent of the downstream migrating pit tagged 0+ Chinook salmon showed growth (FL, Wt), 18% showed a decrease in Wt, 48% showed no change in FL, and 30% showed no change in Wt. Growth was positively related to travel time and negatively related to travel rate. Thus, fish that took longer to reach the lower trap gained more FL and Wt than fish that traveled the distance in less amount of time. The final size of recaptured pit tagged 0+ Chinook salmon was positively related to the initial size at tagging. The importance of this relationship is that fish size at the upper trap (initial size) had a large impact on fish size at the lower trap (final size); larger fish recaptured at the lower trap were more likely to have been the larger fish released at the upper trap.

RECOMMENDATIONS

This study is one of the few studies that is designed to document smolt abundance and population trends of the California Coastal Chinook salmon ESU, Southern Oregon/Northern California Coasts Coho salmon ESU, and Northern California Steelhead Trout ESU over a relatively long time period. With respect to the Chinook salmon ESU, this study might be the only one that provides population data for a relatively large stream.

The most important recommendation to make is to continue this study over multiple consecutive years (10+) in order to:

1. Collect base line data for future comparisons.

2. Detect changes in population abundance which can be used to assess the status and trends of Chinook salmon, steelhead trout, and coho salmon in upper Redwood Creek.

3. Detect any fish response (population, fish size, etc) to stream and watershed conditions, and restoration activities in the upper basin.

4. Help focus habitat restoration efforts and needs in the basin.

This study, when combined with juvenile salmonid monitoring in the lower basin (lower trap at RM 4, estuarine studies) will also help determine potential bottlenecks to anadromous salmonid production in Redwood Creek.

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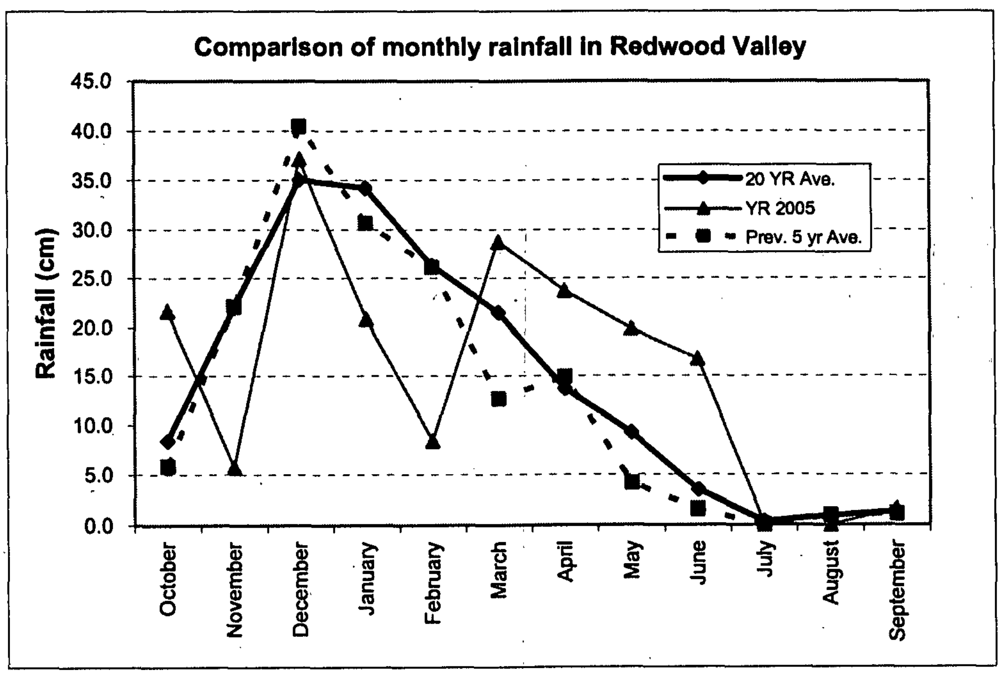
APPENDICES

Appendix 1. Comparison of 20 year average annual rainfall with average of previous five water years (2000 - 2004) and water year 2005 at Hinz family residence, Redwood Valley, Redwood Creek, Humboldt County, California.

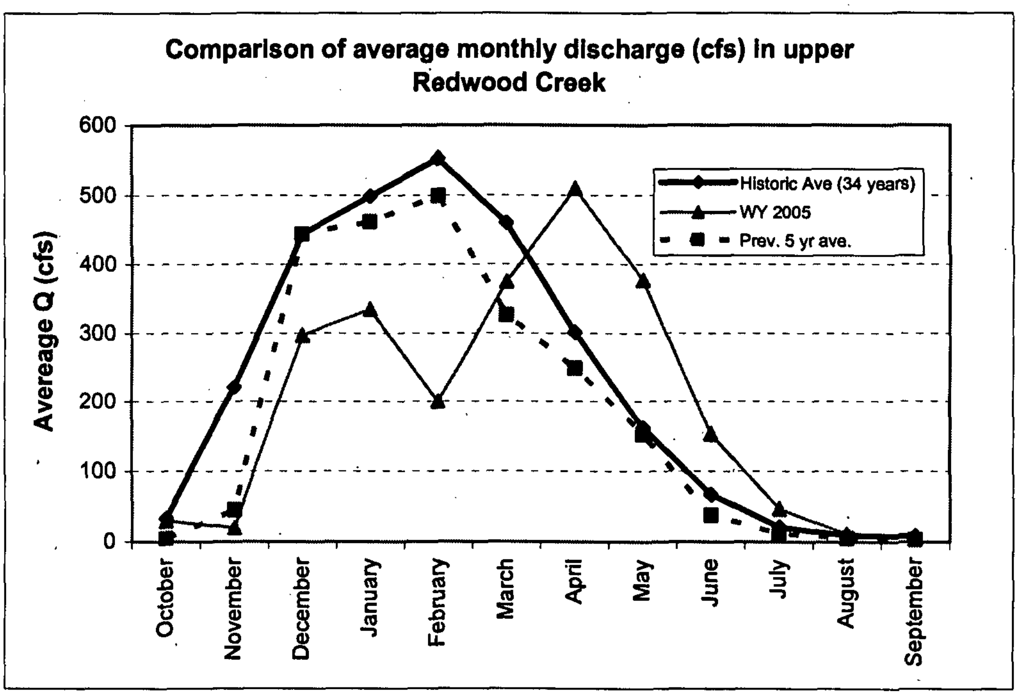
	Annual Rainfall* (centimeters)		
Month	Historic Average	Average of previous 5 study years (2000-04)	Water Year 2005
Oct.	8.4	5.9	21.7
Nov.	22.0	22.1	5.8
Dec.	35.1	40.5	37.2
Jan.	34.2	30.7	20.9
Feb.	26.3	26.1	8.4
Mar.	21.5	12.7	28.8
Apr.	13.7	14.9	23.8
May	9.2	4.2	19.9
June	3.5	1.6	16.8
July	0.3	0.0	0.0
Aug.	0.9	1.0	0.0
Sept.	1.3	1.1	1.6
Total:	176.6	160.8	184.9

* Data courtesy of Redwood National Park, Vicki Ozaki pers. comm. 2005.

