Exxon Valdez Oil Spill
Restoration Project Final Report

Little Waterfall Creek Barrier Bypass Improvement: Pink and Coho Salmon Habitat Enhancement

Restoration Project 97139A1
Final Report

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Study History: The project was initiated in 1994 (Project 94139A1) as a result of surveys (Restoration Study 93063) conducted on Kodiak Island that evaluated instream habitat and stock restoration techniques for wild salmon stocks. The emphasis of this evaluation was to improve or develop spawning habitat at systems with barriers to salmon passage, which have historically prevented access. Surveys focused on systems which were directly impacted or were located in proximity to areas impacted by the *Exxon Valdez* oil spill (EVOS) with the intent of mitigating for injured spawning habitat. Data collected from these surveys were analyzed, including a cost to benefit analysis, to determine the most effective mitigation techniques for Kodiak Island salmon. As result of these surveys, the Exxon Valdez Oil Spill Trustee Council selected Little Waterfall Creek as a site for spawning habitat mitigation.

Salmon escapements (pink *Oncorhynchus gorbuscha* and coho *Oncorhynchus kisutch* salmon), egg-to-fry abundance (pink salmon), and the pre-construction bypass design were assessed in 1994. Engineering data provided for the development of an initial design for improving the bypass. Additional escapement and juvenile (including coho rearing relative abundance) production data were collected in 1995. The final bypass design and associated engineering documents were also completed, and a contract was awarded to SeaCoast Construction. Construction was scheduled to begin in July and be completed by September 1995; however, high water events delayed initial construction until October 1995. The improvements to the bypass were completed in November 1995. The delay in construction prevented evaluation of the bypass in 1995, because annual Little Waterfall Creek salmon runs were complete by mid-October. The post-construction evaluation began in February 1996 with an inspection of over-wintering condition of the bypass, followed by escapement estimation and observations of bypass use in August and September. Post-bypass assessment of escapements continued through 1998. The relative abundance of pink (pre-emergent sampling) and coho (minnow trapping) salmon fry continued in 1996 as part of the pre-bypass use evaluation (pre-construction brood years); post-bypass juvenile salmon relative abundance was evaluated in 1997.

Annual reports were submitted in 1996 and 1997 summarizing project (95139A1 and 96139A1) activity. The project was continued under Restoration Project 97139A1 and 98139A1; however, annual reports were not required.

Abstract: Surveys were conducted in 1992-93 at Little Waterfall Creek (LWC), Afognak Island, to evaluate instream habitat and potential stock restoration techniques for wild salmon stocks. Data indicated that LWC contained significant amounts of spawning habitat that were underutilized by pink and coho salmon due to an ineffective barrier bypass structure. The project priorities were to renovate the bypass to reduce gradients and design resting pools to minimize water velocity. The bypass renovation was completed in the fall 1995; bypass gradients were reduced from 27% to 17-20% and two additional resting pools and an entrance pool were installed. The steeppass sections were staggered between pools to reduce the velocity of stream flows. The historical performance of the three bypasses at LWC, since installation in

1981, has been significant, increasing average pink salmon escapements from ~7,000 to ~70,000 fish. The number of pink salmon migrating by way of all three bypasses to spawn in upstream habitat has significantly increased resultant returns; however, regression analysis was driven by the large upstream escapement in 1993. The historical proportion of the total annual pink salmon escapement to migrate upstream has primarily been a function of the design and performance of the largest (most upstream) bypass.

Key Words: Afognak Island, barrier bypass, coho salmon, *Exxon Valdez* oil spill, Kodiak Island, *Oncorhynchus gorbuscha*, *Oncorhynchus kisutch,* pink salmon, spawning habitat.

Project Data: *Description of data* – Little Waterfall Creek pink and coho salmon escapements and distribution (1968-1998); pink salmon harvests (1981-1998); pre-emergent sampling results (1982-1997); minnow trapping results (1995-1997); and statistical analysis results. *Format* – Microsoft Excel tables, graphs; text summaries in Microsoft Word. *Custodian* – Steven G. Honnold, Alaska Dept. of Fish and Game, Division of Commercial Fisheries, Kodiak. *Availability* – Available upon request for cost of duplication.