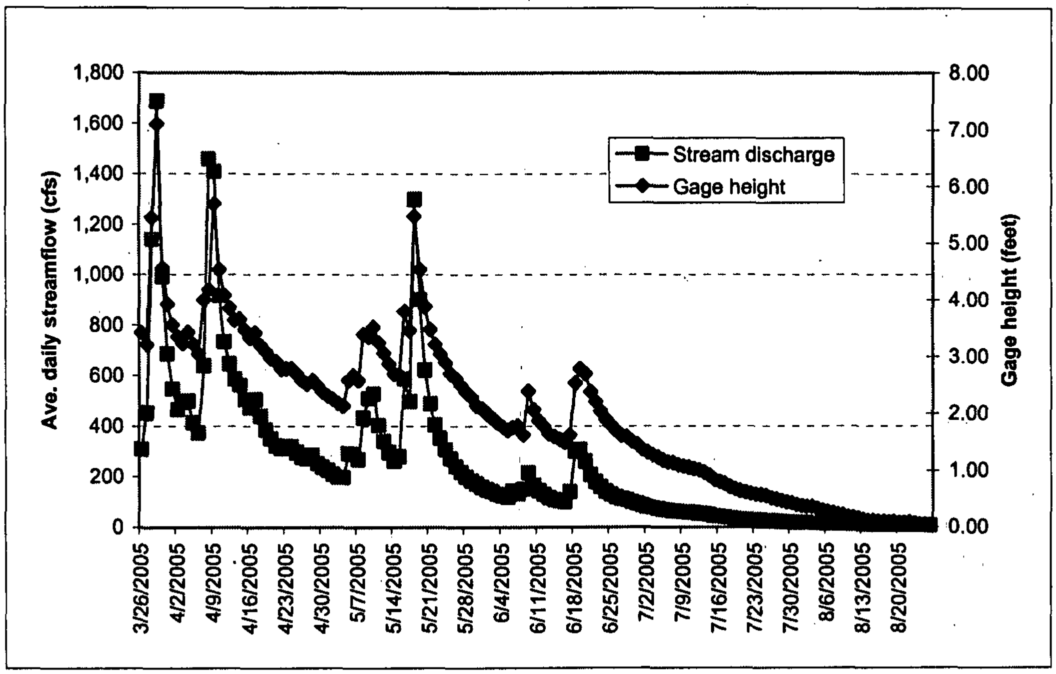


Appendix 2. Comparison of 34 year average monthly discharge (cfs) with average of previous five water years and water year 2005, O'Kane gaging station, upper Redwood Creek, Humboldt County, CA. (USGS 2005).

	Annual Discharge (cfs)		
Month	Historic Average	Average of previous 5 study years (2000-04)	Water Year 2005
Oct.	33	5	30
Nov.	222	45	20
Dec.	444	444	298
Jan.	499	462	335
Feb.	553	500	200
Mar.	460	327	375
Apr.	302	250	511
May	162	153	377
June	67	38	153
July	21	12	47
Aug.	9	5	11
Sept.	8	3	6
Ave:	232	187	197



Appendix 3. Graphical representation of daily stream gage height (feet) at trap site and average daily stream flow (cfs) at O'Kane gaging station (USGS 2005), upper Redwood Creek, Humboldt County, CA.



Appendix 4. Regression and correlation results for tests of average weekly gage height (ft), stream discharge (cfs), stream temperature (°C), and time (week number) on catches of all species combined and for each species at age, and regression results of trapping efficiencies on 0+ Chinook salmon, 1+ steelhead trout, and 2+ steelhead trout catches, upper Redwood Creek, Humboldt County, CA., 2005

Weekly Values		Regression Results			
Y variable (Catches)	X variable	p value	R^2 or r*	Slope Sign	Power of test
All spp.**	Gage height	0.23	0.07	Negative	0.22
All spp.**	Discharge**	0.22	0.07	Negative	0.22
All spp.	Temperature	0.02	0.23	Positive	0.65
All spp.**	Week number*	0.21	0.08	Positive	0.24
0+ KS	Gage height	0.77	0.00	Negative	0.06
0+ KS	Discharge	0.22	0.07	Negative	0.22
0+ KS	Temperature	0.71	0.00	Negative	0.06
0+ KS**	Week number**	0.42	0.17*	Negative	0.12
0+ KS	Trap efficiency	0.92	0.00	Positive	0.05
0+ SH**	Gage height	0.0008	0.43	Negative	0.96
0+ SH**	Discharge	0.00002	0.60	Negative	1.00
0+ SH**	Temperature	0.002	0.38	Positive	0.92
0+SH**	Week number*	0.002	0.62	Positive	0.93
1+ SH**	Gage height	0.006	0.32	Positive	0.83
1+ SH**	Discharge	0.01	0.27	Positive	0.74
1+ SH**	Temperature	0.004	0.35	Negative	0.88
1+ SH**	Week number*	0.00007	0.74	Negative	1.00
1+ SH**	Trap efficiency	0.002	0.39	Negative	0.92
2+ SH	Gage height	0.009	0.29	Positive	0.78
2+ SH**	Discharge	0.008	0.30	Positive	0.80
2+ SH	Temperature	0.001	0.41	Negative	0.94
2+ SH	Week number*	0.0002	0.70	Negative	0.99
2+ SH	Trap efficiency	0.11	0.12	Negative	0.34

* R^2 is for physical variables (temperature, etc.), "r" is for trapping week number.
** Log (x+1) transformation.

Appendix 5. Regression and correlation results for tests of average weekly gage height (ft), stream discharge (cfs), and stream temperature (°C) on weekly population emigration of 0+ Chinook salmon, 1+ steelhead trout, and 2+ steelhead trout in YR 2005.

Weekly Values		Regression Results			
Y variable (Population)	X variable	p value	R^2 or r*	Slope Sign	Power of test
0+ KS**	Gage height**	0.008	0.30	Positive	0.80
0+ KS**	Discharge**	0.008	0.30	Positive	0.80
0+ KS**	Temperature	0.02	0.25	Negative	0.69
0+ KS**	Week number*	0.02	0.48	Negative	0.64
1+ SH**	Gage height	0.003	0.37	Positive	0.90
1+ SH**	Discharge	0.006	0.32	Positive	0.83
1+ SH	Temperature	0.002	0.39	Negative	0.92
1+ SH**	Week number*	0.0002	0.72	Negative	0.99
2+ SH	Gage height	0.006	0.32	Positive	0.84
2+ SH**	Discharge	0.003	0.36	Positive	0.90
2+ SH	Temperature	0.0007	0.44	Negative	0.97
2+ SH	Week number*	0.0001	0.73	Negative	0.99

* R^2 is for physical variables (temperature, etc.), "r" is for trapping week number.
** Log (x+1) transformation.

Appendix 6. **Travel time (d) and travel rate (mi per day) for 0+ Chinook salmon released at upper trap site and recaptured at lower trap (distance of 29 miles) in Redwood Creek, Humboldt County, CA., 2005.**

Travel Time Experiments

Age/species	Initial FL mm	Mark or Tag type	Date Released*	Date Recaptured**	Travel time (d)	Travel rate (mi d^{-1})
0+ KS	76	Pit Tag	6/03/05	6/14/05	10.5	2.8
0+ KS	77	Pit Tag	6/08/05	6/15/05	6.5	4.5
0+ KS	87	Pit Tag	6/09/05	6/12/05	2.5	11.6
0+ KS	79	Pit Tag	6/09/05	6/15/05	5.5	5.3
0+ KS	70	Pit Tag	6/09/05	6/17/05	7.5	3.9
0+ KS	83	Pit Tag	6/15/05	6/24/05	8.5	3.4
0+ KS	84	Pit Tag	6/15/05	7/03/05	17.5	1.7
0+ KS	83	Pit Tag	6/16/05	7/02/05	15.5	1.9
0+ KS	81	Pit Tag	6/24/05	6/26/05	1.5	19.3
0+ KS	85	Pit Tag	6/24/05	6/27/05	2.5	11.6
0+ KS	87	Pit Tag	6/30/05	7/02/05	1.5	19.3
0+ KS	85	Pit Tag	6/30/05	7/02/05	1.5	19.3
0+ KS	87	Pit Tag	6/30/05	7/02/05	1.5	19.3
0+ KS	90	Pit Tag	6/30/05	7/02/05	1.5	19.3
0+ KS	84	Pit Tag	6/30/05	7/02/05	1.5	19.3
0+ KS	72	Pit Tag	7/01/05	7/04/05	2.5	11.6
0+ KS	74	Pit Tag	7/07/05	7/10/05	2.5	11.6
0+ KS	76	Pit Tag	7/08/05	7/23/05	14.5	2.0
0+ KS	73	Pit Tag	7/14/05	7/18/05	3.5	8.3
0+ KS	72	Pit Tag	7/15/05	8/03/05	18.5	1.6
0+ KS	76	Pit Tag	7/21/05	7/26/05	4.5	6.4
0+ KS	73	Pit Tag	7/21/05	7/30/05	8.5	3.4
0+ KS	81	Pit Tag	7/21/05	8/01/05	10.5	2.8
0+ KS	74	Pit Tag	7/21/05	8/04/05	13.5	2.1
0+ KS	76	Pit Tag	7/21/05	8/10/05	19.5	1.5
0+ KS	85	Pit Tag	7/28/05	8/03/05	5.5	5.3
0+ KS	87	Pit Tag	7/28/05	8/10/05	13.5	2.1
Ave:	80 (SD =5.9)				7.5 (SD = 5.9)	8.2 (SD = 6.9)

* Released at upper trap site (RM33) at night (2100).
** Recaptured at lower trap (RM4).

Appendix 7. Growth of recaptured pit tagged 0+ Chinook salmon (n = 27) migrating from upper trap to the lower trap (distance of 29 mi.) in Redwood Creek, Humboldt County, CA., 2005.

	Initial Size		Size at Recapture		Period of	% Change in:		AGR**		SGRsc**		RGR**	
Age/spp	FL (mm)	Wt (g)	FL (mm)	Wt (g)*	growth (d)	FL (mm)	Wt (g)	mm/d	g/d	% (mm/d)	% (g/d)	mm/mm/d	mm/mm/d
0+ KS	87	7.6	88	7.51	2.5	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000
0+ KS	76	4.8	80	5.41	10.5	5.26	12.71	0.38	0.06	0.489	1.139	0.005	0.012
0+ KS	77	5.1	79	5.41	6.5	2.60	6.08	0.31	0.05	0.394	0.908	0.004	0.009
0+ KS	79	5.0	79	5.21	5.5	0.00	4.20	0.00	0.04	0.000	0.748	0.000	0.008
0+ KS	70	4.1	74	4.41	7.5	5.71	7.56	0.53	0.04	0.741	0.972	0.008	0.010
0+ KS	83	6.4	86	7.01	8.5	3.61	9.53	0.35	0.07	0.418	1.071	0.004	0.011
0+ KS	81	5.7	82	5.41	1.5	0.00	-5.09	0.00	-0.19	0.000	-3.481	0.000	-0.034
0+ KS	85	6.8	86	6.71	2.5	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000
0+ KS	87	7.5	87	7.01	1.5	0.00	-6.53	0.00	-0.33	0.000	-4.504	0.000	-0.044
0+ KS	83	6.2	92	8.61	15.5	10.84	38.87	0.58	0.16	0.664	2.119	0.007	0.025
0+ KS	85	6.7	86	6.31	1.5	0.00	-5.82	0.00	-0.26	0.000	-3.998	0.000	-0.039
0+ KS	87	7.7	87	7.11	1.5	0.00	-7.66	0.00	-0.39	0.000	-5.315	0.000	-0.051
0+ KS	90	8.4	90	8.81	1.5	0.00	4.88	0.00	0.27	0.000	3.177	0.000	0.033
0+ KS	84	6.3	84	5.91	1.5	0.00	-6.19	0.00	-0.26	0.000	-4.260	0.000	-0.041
0+ KS	84	6.4	91	8.31	17.5	8.33	29.84	0.40	0.11	0.457	1.492	0.005	0.017
0+ KS	72	4.0	73	4.01	2.5	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000
0+ KS	74	4.4	74	4.41	2.5	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000
0+ KS	73	4.0	74	3.91	3.5	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000
0+ KS	76	4.9	84	6.61	14.5	10.53	34.90	0.55	0.12	0.690	2.064	0.007	0.024
0+ KS	76	5.0	78	4.91	4.5	2.63	0.00	0.44	0.00	0.577	0.000	0.006	0.000
0+ KS	73	4.1	76	4.71	8.5	4.11	14.88	0.35	0.07	0.474	1.632	0.005	0.018
0+ KS	81	5.8	83	5.91	10.5	2.47	0.00	0.19	0.00	0.232	0.000	0.002	0.000
0+ KS	85	6.3	85	6.21	5.5	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000
0+ KS	72	3.9	80	5.61	18.5	11.11	43.85	0.43	0.09	0.570	1.965	0.006	0.024
0+ KS	74	4.6	82	6.11	13.5	10.81	32.83	0.59	0.11	0.760	2.103	0.008	0.024
0+ KS	87	7.2	90	7.51	13.5	3.45	4.31	0.22	0.02	0.251	0.312	0.003	0.003
0+ KS	76	4.8	89	7.01	19.5	17.11	46.04	0.67	0.11	0.810	1.942	0.009	0.024
Ave.	**80**	**5.7**	**83**	**6.15**	**7.5**	**3.65**	**9.60**	**0.22**	**0.00**	**0.279**	**0.003**	**0.003**	**0.001**

* Final weight equals weight of fish at recapture minus pit tag weight (0.09g).

** AGR = absolute growth rate, SGRsc = specific growth rate scaled, RGR = relative growth rate.

Appendix 8. Descriptive statistics of size at time 1 (T1) and time 2 (T2), percent change in size (FL, Wt), absolute growth rate (FL, Wt), relative growth rate (FL, Wt) and specific growth rate scaled (FL, Wt) for pit tagged 0+ Chinook salmon recaptured (n = 27) at the lower trap in Redwood Creek, Humboldt County, CA., YR 2005.

	Descriptive Statistics			
Variable	Min.	Max.	Ave. (median)	SD**
Size at T1				
FL mm	70	90	79.9 (81.0)	5.9
Wt g	3.9	8.4	5.69 (5.70)	1.32
Size at T2				
FL mm	73	92	82.9 (84.0)	5.7
Wt g	3.9	8.8	6.15 (6.11)	1.35
% change in				
FL mm	0.00	17.11	3.65 (2.47)	4.77
Wt g	- 7.66	46.04	9.60 (4.20)	16.50
AGR*				
FL mm	0.00	0.67	0.22 (0.19)	0.240
Wt g	- 0.39	0.27	0.00 (0.02)	0.153
RGR*				
FL mm	0.000	0.009	0.003 (0.002)	0.003
Wt g	- 0.051	0.033	0.001 (0.003)	0.023
SGR*				
FL mm	0.000	0.810	0.279 (0.232)	0.302
Wt g	- 5.315	3.177	0.003 (0.312)	2.282

* AGR = absolute growth rate (FL, mm/d; Wt g/d), RGR = relative growth rate (FL, mm/mm/d; Wt, g/g/d), SGR = specific growth rate scaled, [FL, %(mm/d); Wt %(g/d)].

** SD = standard deviation of mean.

Appendix 9. Results of linear regressions using travel time (d), travel rate (mi/d), average water temperature (°C), and average stream discharge (cfs) on various growth indices for pit tagged 0+ Chinook salmon recaptured at the lower trap in Redwood Creek, Humboldt County, CA., YR 2005.