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EXECUTIVE SUMMARY

This report describes restoration activities on northern Afognak Island, Alaska, at Little Waterfall Creek, which were intended to provide for replacement of lost salmon spawning habitat and harvest opportunities due to impacts from the *Exxon Valdez* oil spill. This project resulted from feasibility studies, which identified design deficiencies in the largest of three existing barrier bypasses (fish ladders) at Little Waterfall Creek. Pink *Oncorhynchus gorbuscha* and coho *Oncorhynchus kisutch* salmon were observed to have difficulty utilizing this bypass and were not fully seeding upstream spawning habitat.

The primary goal of this project was to improve the design of the largest bypass and, in turn, improve salmon passage to upstream spawning habitat. The achievement of this goal would result in optimal colonization levels in upstream habitat (24,000 pink salmon and 2,700 coho salmon) producing an additional harvestable surplus of approximately 24,000 pink salmon and 4,000 coho salmon. Adult and juvenile pink and coho salmon production data were collected to assess pre- and post- project affects. Also, historical data previously collected by ADF&G were included in the project evaluation and also analyzed to determine the overall performance of the three bypasses.

Six null hypotheses were tested as part of the project evaluation. These were: (1) bypass modifications will not significantly increase the proportion of the overall pink and coho salmon annual escapement to use the bypass and spawn in upstream habitat; (2) bypass modifications will not significantly increase the relative abundance of juvenile pink (incubating) and coho (rearing) salmon in upstream habitat; (3) there is not a significant difference in average pink salmon production prior to and after the installation of all bypasses; (4) there is not a significant relationship between escapement and resulting adult returns for Little Waterfall Creek pink salmon; (5) the proportion of the annual escapement upstream is not a function of spawner density downstream of the bypass; and (6) the proportion of the annual escapement upstream is not a function of (the most upstream) bypass design.

The project objectives were: (1) to estimate the salmon escapement in habitat upstream and downstream of the improved bypass, and the harvest of pink salmon attributed to Little Waterfall Creek production; (2) to determine the relative abundance of juvenile salmon in habitat upstream of the improved bypass as compared to downstream areas; (3) to conduct statistical analysis of pre- and post-bypass improvement salmon production data; (4) to document project progress and results; and (5) to comply with supplementation criteria and guidelines.

Engineering surveys determined that the deficiencies of the bypass included a too-steep grade (27%), insufficient number and placement of resting pools, and excessive water velocity. As a result, the appropriate improvements were made to the bypass in 1995. In 1996 and 1997, pre-emergent sampling and minnow trapping were conducted at sites upstream and downstream of the bypass to determine a relative index of abundance for pink salmon fry and coho salmon juveniles. The post-construction pink salmon escapement and distribution estimates in Little Waterfall Creek were completed in 1998; coho salmon escapements and system distribution were incomplete due to high water events. Observations of salmon use of the modified bypass were made in conjunction with these estimates. Single-factor ANOVA tests were used to evaluate null hypotheses (1) and (3). Simple linear regressions were used to evaluate null

hypotheses (4) and (5). Null hypothesis (2) was not statistically evaluated due to insufficient data. Null hypothesis (6) was not statistically evaluated; however, the statistical evaluation of null hypothesis (5) provided indirect data for an assessment.

The completed modifications to the bypass (in November 1995) provide slopes of 20% or less for all sections, which were within the recommended specifications for pink and coho salmon use, compared to 27% prior to the project. Bypass sections were also staggered to reduce water velocity, two resting pools were added, and the previous entrance tank was modified into an additional resting pool. The contract specifications were adhered to with the exception of the entrance tank, which was mounted on a concrete pad instead of flush with the streambed. This resulted in the entrance slot or opening being located higher than intended and was observed to hinder pink salmon entry into the entrance tank. The entrance tank was modified in 1996 to correct this problem.

The average pink salmon escapement into Little Waterfall Creek was 6,824 fish prior to installation of three bypasses (1968-1980). The installation and operation of the three bypasses increased the average pink salmon escapement ~ ten-fold during 1981-1995 (71,130 fish average annual escapement); average odd-year (94,968 fish) and even-year (43,888 fish) pink salmon escapement increased approximately 13-fold and 8-fold, respectively. The bypasses increased the utilization of upstream spawning habitat during this period; however, only 21% (14,659) of the average annual escapement was observed in spawning habitat upstream of the largest bypass.