Variables		Regression Output (Results)			
Dependent (Y)	Independent (X)	p value	R2	Slope Sign	Power of test
% Change FL	Travel Time	0.000001	0.84	Positive	1.00
% Change FL	Travel Rate*	0.000001	0.64	Negative	1.00
% Change FL	Water Temp	0.32	0.04	Positive	0.16
% Change FL	Stream discharge	0.44	0.02	Negative	0.12
% Change Wt	Travel Time	0.000001	0.82	Positive	1.00
% Change Wt	Travel Rate	0.00007	0.47	Negative	1.00
% Change Wt	Water Temperature	0.41	0.03	Positive	0.12
% Change Wt	Stream discharge	0.62	0.01	Negative	0.08
AGR** FL	Travel Time	0.000001	0.69	Positive	1.00
AGR** FL	Travel Rate	0.000004	0.58	Negative	1.00
AGR** FL	Water Temperature	0.67	0.01	Positive	0.07
AGR** FL	Stream discharge	0.70	0.01	Negative	0.07
AGR** Wt	Travel Time	0.002	0.32	Positive	0.91
AGR** Wt	Travel Rate	Test assumptions not met, test not reliable.			
AGR** Wt	Water Temperature	Test assumptions not met, test not reliable.			
AGR** Wt	Stream discharge	Test assumptions not met, test not reliable.			
SGRsc** FL	Travel Time*	0.000001	0.68	Positive	1.00
SGRsc** FL	Travel Rate	0.000006	0.56	Negative	1.00
SGRsc** FL	Water Temperature	Test assumptions not met, test not reliable.			
SGRsc** FL	Stream discharge	Test assumptions not met, test not reliable.			
SGRsc** Wt	Travel Time	0.005	0.39	Positive	0.97
SGRsc** Wt	Travel Rate	Test assumptions not met, test not reliable.			
SGRsc** Wt	Water Temperature	Test assumptions not met, test not reliable.			
SGRsc** Wt	Stream discharge*	0.37	0.03	Negative	0.14
RGR** FL	Travel Time*	0.000001	0.68	Positive	1.00
RGR** FL	Travel Rate	0.000008	0.56	Negative	1.00
RGR** FL	Water Temperature	Test assumptions not met, test not reliable.			
RGR** FL	Stream discharge	Test assumptions not met, test not reliable.			
RGR** Wt	Travel Time	0.002	0.43	Positive	0.99
RGR** Wt	Travel Rate	Test assumptions not met, test not reliable.			
RGR** Wt	Water Temp	0.83	0.00	Positive	0.05
RGR** Wt	Stream discharge	0.72	0.00	Negative	0.06

* Denotes Log (x+1) transformation to approximate linearity.

** AGR = absolute growth rate (FL mm/d; Wt g/d), RGR = relative growth rate (FL mm/mm/d; Wt g/g/d), SGR = specific growth rate scaled, [FL %(mm/d); Wt %(g/d)].

Appendix 10. 0+ Chinook salmon delayed mortality experiments, upper Redwood Creek, Humboldt County, CA., 2005.

				Fin Clipping (24 hr)		Pit Tagging (34 hr)	
Age / spp.	Date	(n)	Ave. Water Temp (C)	Morts./total	Percent Mortality	Morts./total	Percent Mortality
0+KS	4/16 - 4/17	4	9.0	0/4	0.00		
0+KS	4/19 - 4/20	6	9.3	0/6	0.00		
0+KS	5/20 - 5/21	6	10.8	0/6	0.00		
0+KS	5/23 - 5/24	9	11.9	0/9	0.00		
0+KS	6/02 - 6/03	18	13.6			0/18	0.00
0+KS	6/07 - 6/08	26	11.4			0/26	0.00
0+KS	6/08 - 6/09	32	13.4			0/32	0.00
0+KS	6/09 - 6/10	6	13.2			0/6	0.00
0+KS	6/14 - 6/15	52	13.1			0/52	0.00
0+KS	6/15 - 6/16	40	13.4			0/40	0.00
0+KS	6/16 - 6/17	50	12.2			0/50	0.00
0+KS	6/18 - 6/19	50	11.3	1/50*	2.00		
0+KS	6/22 - 6/23	23	14.4			0/23	0.00
0+KS	6/23 - 6/24	32	15.3			0/32	0.00
0+KS	6/28 - 6/29	22	17.0			0/22	0.00
0+KS	6/29 - 6/30	30	17.8			0/30	0.00
0+KS	6/30 - 7/01	30	18.1			0/30	0.00
0+KS	7/06 - 7/07	30	18.0			0/30	0.00
0+KS	7/07 - 7/08	20	17.8			0/20	0.00
0+KS	7/13 - 7/14	30	19.9			0/30	0.00
0+KS	7/14 - 7/15	30	20.9			0/30	0.00
0+KS	7/19 - 7/20	22	21.7			0/21	0.00
0+KS	7/20 - 7/21	30	21.8			0/30	0.00
0+KS	7/21 - 7/22	18	21.1			0/18	0.00
0+KS	7/27 - 7/28	10	21.9			0/10	0.00
0+KS	7/28 - 7/29	4	21.9			0/4	0.00
0+KS	7/29 – 7/30	1	22.1	0/1	0.00		
0+KS	7/31 – 8/01	2	21.6	0/2	0.00		

* Unexpected storm event occurred during this trial.

Appendix 11. 1+ Steelhead trout delayed mortality experiments, upper Redwood Creek, Humboldt County, CA., 2005.

				Fin Clipping (24 hr)		Pit Tagging (34 hr)		Elastomer (24 hr)	
Age/ Spp.	Date	(n)	Average Water Temp (°C)	Morts./ Total	Percent Mortality	Morts./ Total	Percent Mortality	Morts./ Total	Percent Mortality
1+SH	4/20-4/21	25	10.0	0/25	0.00				
1+SH	4/27-4/28	50	10.8					0/50	0.00
1+SH	5/04-5/05	48*	11.7					0/48	0.00
1+SH	5/20-5/21	1	10.8	0/1	0.00				
1+SH	5/26-5/27	27	14.2					0/27	0.00
1+SH	5/27-5/28	21	14.2					0/21	0.00
1+SH	6/01-6/02	34	13.6			0/34	0.00		
1+SH	6/08-6/09	10	13.4			0/10	0.00		
1+SH	6/09-6/10	4	13.2			0/4	0.00		
1+SH	6/11-6/12	3	13.4	0/3	0.00				
1+SH	6/15-6/16	14	13.4			0/14	0.00		
1+SH	6/16-6/17	8	12.2			0/8	0.00		
1+SH	6/18-6/19	10	11.3	0/10	0.00				
1+SH	6/20-6/21	3	13.0	0/3	0.00				
1+SH	6/22-6/23	2	14.4			0/2	0.00		
1+SH	6/23-6/24	1	15.3			0/1	0.00		
1+SH	6/24-6/25	3	15.6	0/3	0.00				
1+SH	6/26-6/27	4	15.8	0/4	0.00				
1+SH	6/27-6/28	4	15.9	0/4	0.00				
1+SH	6/29-6/30	7	17.8			0/7	0.00		
1+SH	6/30-7/01	6	18.1			0/6	0.00		
1+SH	7/06-7/07	12	18.0			0/12	0.00		
1+SH	7/07-7/08	18	17.8			0/18	0.00		
1+SH	7/13-7/14	19	19.9			0/19	0.00		
1+SH	7/14-7/15	12	20.9			0/12	0.00		
1+SH	7/18-7/19	8	21.7	0/8	0.00				
1+SH	8/05-8/06	5	22.8	0/5	0.00				
1+SH	8/08-8/09	10	22.0	0/10	0.00				
1+SH	8/12-8/13	4	21.3	0/4	0.00				
1+SH	8/19-8/20	5	21.3	0/5	0.00				
1+SH	8/22-8/23	1	21.3	0/1	0.00				

* Sample size was originally 50, two fish died immediately (w/in 5 minutes after injection).

Appendix 12. 2+ Steelhead trout delayed mortality experiments, upper Redwood Creek, Humboldt County, CA., 2005.

				Fin Clipping (24 hr)		Pit Tagging (34 hr)		Elastomer (24 hr)	
Age/ Spp.	Date	(n)	Average Water Temp (°C)	Morts./ Total	Percent Mortality	Morts./ Total	Percent Mortality	Morts./ Total	Percent Mortality
2+SH	4/20-4/21	10	10.0	0/10	0.00				
2+SH	4/27-4/28	22	10.8					0/22	0.00
2+SH	5/04-5/05	7	11.7					0/7	0.00
2+SH	5/22-5/23	1	11.6	0/1	0.00				
2+SH	5/26-5/27	4	14.2					0/4	0.00
2+SH	5/27-5/28	4	14.2					0/4	0.00
2+SH	6/01-6/02	4	13.6			0/4	0.00		
2+SH	6/02-6/03	9	13.6			0/9	0.00		
2+SH	6/04-6/05	1	13.3			0/1	0.00		
2+SH	6/07-6/08	4	11.4			0/4	0.00		
2+SH	6/08-6/09	3	13.4			0/3	0.00		
2+SH	6/09-6/10	1	13.2			0/1	0.00		
2+SH	6/10-6/11	1	13.5	0/1	0.00				
2+SH	6/13-6/14	1	14.0			0/1	0.00		
2+SH	6/15-6/16	3	13.4			0/3	0.00		
2+SH	6/16-6/17	4	12.2			0/4	0.00		
2+SH	6/17-6/18	1	11.3	0/1	0.00				
2+SH	6/20-6/21	1	13.0	0/1	0.00				
2+SH	6/22-6/23	1	14.4			0/1	0.00		
2+SH	6/23-6/24	2	15.3			0/2	0.00		
2+SH	6/24-6/25	2	15.6	0/2	0.00				
2+SH	6/27-6/28	1	15.9	0/1	0.00				
2+SH	6/29-6/30	4	17.8			0/4	0.00		
2+SH	6/30-7/01	1	18.1			0/1	0.00		
2+SH	7/04-7/05	1	17.4	0/1	0.00				
2+SH	7/06-7/07	1	18.0			0/1	0.00		
2+SH	7/07-7/08	4	17.8			0/4	0.00		
2+SH	7/08-7/09	1	18.1	0/1	0.00				
2+SH	7/13-7/14	1	19.9	0/1	0.00				
2+SH	7/14-7/15	1	20.9			0/1	0.00		
2+SH	7/17-7/18	2	21.8	0/2	0.00				
2+SH	7/22-7/23	1	20.9	0/1	0.00				
2+SH	7/26-7/27	1	21.8	0/1	0.00				
2+SH	7/29-7/30	2	22.1	0/2	0.00				
2+SH	8/05-8/06	1	22.8	0/1	0.00				
2+SH	8/08-8/09	2	22.0	0/2	0.00				
2+SH	8/11-8/12	4	21.2	0/4	0.00				
2+SH	8/18-8/19	2	21.6			0/2	0.00		
2+SH	8/19-8/20	2	21.3	0/2	0.00				
2+SH	8/20-8/21	1	20.8	0/1	0.00				
2+SH	8/22-8/23	1	21.3	0/1	0.00				

10/25/06 BdMtg Item 10
303(d) List
Deadline: 10/20/06 5pm

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COACHELLA VALLEY WATER DISTRICT

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October 19, 2006

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Song Her
State Water Resources Control Board
Executive Office
1001 I Street, 24th Floor
Sacramento, CA 95814

Dear Ms. Her:

Subject: Comment Letter-2006 Federal Clean Water Act, Section 303(d) List of Water Quality Limited Segments for California

Thank you for giving the District the opportunity to comment on the proposed revisions to the 303(d) list of impaired water segments for California.

We encourage the State Water Resources Control Board to remove the specific listings identified in our enclosed comments for the All-American Canal, Coachella Valley Stormwater Channel and Colorado River.

If you have any questions, please call me at extension 2286.

Yours very truly,

Steve Bigley
Water Quality Manager

Enclosure/1/as

cc: Dave Bolland (with enclosure)
ACWA
910 K Street, Suite 100
Sacramento, CA 95814

Tina Shields (with enclosure)
Imperial Irrigation District
Post Office Box 937
Imperial, CA 92251

Marcia Torobin (with enclosure)
Metropolitan Water District of Southern California
Post Office Box 54153
Los Angeles, CA 90012

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SB:md\eng\wr\06\oct\comments-clean water

California Department of Health Services recently adopted revisions to the California Code of Regulations, Secondary Water Standards. On September 27, these revisions became effective for all California public water systems. These regulations were revised to clarify that the secondary MCL's listed for total dissolved solids, specific conductance, chloride and sulfate are "Consumer Acceptance Contaminant Level Ranges." These regulations state that no fixed consumer acceptance contaminant level has been established for these parameters and that concentrations ranging to the Upper contaminant level are acceptable for public water supplies. No corrective action is required for water supplies with contaminant levels occurring between the recommended and upper portion of the consumer acceptance contaminant level range.

This revision to California drinking water standards occurred after the initial comment period closed on the proposed 303(d) listing. SWRCB staff needs to reevaluate the proposed ACC listing based on this regulatory action. Salinity levels in the All American Canal are below the upper level of the consumer acceptance contaminant level range. No impairment of the municipal beneficial use exists in the All American Canal for total dissolved solids, specific conductance and sulfate.

Significant resources have been spent by many State and governmental agencies participating in the Colorado River Salinity Control Forum to understand, acknowledge and manage elevated salinity levels in the Colorado River. The SWRCB reaffirmed the conclusions and recommendations for salinity management provided by this Forum in October 2005 and no salinity impairment is proposed for the Colorado River. Like the Colorado River, which supplies the All American Canal and is the source of drinking water for over 23 million people, the All American Canal continues to be an important drinking water supply for the public. The salinity, including specific conductance, sulfate and total dissolved solids, in the ACC is a result of processes occurring within the Colorado River watershed upstream of the ACC and is not the result of controllable discharges into the ACC. It would be unreasonable and inconsistent to condemn the All American Canal to an impaired water status, when your agency has already concluded the Colorado River is not impaired for these same parameters.

We respectively request that the SWRCB withdraw the recommendation to list the All American Canal as impaired for total dissolved solids, specific conductance and sulfate.

3. Recommendation to list the Colorado River for selenium

The SWRCB proposes to list the Colorado River (Imperial Reservoir to California-Mexico Border) as water quality limited for selenium. The SWRCB's justification is based on fish tissue test results for five samples collected in 1992, 1999, and 2000-2001 on largemouth bass. It is indicated that three of the five samples exceeded the Office of Environmental Health Hazard Assessment (OEHHA) 2 *ug*/g tissue screening value guideline.

The five fish tissue samples do not provide a scientifically robust data set to support the proposed listing. A larger study of fish tissue samples representative of water supplying the subject segment was developed for the Salton Sea Ecosystem Restoration Plan in May 2005, when 18 fish samples were collected and tested for selenium. The sample locations included sites from the Lake Havasu to Lake Martinez area, which is immediately upstream of the Imperial Dam. The selenium results range from 0.56 to a maximum of 2.26 *ug*/g fish tissue screening value.

- The Basin Plan does not contain a water quality objective of 0.005 mg/L for selenium applicable to the CVSC as indicated in the SWRCB response to comments. The toxaphene drinking water standard of 0.005 mg/L does not apply to the CVSC which is not designated for municipal beneficial uses. No data exists to indicate toxaphene is present in the CVSC. We have performed water monitoring for toxaphene within the subject segment at our monitoring station where Lincoln Street and Avenue 72 intersect the CVSC for 18 years. The results of this monitoring, summarized in the attached table 1, confirm no toxaphene is found in water within the CVSC.

- The only evidence provided to support the decision to list the CVSC for toxaphene is the results of tests performed on 8 fish, 3 of which consisted of two red shiners and one tilapia containing toxaphene in levels exceeding the NAS guidelines for fish tissue. Tissue results performed on these fish do not provide sufficient evidence to link toxaphene in the fish tissue samples to exposure in the CVSC. Red shiner is a popular bait fish used for fishing in the Salton Sea downstream of the CVSC. The red shiners collected may have been bait fish that were raised in a farm where they were exposed to toxaphene when consuming fish food contaminated with toxaphene. Toxaphene is one of many persistent organochlorine pesticides that has been used historically on crops and is found in fish food. Studies show that toxaphene occurs in farm raised fish at concentrations significantly higher than in wild fish. Fish food does not undergo the same level of quality control as does other food crops used for human consumption so it is common to find contaminants in food used at fish farms. It would be inappropriate to use bait fish like red shiner that are likely to have been raised in another water body to support the proposed toxaphene listing. Without the results of fish tissue samples from the 2 red shiners, there is insufficient evidence to support the proposed listing.

Board staff has failed to provide sufficient evidence to support listing the CVSC as water quality limited for toxaphene. There is no sediment or water column data indicating toxaphene is present in this water body. Contrary to the SWRCB response to comments, there is no water quality objective for toxaphene in the Basin Plan for the Colorado River Basin. Board staff has not provided adequate evidence to link fish tissue sample results to toxaphene exposure in the CVSC.