Post-modification escapements were 13,624, 24,339, and 151,655 pink salmon in 1996, 1997, and 1998, respectively. The proportion of the escapement observed upstream of the largest bypass was 41% (5,578) in 1996, 59% (14,442) in 1997, and 49% (74,845) in 1998.

Coho salmon escapement data are available during 1981-1998; however, they are sporadic due to enumeration deficiencies as a result of high water events. The average coho salmon escapement during 1981-1995 was 97 fish. Approximately 38 (39%) coho salmon, on average, were observed in habitat upstream of the largest bypass, but the average proportion upstream was 50% of the overall escapement.

Post-modification escapements were 218, 0, and 254 coho salmon in 1996, 1997, and 1998, respectively (Table 3). The proportion of the escapement observed upstream of the largest bypass was 16% (36) in 1996, 0% (0) in 1997, and 50% (127) in 1998.

Annual pre-bypass (1968-1980) harvests of Little Waterfall Creek pink salmon ranged from a high of 5,937 (1980) to a low of 0 (several years) and averaged 1,022 pink salmon. Post-bypass (1981-1998) harvests ranged from a high of 381,679 (1995) to a low of 183 (1996), and averaged 51,264 pink salmon (not including 1989 when the EVOS prevented fishing). Harvests were extremely low during 1996-1998 due to poor runs (1996,1997), and limited fishing effort (1998).

Little Waterfall Creek was sampled in March or April in 1982, 1986, 1987, 1992, 1994, 1996, and 1997 to estimate pre-emergent salmon fry relative abundance. The indexed number of pink salmon fry/m^2 for the system ranged from a high of 586 (1982) to a low of 66 (1997), averaging 288 fry. The majority of the fry were estimated downstream of the largest bypass for all years and fry were only observed upstream of the bypass in 1992 and 1994. The only post bypass modification sampling occurred in 1997 and revealed low numbers of pink salmon fry in the system and none in upstream habitat. Pre-emergent coho salmon have not been captured at any sample locations for any sample years.

Minnow trapping in Little Waterfall Creek resulted in a total catch of 68 juvenile coho salmon in 1996 and 159 coho salmon in 1997. Approximately, 63% (43) were captured at downstream sites and 37% (25) from upstream sites in 1996. In 1997, downstream sites represented 55% (88) of the total catch compared to 45% (71) at upstream sites. Upstream catches of coho salmon increased almost three-fold from 1996 (25) to 1997 (71) and the proportion of the overall catch (downstream and upstream sites combined) increased from 37% to 45%. Upstream coho salmon CPUE (catch per hour fished) increased substantially in 1997 (0.99) compared to 1996 (0.35).

The results of a single-factor ANOVA comparing the mean proportion of the annual pink salmon escapements to use the largest bypass and migrate upstream prior to modification (1981-1995) to the mean proportion after modification (1996-1998) indicates a significant difference ($P<0.001$). The null hypothesis (1) - *bypass modifications will not significantly increase the proportion of the overall pink and coho salmon annual escapement to use the bypass and spawn in upstream habitat* - was rejected (for pink salmon) for all years ($P<0.001$) and when only even years ($P=0.003$) were analyzed. Insufficient data were available to conduct analysis of the proportional use of the bypass by pink salmon in odd-years only, and for coho salmon.

A single-factor ANOVA comparing average pink salmon production (escapement) prior to (1968-1980) and after (1981-1998) the installation of all bypasses resulted in significant differences when all years ($P=0.001$) and only even years ($P=0.009$) were tested. These statistical data support rejection of the null hypothesis (3) - *there is not a significant difference in average pink salmon production prior to and after the installation of all bypasses* – for all-year and even-year pink salmon escapements.

Eleven simple linear regression analyses were computed to test the null hypothesis (4) - *there is not a significant relationship between escapement (independent variable) and resulting adult returns (dependent variable) for Little Waterfall Creek pink salmon.* The results indicate that in most cases (9) the null hypothesis would not be rejected; however, exceptions were indicated for the regressions of all-year and odd-year upstream escapements (x) for 1981-1996 parent years compared to overall returns (y). These results show a strong positive linear relationship between upstream escapement and overall returns. The regression lines were significant ($P < 0.001$ for all years and $P=0.014$ for odd years) for both data sets. However, when the 1993 escapement and resultant return data were excluded from the data sets, regressions indicated poor linear relationships and were not significant. Thus, the large upstream escapement in 1993 (~75,000 pink salmon) appears to drive the regressions for both complete data sets.