We respectively request that the Board withdraw the recommendation to list the Coachella Valley Storm Water Channel as water quality limited for toxaphene.

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10545 Armstrong Avenue
Mather, CA 95655
Tele: [916] 876-6000
Fax: [916] 876-6160
Website: www.srcsd.com

October 18, 2006

Song Her, Clerk to the Board
State Water Resources Control Board
1001 I Street
Sacramento, California 95814

Subject: Comment Letter - 2006 Federal CWA Section 303(d) List

Dear Ms. Her:

The Sacramento Regional County Sanitation District (SRCSD) appreciates the opportunity to provide written comments both on the State Water Resources Control Board's (State Water Board) September 2006 Staff Report regarding preparation of the 2006 303(d) List, and on the September 15, 2006 List itself. SRCSD is a regional sanitation district that serves over a million customers in the Sacramento metropolitan area and owns and operates the Sacramento Regional Wastewater Treatment Plant (SRWTP). The SRWTP discharges directly into the Sacramento River downstream of Freeport, which in this revision of the 303(d) list is now part of a new water quality limited segment titled the Delta Waterways (northern portion), in Region 5.

We commend the State Water Board staff again for the obvious effort that has gone into the documentation for the proposed 2006 listings, and the preparation of the September 2006 update of the Staff Report titled, *Revision of the Clean Water Act Section 303(d) List of Water Quality Segments.* The Staff Report continues to contain a much more detailed description and analysis of the basis and information used for listing recommendations than past processes. However, SRCSD has found five items that are incorrect in the Staff Report and is continuing to propose two additional revisions. These recommended revisions in the Staff Report would result in not adding DDT and polychlorinated biphenyls (PCBs) to the September 15, 2006 Proposed 2006 List in the Delta Waterways (northern portion) water quality segment of the Central Valley, Region 5. Our specific comments to various portions of the Listing Document are outlined below, which we believe must be addressed to ensure clarity, consistency and the use of sound science.

CORRECTIONS AND PROPOSED REVISIONS TO THE 2006 303(d) LIST

Two of the five corrections are for not completely addressing two of SRCSD's comments made in our January 31, 2006 comment letter that is enclosed for your review. The other three corrections are related to use of new Delta Waterway mapping areas. The two recommended revisions are for requested changes in response to the two comments that were not completely addressed.

The sequence of our comments below follows the order of the Staff Report and the resulting 2006 Section 303(d) List. However, because Volumes II, III and IV of the Staff Report serve as the foundation for Volume I, we have addressed items in the foundation volumes prior to Volume I. Similarly, because the 2006 List itself is the result of all work in the various volumes of the Staff Report, we have addressed that last in our comments (not because it is least important).

Corrections

In the Staff Report, Volume IV (Responses to Comments) SRCSD's comments numbers 1, 2, and 5 were correctly placed, but comments 3 and 4 were not. Comment 1 (page 19) is with the set of comments on Staff Report Volume 1, while comments 2 and 5 are on page 114 with the Central Valley Region Fact Sheets. However, comments 3 and 4 were mistakenly placed with the Santa Ana Region Fact Sheet comments on page 134. Apparently the two comments were placed there because the first part of each comment argues against using OEHHA screening values for fish tissue pollutant concentrations. However, each of the two comments has five parts, and the other four parts present arguments about the data used for DDT and PCB evaluations, and other information about the Delta Waterways (northern portion) water quality segment in Region 5. This error should be corrected by placing a complete answer to all five parts of these two comments, with our comments 2 and 5 on page 114 of the Central Valley Region Fact Sheet comments. Specifically, the contents of SRCSD's comments that were omitted from page 114 of Volume IV, requested that the SWRCB consider:

3. Not adding DDT as a pollutant in the Delta Waterways (northern portion) water quality limited segment.
4. Not adding polychlorinated biphenyls (PCBs) as a pollutant in the Delta Waterways (northern portion) water quality limited segment.

In the Staff Report, Volume III (Water Body Fact Sheets Supporting the Listing and Delisting Recommendations), for the Central Valley (Region 5), in the section of that document labeled Area Change Recommendations, descriptions are correctly made that place SRCSD in the Delta Waterways (northern portion), one of eight currently defined Delta segments. However, the section of that same document labeled List as Being Addressed Recommendations for the Delta only includes the 2002 set of three Delta waterways (pages 89 to 95). This list should be corrected to expand it to include all eight Delta Waterways and should also include Chlorpyrifos and Diazinon in the Delta Waterways (northern portion), since that TMDL was completed for the entire Delta in June 2006.

In the Staff Report, Volume I, Table 8 (Additions to the List Being Addressed), should be corrected on page 44 to expand it to include all eight new Delta Waterways in Region 5, including the northern portion, for Chlorpyrifos and Diazinon, as was done for the old 2002 3-Delta-waterways definitions.

Also in the Staff Report, Volume I, Table 11 (Schedule) should be corrected on page 85 to include the Delta Waterways (northern portion), and all other new Delta Waterway descriptions in Region 5, in this case for work on mercury, and not just the three old Delta designations of the Stockton Ship Channel, the eastern portion and the western portion.

All of the above corrections should be incorporated in the revised 2006 Section 303(d) List itself for the Delta Waterways (northern portion) water quality limited segment.

Proposed Revisions

In the Staff Report, Volume III (Water Body Fact Sheets Supporting the Listing and Delisting Recommendations) for the Central Valley (Region 5), SRCSD's two comments (3 and 4) that were misplaced in Volume IV should be considered completely.. We would request again, that both DDT and PCBs not be added to the 2006 list, in the Delta Waterways (northern portion), for the multiple reasons stated in our January 31, 2006 letter.

In the Staff Report, Volume I, Table 7 (Additions to the List) should be revised on page 27 to delete DDT and PCBs from the Delta Waterways (northern portion) of Region 5 as a result of the changes in Volume III above, again based on the multiple reasons listed in our letter of January 31, 2006.

As a result of the revisions requested above, the 2006 Section 303(d) List should also be revised by not adding DDT and PCBs to the Delta Waterways (northern portion) water quality limited segment.

Conclusion

In summary, SRCSD has reviewed the State Water Board September 2006 Staff Report and the September 15, 2006 proposed 2006 CWA Section 303(d) List. SRCSD appreciates the opportunity to review these documents and requests that the SWRCB make changes in the proposed 303(d) list as specifically stated above to improve the documents clarity, consistency and the use of sound science. Our staff is available to discuss these corrections and requested changes in greater detail at the convenience of State Water Board staff.

Sincerely,

Wendell H. Kido

Wendell H. Kido
District Manager

Enclosure (1)

MKS/TM:mf

cc: Mary Snyder, SRCSD
Terrie Mitchell, SRCSD
Craig Wilson, State Water Resources Control Board
Dorena Goding, State Water Resources Control Board

SRCSD

Wastewater Treatment

Technology in balance with nature

10545 Armstrong Avenue
Mather, CA 95655
Tele: [916] 876-6000
Fax: [916] 876-6160
Website: www.srcsd.com

January 31, 2006

Craig J. Wilson, Chief
Water Quality Assessment Unit
Division of Water Quality
State Water Resources Control Board
P.O. Box 100
Sacramento, California 95812-0100

Subject: **Comments on *Draft Staff Report on Revision of the Clean Water Act Section 303(d) List of Water Quality Limited Segments, September 2005*, Prepared by the State Water Resources Control Board**

Dear Mr. Wilson:

The Sacramento Regional County Sanitation District (SRCSD) appreciates the opportunity to provide written comments on the State Water Resources Control Board's draft Staff Report regarding preparation of the 2006 303(d) List. SRCSD is a regional sanitation district that serves over a million customers in the Sacramento metropolitan area and owns and operates the Sacramento Regional Wastewater Treatment Plant (SRWTP). The SRWTP discharges directly into the Sacramento River downstream of Freeport, which in this latest revision of the 303(d) list is now part of a new water quality limited segment titled the Delta Waterways (northern portion), in Region 5.