Simple linear regression analyses were also computed to test the null hypothesis (5) - *the proportion of the annual escapement upstream is not a function of spawner density downstream of the bypass.* The results of these analyses were also used as an indirect measure to test null hypothesis (6) - *the proportion of the annual escapement upstream is not a function of bypass (the most upstream) design.* Statistics were computed for 11 data sets (1981-1998) of downstream pink salmon escapements (x) regressed against the proportion of the overall escapement observed upstream. None of the analyses indicated strong linear relationships (R values ≤ 0.49) with the exception of even-year downstream escapements during 1981-1995 and excluding 1988 ($R=0.80$). This linear relationship suggests that downstream escapement explains 64% of the variation in the upstream proportion of the overall escapement for these years. The regression line was marginally significant ($P = 0.055$).

The data presented indicate that the null hypotheses: 1) *bypass modifications will not significantly increase the proportion of the overall pink salmon annual escapement to use the bypass and spawn in upstream habitat*; and 3) *there is not a significant difference in average pink salmon production prior to and after the installation of all bypasses* should be rejected. Also, the data suggest that the null hypothesis - 4) *there is not a significant relationship between escapement and resulting adult returns for Little Waterfall Creek pink salmon* should be rejected when upstream escapement for all years and odd-years are the dependent (x) variables. The latter relationship, however, is largely leveraged by one data point (resultant return from the 1993 escapement) and breaks down when it is excluded for both the all years and odd-years data sets. All other data tested (dependent variables overall or downstream escapement for all years, odd-years, or even-years) indicate failure to reject the null hypothesis. The data analyzed also indicate failure to reject null hypothesis 5) - *the proportion of the annual escapement upstream is not a function of spawner density, downstream of the bypass*. These results for hypothesis 5) suggest that hypothesis 6) - *the proportion of the annual escapement upstream is not a function of (the most upstream) bypass design* should be rejected. Insufficient data were available to statistically test the null hypothesis - 2) *bypass modifications will not significantly increase the relative abundance of juvenile pink (incubating) and coho (rearing) salmon in upstream habitat*; however, data suggest that more coho salmon were rearing after the bypass modification (1997) than prior to bypass modification (1996).

In summary, the installation of the three bypasses in Little Waterfall Creek significantly increased average pink salmon production. The modification to the largest, most upstream bypass significantly increased upstream spawning habitat use by the pink salmon escaping annually into the system. In addition, downstream pink salmon abundance did not significantly influence the numbers of pink salmon to use the most upstream bypass, but rather the bypass design determined the use of the bypass and the seeding of upstream spawning habitat. The data also suggest that the modification increased coho salmon use of upstream habitat as reflected by increased numbers of rearing juveniles present upstream after bypass modification. Although there did not appear to be a strong positive relationship between the pink salmon escapement and resulting returns, pink salmon returning to Little Waterfall Creek in ensuing years are expected to have improved access to the primary spawning habitat upstream (~17,000 m^2) of the largest barrier bypass. This habitat is predicted to support 24,000 pink and 2,700 coho salmon. At this seeding level, a harvestable surplus of an additional 24,000 pink and 4,000 coho salmon is expected to be available to fishers. The Little Waterfall coho salmon runs have been small and harvest has been minimal; thus a new harvest opportunity may be afforded. The seeding of spawning habitat by coho salmon at current escapement levels is expected to be slow, until optimum escapement levels are reached.

INTRODUCTION

The *Exxon Valdez* spilled approximately 42 million liters of crude oil in Prince William Sound (PWS) on March 24, 1989 (Bragg et al. 1994). The resulting oil slick contaminated 2,000 kilometers of coastal habitat in western PWS and the western Gulf of Alaska. (Bue et al. 1998). Several beaches on Afognak Island were heavily oiled in 1989 and remained oiled in 1990 (Middleton et al. 1992; Willette et al. 1994; Figure 1). Little Waterfall Bay (Little Waterfall

Creek drainage - "local" stream designator 251-822; anadromous stream catalogue number 251-82-10020) was directly contaminated by oil. Similar contamination in PWS resulted in sub lethal effects to herring and salmon stocks (Hose et al. 1996; Wiedmer et al. 1996; Marty et al. 1997). Pink salmon (*Oncorhynchus gorbuscha*) adults and juveniles were vulnerable to oil exposure due to their extensive use of intertidal spawning areas and nearshore marine rearing areas, respectively (Bue et al. 1998). Significantly greater pink salmon embryo mortality was measured in oiled versus reference streams (Bue et al. 1996; 1998) and also similar results were observed in laboratory tests (Heintz et al. 1995; Marty et al. 1997). In addition, past research indicated that pink salmon embryos absorb poly-cyclic aromatic hydrocarbons (PAH's; Moles et al. 1987) and that these compounds were capable of inducing chromosomal lesions (McBee and Bickman 1988) and influence endocrine function (Thomas and Budiantara 1995). Genetic or physiological damage to one brood year would be expressed two years later in pink salmon since they have two genetically isolated lineages (odd and even years; Heard 1991).

Oil spill damage assessment studies for pink salmon stocks on the Afognak Island were not funded; however, similar damage may have occurred as described above.

This project began as result of surveys (Restoration Study 93063) conducted on Kodiak Island which evaluated instream habitat and stock restoration techniques for wild salmon stocks (Willette et al. 1994). The emphasis of this evaluation was to improve or develop spawning habitat at systems with barriers to salmon passage which have historically prevented access. Surveys focused on systems that were directly impacted or were located in proximity to areas impacted by the EVOS with the intent of mitigating for contaminated spawning habitat (Figure 1). Data collected from these surveys were analyzed, including a cost to benefit analysis (Hartman and Richardson 1993), to determine the most effective mitigation techniques for Kodiak Island salmon systems. As result of these surveys, the Exxon Valdez Oil Spill (EVOS) Trustee Council selected Little Waterfall Creek as a site for spawning habitat mitigation.

The modified Denil fishway design or Alaska steep pass (Zeimer 1962) has been used extensively on Afognak Island (Figure 2) to restore and enhance sockeye (*O. nerka*), coho (*O. kisutch*) and pink salmon runs (Honnold 1991; Honnold and Edmundson 1993 and Edmundson et al. 1994). For example, the Laura Lake sockeye and coho salmon runs were initially started, and are currently sustained, by two bypasses which enable spawner access to underutilized habitat (Honnold and Edmundson 1993). Similarly, pink salmon production at Little Waterfall has been significantly improved through bypasses and increased spawning habitat use (Honnold 1991, 1996, 1997).

Three barriers in Little Waterfall Creek have been bypassed with structures allowing increased pink and coho salmon passage to previously unused spawning habitat (Honnold 1991; Edmundson et al. 1994; Honnold 1997; Figure 3). Two bypasses were constructed and installed in Little Waterfall Creek in the mid-1970's; construction and installation of a third bypass (the largest and most upstream) was completed in the fall of 1980. Little Waterfall Creek pink salmon pre-bypass (1968-1980) average escapement (~7,000) increased approximately ten-fold compared to the post-bypass (1981-1998) average (~ 70,000; Table 2). Post-bypass average harvest of pink salmon increased almost 50-fold. The system has obviously benefited from the installation of the barrier bypasses, as indicated by the increased pink salmon runs; however, the largest barrier bypass structure did not operate efficiently as originally constructed and impeded salmon passage (1981-1995) into the largest portion of spawning habitat (Honnold 1994;

Willette et al. 1994). Pink salmon use of this bypass averaged ~ 8,500 (21% of overall escapement) during 1981-1995. Coho salmon escapement data are incomplete due to enumeration deficiencies (Honnold 1996, 1997); however, peak foot survey counts have ranged from a low of zero (several years during 1980 -1993) to a high of 200 (1986) coho salmon. Juvenile production data parallel the adult escapement data, with pink salmon fry abundance indices less upstream of the bypass compared to downstream (Honnold 1996, 1997). Coho salmon fry have not been identified during any pre-emergent sampling efforts, but were observed rearing above and below the barrier as indicated by minnow trapping (Honnold 1996, 1997).