We commend you and your staff for the obvious effort that has gone into the documentation for the proposed 2006 listings. The draft Staff Report contains a much more detailed description and analysis of the basis and information used for listing recommendations than past processes. However, SRCSD has four major areas of disagreement with the proposed 303(d) list, as described below. SRCSD also agrees with both the decisions to delete water quality segments from the 2002 list, and not to add four segments to the previous list.

MAJOR AREAS OF DISAGREEMENT WITH THE PROPOSED REVISED 2006 LIST

One of the four points of disagreement is a continuing concern from past listing and policy preparation products. The other three are new issues from the September 2005 documents. In summary, our major concerns are:

1. Use of un-adopted numeric "criteria" and other bases identified in the Listing Policy that are not water quality standards.

2. Listing of Exotic Species as a pollutant in many water quality limited segments.

3. Adding DDT as a pollutant in the Delta Waterways (northern portion) water quality limited segment.

4. Adding polychlorinated biphenyls (PCBs) as a pollutant in the Delta Waterways (northern portion) water quality limited segment.

1. Use of Un-adopted Numeric Values as Surrogates for Numeric Water Quality Objectives in the 303(d) Listing Process

SRCSD has continuously pointed out that the use of un-adopted numeric values as surrogate water quality objectives without formally adopting these values through the process defined in the California Water Code is inconsistent with State Law, specifically the Porter Cologne Act and the Administrative Procedures Act. As previously noted, the California Water Code establishes a clear process for the adoption of water quality objectives as part of the standard-setting process in Sections 13000, 13241 and 13242.

- In SRCSD's letter of November 2, 2001 to the Central Valley Regional Water Quality Control Board (Regional Board), we stated that the Regional Board was using numeric surrogate values for fish tissue criteria, USEPA 304(a) advisory criteria or guidelines, un-adopted California Department of Fish and Game or Department of Health Services guidelines, and health advisories imposed outside the Clean Water Act process. In that letter we also stated that SRCSD had cited this inconsistency in previous letters to the Regional Board (January 20, 1998) and the State Board (March 17 and May 26, 1998) regarding the 1998 303 (d) list.

- Similarly in SRCSD's letter to Rik Rasmussen of the State Board on February 18, 2004 we indicated that the proposed Listing Policy, Regulatory Structure and Options and the S.B. 469 TMDL Guidance were flawed because they were not using water quality standards. The 303(d) listing process and Total Maximum Daily Loads (TMDLs) that result from them are necessary to correct impairments to the standards, and if the standards are not appropriate the TMDLs also will be inappropriate. The letter to Mr. Rasmussen also explained that current standards need to be reevaluated because it is well documented that standards contained in the Regional Board's Water Quality Control Plan for the Sacramento-San Joaquin Delta and the San Joaquin River were not adopted in accordance with state law requirements. (see *A Review of the Administrative Record for the Central Valley Water Quality Control Plan, 1973-1994*, by the California Resources Management Institute, September 2003.) Consequently, that letter strongly recommended that all new policy and guidance documents advise the Regional Boards to conduct standards reviews where appropriate, and not just rely on developing Use Attainability Analyses or Site-Specific Objectives.

2. Listing of Exotic Species as a Pollutant

State Board staff have included Exotic Species as a pollutant in the 2006 303(d) listing process for the first time. While SRCSD agrees that invasive species have caused detrimental aquatic use impacts in some areas of the state, we recommend that consideration of Exotic Species as pollutants, as defined in the draft Staff Report should be deleted from this revision. SRCSD has reached this recommendation based on the following four facts:

- We agree with the Central Valley Regional Board that there are legal issues with the pollutant definition as included in this Staff Report. The draft Staff Report cites a recent court ruling (Northwest Environmental Advocates et al. vs. USEPA, 2005) regarding discharges from vessels. In the ruling, the Court specifically referred to invasive species discharged from ballast water as being pollutants. However, the State Board proposed listing would expand the applicability of this ruling to any established "non-native" species (e.g. striped bass) when there is no ongoing discharge of these non-native species. The Regional Board has reviewed this ruling and found that it does not have the authority to regulate the distribution and population of established non-native species (Executive Officer's Report – 28/29 November 2005).

- We also agree with the Central Valley Regional Board that there are technical issues with the description of the term pollutant. Specifically, a portion of the discussion in the draft Staff Report suggests that hydromodification and changes in flow regime are primarily responsible for the decline in native fish species. The Regional Board reviewed this portion of the listing discussion and finds that causes of declines of native fishes for these reasons are also outside their jurisdiction (Executive Officer's Report – 28/29 November 2005).

- The draft Staff Report admits that "no evaluation guidelines are available that can be used to assess the potential for impact from exotic species."

- The Fact Sheets on the use of Exotic Species present a confusing array of criteria, guidelines, impacts and locations. In addition, some non-native species may be beneficial.

3. Adding DDT as a Pollutant in the Delta Waterways (northern portion) Segment

State Board staff have added DDT as a pollutant in this water quality limited segment based on the fact that four of six samples exceeded in the OEHHA Screening Value for fish tissue, a frequency that exceeds the allowable level in the Listing Policy. The Evaluation Guideline used in the Fact Sheet is 100 ng/g, the OEHHA Screening Value set in 1999. SRCSD strongly disagrees with this conclusion for the following reasons:

- The use of OEHHA screening values for fish tissue is not appropriate from a technical or legal standpoint. Please refer to the comments made by Central Valley Clean Water Agencies on this point, positions which SRCSD endorses.

- The last sample of fish tissue taken in the analysis that exceeded the Screening Value was in 1998, eight years ago. Smallmouth bass collected in 2001 did not exceed the Screening Value. Therefore the most recent sample taken did not exceed the Screening Value.

- Four types of fish were sampled between 1992 and 1998, smallmouth bass, largemouth bass, channel catfish and white catfish. While all of the catfish sampled exceeded the Screening Value, none of the bass exceeded the value.

- SRCSD has been collecting effluent data on DDT since 1983. All 194 samples of effluent have been non-detects over that time period, with a detection limit of <0.15 ug/L for DDT.

- Significant changes have occurred in the Sacramento River and its watershed since 1998. DDT should not be listed unless data within the last five years are available.

4. Adding PCBs as a Pollutant in the Delta Waterways (northern portion) Segment

State Board staff have added PCBs as a pollutant in this water quality limited segment based on the fact that two of six sample exceeded the OEHHA Screening Value for fish tissue, because this exceeds the allowable frequency in the Listing Policy. The Evaluation Guideline used in the Fact Sheet for PCBs is 20 ng/g, the Screening Value set in 1999. SRCSD also strongly disagrees with this conclusion for the following reasons:

- The use of OEHHA screening values for fish tissue is not appropriate from a technical or legal standpoint. Please refer to the comments made by Central Valley Clean Water Agencies on this point, positions which SRCSD endorses.

- Fish tissue samples that exceeded the Screening Value were in catfish, as long ago as 1992 and only as recent as 1998, 14 years ago and eight years ago, respectively. Smallmouth bass collected in 2001 did not exceed the Screening Value. Therefore the most recent sample did not exceed the Screening value.

- Four types of fish were sampled and analyzed between 1992 and 1998, white catfish, channel catfish, smallmouth bass and largemouth bass. Only one type of the four, white catfish, exceeded the Screening Value.

- SRCSD has been collecting effluent data on PCBs since 1983. All 194 samples of effluent have been non-detects over that time period, with a detection limit of <0.5 ug/L for PCBs.

- Significant changes have occurred in the Sacramento River and its watershed since 1998. PCBs should not be added to the list unless data within the last five years are used.

POINTS OF AGREEMENT WITH THE PROPOSED REVISED 2006 303(d) LIST

SRCSD has reviewed the Fact Sheets for water segments and pollutants of interest to, or geographically near, our service area. Our review finds several points of agreement with State Board staff both on deleting water quality segments from the 2002 list, and on not adding further segments to the 303(d) list in Region 5.

Deleting Diazinon as a Pollutant in Four Segments in Region 5

State Board staff have removed diazinon as a pollutant from four water quality segments in Region 5. SRCSD agrees with and supports these deletions based on a combination of water quality data analyses and the completion and implementation of a TMDL program. The four segments cited are:

- The Feather River, Lower (Lake Oroville Dam to Confluence with Sacramento River)
- Morrison Creek
- Sacramento River (Knights Landing to the Delta)
- Sutter Bypass

Not Adding to Four Water Quality Segments in Region 5

State Board staff have reviewed and decided not to add a number of segments to the 303(d) list in Region 5. Among those of particular interest to SRCSD, we agree and support the decisions not to list the following combinations of water quality segments and pollutants:

- Diazinon in the American River, Lower (Nimbus Dam to Confluence with Sacramento River)
- Mercury in the Bear River, Lower (below Camp Far West Reservoir)
- Chlorpyrifos and Diazinon in the Sacramento River (Red Bluff to Knights Landing)
- Chlorpyrifos in the Sacramento River (Knights Landing to the Delta)

In summary, SRCSD has reviewed the State Board staff report and supporting documents regarding proposed revisions to the 2002 303(d) list for implementation in 2006. SRCSD appreciates the opportunity to review these documents and requests that the SWRCB make changes in the proposed 303(d) list as specifically stated above. Our staff is available to discuss these requested changes and/or the basis for these requests in greater detail at your convenience.

Sincerely,

Terrie L. Mitchell for

Robert F. Shanks
District Engineer

RFS/TM:jc

cc: Members, State Water Resources Control Board
Celeste Cantú, Executive Officer, State Water Resources Control Board
Wendell Kido, SRCSD
Terrie Mitchell, SRCSD

10/25/06 BdMtg Item 10
303(d) List
Deadline: 10/20/06 5pm

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COACHELLA VALLEY WATER DISTRICT

POST OFFICE BOX 1058 • COACHELLA, CALIFORNIA 92236 • TELEPHONE (760) 398-2651 • FAX (760) 398-3711

October 19, 2006

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RECEIVED
OCT 2006
SWRCB
Executive Ofc.

Song Her
State Water Resources Control Board
Executive Office
1001 I Street, 24th Floor
Sacramento, CA 95814

Dear Ms. Her:

Subject: Comment Letter-2006 Federal Clean Water Act, Section 303(d) List of Water Quality Limited Segments for California

Thank you for giving the District the opportunity to comment on the proposed revisions to the 303(d) list of impaired water segments for California.

We encourage the State Water Resources Control Board to remove the specific listings identified in our enclosed comments for the All-American Canal, Coachella Valley Stormwater Channel and Colorado River.

If you have any questions, please call me at extension 2286.

Yours very truly,

Steve Bigley
Water Quality Manager

Enclosure/1/as

cc: Dave Bolland (with enclosure)
ACWA
910 K Street, Suite 100
Sacramento, CA 95814

Tina Shields (with enclosure)
Imperial Irrigation District
Post Office Box 937
Imperial, CA 92251

Marcia Torobin (with enclosure)
Metropolitan Water District of Southern California
Post Office Box 54153
Los Angeles, CA 90012

TRUE CONSERVATION
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SB:md\eng\wr\06\oct\comments-clean water

California Department of Health Services recently adopted revisions to the California Code of Regulations, Secondary Water Standards. On September 27, these revisions became effective for all California public water systems. These regulations were revised to clarify that the secondary MCL's listed for total dissolved solids, specific conductance, chloride and sulfate are "Consumer Acceptance Contaminant Level Ranges." These regulations state that no fixed consumer acceptance contaminant level has been established for these parameters and that concentrations ranging to the Upper contaminant level are acceptable for public water supplies. No corrective action is required for water supplies with contaminant levels occurring between the recommended and upper portion of the consumer acceptance contaminant level range.

This revision to California drinking water standards occurred after the initial comment period closed on the proposed 303(d) listing. SWRCB staff needs to reevaluate the proposed ACC listing based on this regulatory action. Salinity levels in the All American Canal are below the upper level of the consumer acceptance contaminant level range. No impairment of the municipal beneficial use exists in the All American Canal for total dissolved solids, specific conductance and sulfate.

Significant resources have been spent by many State and governmental agencies participating in the Colorado River Salinity Control Forum to understand, acknowledge and manage elevated salinity levels in the Colorado River. The SWRCB reaffirmed the conclusions and recommendations for salinity management provided by this Forum in October 2005 and no salinity impairment is proposed for the Colorado River. Like the Colorado River, which supplies the All American Canal and is the source of drinking water for over 23 million people, the All American Canal continues to be an important drinking water supply for the public. The salinity, including specific conductance, sulfate and total dissolved solids, in the ACC is a result of processes occurring within the Colorado River watershed upstream of the ACC and is not the result of controllable discharges into the ACC. It would be unreasonable and inconsistent to condemn the All American Canal to an impaired water status, when your agency has already concluded the Colorado River is not impaired for these same parameters.

We respectively request that the SWRCB withdraw the recommendation to list the All American Canal as impaired for total dissolved solids, specific conductance and sulfate.

3. Recommendation to list the Colorado River for selenium

The SWRCB proposes to list the Colorado River (Imperial Reservoir to California-Mexico Border) as water quality limited for selenium. The SWRCB's justification is based on fish tissue test results for five samples collected in 1992, 1999, and 2000-2001 on largemouth bass. It is indicated that three of the five samples exceeded the Office of Environmental Health Hazard Assessment (OEHHA) 2 *ug*/g tissue screening value guideline.

The five fish tissue samples do not provide a scientifically robust data set to support the proposed listing. A larger study of fish tissue samples representative of water supplying the subject segment was developed for the Salton Sea Ecosystem Restoration Plan in May 2005, when 18 fish samples were collected and tested for selenium. The sample locations included sites from the Lake Havasu to Lake Martinez area, which is immediately upstream of the Imperial Dam. The selenium results range from 0.56 to a maximum of 2.26 *ug*/g fish tissue screening value.

- The Basin Plan does not contain a water quality objective of 0.005 mg/L for selenium applicable to the CVSC as indicated in the SWRCB response to comments. The toxaphene drinking water standard of 0.005 mg/L does not apply to the CVSC which is not designated for municipal beneficial uses. No data exists to indicate toxaphene is present in the CVSC. We have performed water monitoring for toxaphene within the subject segment at our monitoring station where Lincoln Street and Avenue 72 intersect the CVSC for 18 years. The results of this monitoring, summarized in the attached table 1, confirm no toxaphene is found in water within the CVSC.

- The only evidence provided to support the decision to list the CVSC for toxaphene is the results of tests performed on 8 fish, 3 of which consisted of two red shiners and one tilapia containing toxaphene in levels exceeding the NAS guidelines for fish tissue. Tissue results performed on these fish do not provide sufficient evidence to link toxaphene in the fish tissue samples to exposure in the CVSC. Red shiner is a popular bait fish used for fishing in the Salton Sea downstream of the CVSC. The red shiners collected may have been bait fish that were raised in a farm where they were exposed to toxaphene when consuming fish food contaminated with toxaphene. Toxaphene is one of many persistent organochlorine pesticides that has been used historically on crops and is found in fish food. Studies show that toxaphene occurs in farm raised fish at concentrations significantly higher than in wild fish. Fish food does not undergo the same level of quality control as does other food crops used for human consumption so it is common to find contaminants in food used at fish farms. It would be inappropriate to use bait fish like red shiner that are likely to have been raised in another water body to support the proposed toxaphene listing. Without the results of fish tissue samples from the 2 red shiners, there is insufficient evidence to support the proposed listing.

Board staff has failed to provide sufficient evidence to support listing the CVSC as water quality limited for toxaphene. There is no sediment or water column data indicating toxaphene is present in this water body. Contrary to the SWRCB response to comments, there is no water quality objective for toxaphene in the Basin Plan for the Colorado River Basin. Board staff has not provided adequate evidence to link fish tissue sample results to toxaphene exposure in the CVSC.

We respectively request that the Board withdraw the recommendation to list the Coachella Valley Storm Water Channel as water quality limited for toxaphene.