Barrier height, the quality and quantity of spawning habitat above barriers, and the degree of utilization of available spawning habitat significantly affects the efficiency and cost effectiveness of barrier bypasses (Willette et al. 1994). Habitat utilization rates are often considerably less than estimated capacity (McDaniel 1981). An evaluation was conducted in 1992 to characterize the useable salmon spawning habitat in Little Waterfall Creek (Willette et al. 1994). Habitat assessment, using field methods described by Olsen and Wenger (1991) and criteria established by Chambers et al. (1955), determined that the area above the largest bypass comprised approximately 80% (~17,000 m^2) of the total stream habitat. The habitat was estimated to support 24,000 pink salmon and 2,700 coho salmon based upon a 1:1 sex ratio (ADF&G unpublished data), and an optimum female density (no./m^2) for pink and coho salmon of 0.7 (Heard 1978) and 0.08 (Sheng et al. 1990), respectively. At optimum colonization levels, resultant production is estimated to provide a harvestable surplus of approximately 24,000 pink salmon (Willette et al. 1994; Table 1). Originally, coho salmon production at full seeding of the upstream habitat was estimated to provide ~15,000 fish for harvest (Willette et al. 1994); however, egg-to-smolt survival assumptions (7.4%) were derived from sockeye salmon survival data (Honnold and Edmundson 1993). Survival of stream-rearing juvenile coho salmon (1-2%) is much less than that of lake-rearing sockeye (Bradford 1994; Table 1). This lower survival may be related to their aggressive territorial behavior and may result in exclusion of rearing opportunities. Thus, coho production as a result of improved access to upper spawning habitat was revised to ~5,400, of which ~4,000 would be harvested (Honnold 1997). The original cost to benefit data indicated that this project would have long term benefits greater than project costs (Hartman and Richardson 1993). Lower coho salmon survival, however, would decrease the cost to benefit ratio but would still, likely, provide future benefits in excess of project costs.

The evaluation of the design and operation of the largest bypass structure (Figure 4) identified several deficiencies, impacting salmon passage (Willette et al. 1994). The grade of the bypass (27%) was too steep, there were not enough resting areas, and the entrance and resting tanks were improperly aligned within the bypass run. As a general guide, Larinier (FRENCH) suggests a slope of 16-20% for Pacific salmon (Clay 1995). A slope of 22% or less is recommended for sockeye salmon when resting pools (similar to those at Little Waterfall) are employed (Blackett 1987). Pink salmon, a smaller, less vigorous fish, may require even less slope and more resting pools (Honnold 1991), since endurance at maximum swimming speed decreases with fish length (Beach 1984). Resting pools are recommended for every 3-4 m of height ascended when surmounting obstructions greater than 4 m high (Clay 1995). Fish entrance tanks should provide flow strong enough to attract fish (Rajaratnam et al. 1991). It is also necessary to provide depth of about 0.25 meters below the invert for the entering fishway tank and a width of about 0.6 meters and a length of 0.6 meters to provide resting area in the tank (Rajaratnam et al. 1997).

The bypass evaluation indicated that the gradient should be reduced by modifying the existing concrete resting tanks and extending the lower portion of the bypass, a new entrance tank and two new resting tanks should be installed, and that the steeppass runs should be staggered as they enter and exit the modified concrete tanks and new aluminum tanks (Honnold 1995, 1996, 1997; Figure 5). The recommended improvements to the bypass were completed in November 1995 (Figures 6-8).

Pre-project and post-project adult pink salmon production data were collected from 1981-1995 (funded by this project since 1994) and from 1996 - 1998, respectively, whereas, juvenile pink salmon production data were collected periodically (1982, 1986, 1987, 1992, 1994, and 1996) prior to the project and for one post-project year (1997). Coho salmon adult data were collected intermittently and juvenile coho salmon data were collected only from 1995-1997. Thus, pre and post-project comparisons of salmon production data will have some limitations.

The intent of this report is to assess data collected in conjunction with FY 97 and FY 98 project objectives. The primary emphasis is to summarize, analyze, and compare pre-project (prior to 1996) and post-project (1996-1998) adult and juvenile data to determine the success of bypass improvements. In addition, this report will assess all historical pink salmon adult production data to quantify the overall performance of the three bypasses since they were installed, to determine any pink salmon spawner-recruit relationships, and to address if the annual pink salmon escapement downstream (of modified bypass) affects the proportion of escapement using the largest bypass (density effect). The following null hypotheses were tested: 1) Bypass modifications will not significantly increase the proportion of the overall pink and coho salmon annual escapement to use the bypass and spawn in upstream habitat; 2) Bypass modifications will not significantly increase the relative abundance of juvenile pink (incubating) and coho (rearing) salmon in upstream habitat; 3) There is not a significant difference in average pink salmon production prior to and after the installation of all bypasses; 4) There is not a significant relationship between escapement and resulting adult returns for Little Waterfall Creek pink salmon; 5) The proportion of the annual escapement upstream is not a function of (the most upstream) bypass design; and 6) The proportion of the annual escapement upstream is not a function of spawner density downstream of the bypass.

OBJECTIVES

The objectives for FY 94, FY 95, and FY 96 are described in previously submitted annual reports (Honnold 1996, 1997). Objectives for FY 97 and FY 98 were:

1. Estimate the salmon escapement in habitat upstream and downstream of the improved bypass, and the harvest of pink salmon attributed to Little Waterfall Creek production.

2. Determine the relative abundance of juvenile salmon in habitat upstream of the improved bypass as compared to downstream areas.

3. Conduct statistical analysis of pre- and post-bypass improvement salmon production data.

4. Document project progress and results.

5. Comply with supplementation criteria and guidelines.

METHODS

1. Estimate the salmon escapement in habitat upstream and downstream of the improved bypass, and the harvest of pink salmon attributed to Little Waterfall Creek production.

Historically, peak aerial and foot survey counts were used to index pink salmon escapements for Little Waterfall Creek as well as other systems in the KMA (Nelson and Swanton 1996). Peak spawner surveys that occur during excellent visibility may be accurate and indicate the maximum spawning activity for that period, but poor viewing conditions may cause even simple visual counts to underestimate spawning populations (Tshaplinski and Hyatt 1991). Thus, most peak counts likely represented only a portion of the estimated total escapement (Cousens et al. 1982). Peak counts may serve as a rough index of total escapement, but are not necessarily comparable to other peak counts (Johnson and Barrett 1988).

Area-under-the-curve (AUC) methodology was used to improve estimates of pink (Johnson and Barrett 1988) and coho (Beidler and Nickelson 1980; Ames 1984; Tschaplinski and Hyatt 1990; English et al. 1992) salmon escapement in various locations including Kodiak Island (Holmes 1990, 1991; Swanton and Nelson 1993, 1994; Swanton et al. 1993; Nelson and Swanton 1996).

Spawner abundance curves were derived from a series of escapement counts to provide more reliable estimates of abundance and stream life. These applications of the AUC model used fish-days (24-hr period that a single fish is alive) as the unit of measurement. Stream life or the average number of days a fish is alive in the standard survey reach of the stream, was generally assumed to be constant between years. Escapement estimates were derived by dividing the area under the spawner abundance curve by the stream life estimate. The performance of the AUC model improved (increased accuracy of escapement estimates) as survey frequency increased (Johnson and Barrett 1988).

The AUC model was applied to aerial and foot survey data independently due to survey method bias differences (Perrin and Irvine 1990). Surveys rated as poor due to observation conditions were excluded from the analysis. In addition the model was used only where more than two non-zero survey counts were available. The data collected by the more experienced observer were used when two surveys were conducted by different observers on the same day. Counts from the method (foot or aerial) most frequently used to survey a given system were used and the other excluded. Surveys that did not record survey conditions as well as any surveys with comments indicating incomplete data were also excluded.

When the AUC method generated estimates that were less than the peak count of a system, the peak count was assumed to be the best estimate of the total escapement. The peak count was expanded by 1.9 or was added to the mouth count to estimate total escapement if data from only one survey was included for a system (Barrett et al 1990; Swanton and Nelson 1994). The latter was used when a mouth count was conducted along with a peak stream count and when combined was greater than the expanded peak count.

Weir counts were used to estimate total pink salmon escapement at Little Waterfall Creek from 1981-1987 and 1990 -1992. When weir counts were not available, peak live aerial or foot survey counts were used to estimate indexed escapement of pink salmon (Barrett et al. 1990; Honnold 1996, 1997). The latter method was also used to estimate coho salmon indexed escapement.

These methods were modified for this report to estimate Little Waterfall Creek total pink and coho salmon escapement (rather than a combination of indexed and total escapement) for all years. Pink salmon weir counts were assumed to estimate total escapement. The AUC method was used for years with the appropriate number (more than two) of foot or aerial survey counts. The peak count was expanded by 1.9 for pink salmon and 2.4 for coho salmon (Minard 1986) to estimate total escapement for those years with insufficient surveys to apply the AUC model. The *known* total escapement (weir count) was applied to the AUC model to determine the *unknown* stream life when both weir and foot survey counts were available. The average stream life for these years was applied to the AUC model to estimate total escapement for years when only foot survey data were available.

Total pink salmon escapements upstream of the modified bypass were estimated by the AUC model using the average stream life values as described above and multiple (4-5) foot survey counts for a given year. Total coho escapements upstream were estimated by the peak count expansion method. Total downstream pink and coho escapements (of the modified bypass) were estimated by subtracting upstream estimates from total system escapement estimates.

Little Waterfall Creek pink salmon annual harvests were estimated by apportioning the overall catches in the Perenosa Bay District (statistical sections 251-82, 251-83, and 251-84) to specific contributing systems, based on escapement. That is, the pink salmon escapement estimates for Little Waterfall Creek (251-822), Pauls Creek (251-831), and Portage Creek (251-825) were summed (Pauls and Portage Creek escapement estimates were derived as described above for Little Waterfall Creek). Individual creek escapement estimates were divided by this sum to calculate their proportion of the Perenosa Bay District pink salmon escapement. The Perenosa Bay District pink salmon harvests were obtained from the ADF&G fish ticket database, and multiplied by the escapement portions to estimate catches for each system. Little Waterfall Creek pink salmon runs were derived by summing escapement and harvest estimates.

2. Determine the relative abundance of juvenile salmon in habitat upstream of the improved bypass as compared to downstream areas.

Spawning redds downstream and upstream of the modified barrier bypass were sampled prior to fry emergence to estimate the relative index of fry abundance (Donnelly 1983; Swanton et al. 1993) and egg-to-fry survival. Ten redds, each, from downstream and upstream sites were pumped (White 1980, 1986) to capture eggs and fry during 1982-1997. Eggs and fry were enumerated by species (McNeil 1964; White 1988; Swanton et al. 1993).

The relative abundance of juvenile coho salmon rearing downstream and upstream of the modified barrier bypass was assessed by fishing minnow traps for a ~ 24 hour period (Gray et al. 1984; Kyle 1990) each month (June through August) at permanent sampling locations. All juvenile fish captured were enumerated by species, and released. Catch-per-unit-effort (hours; CPUE) was calculated for coho salmon juveniles. Trapping occurred during 1995-1997; however, in 1995, only unbaited traps were fished upstream and downstream at one site each (Figure 3, sites 8B and 9B) of the modified barrier bypass. Traps baited with salmon roe, as well as unbaited traps, were fished at three sites upstream and three sites downstream in 1996 and 1997 (Figure 3, sites 8A-C and 9A-C). The 1995 data will not be included in this report, since they are not comparable to the 1996 and 1997 data.

3. Conduct statistical analysis of pre and post bypass improvement data.

The following statistical analyses were used to the test null hypotheses:

Single-factor analyses of variance (ANOVA) were computed (Microsoft Excel 5.0) to compare the average proportion of the overall pink salmon annual escapement to use the bypass prior to modification (1981-1995) to the average proportional use after modification (1996-1998) for all years, odd-years, and even-years (hypothesis 1). In addition, ANOVAs were computed to compare average pink salmon production (escapement) prior to (1968-1980) and after (1981-1998) the installation of all bypasses for all years, odd-years, and even-years (hypothesis 3).

Simple linear regression analyses (Devore 1995) were computed using the "ordinary least squares" method (Microsoft Excel 5.0) to test if the level of Little Waterfall Creek pink salmon adult returns (y) were significantly dependent upon parent year escapements (x) for brood years 1981-1996 (hypothesis 4). Independent regression analyses were performed for all years, odd-years, and even-years. Additionally, parent year escapements were segregated into downstream (x^{4-6}) and upstream (x^{7-9}) data and independent regression analyses performed for all years, odd-years, and even-years using adult returns as the dependent variable (y).

Simple linear regression analyses were also computed to test if the proportion of the annual Little Waterfall Creek pink salmon upstream escapement (1981-1998; y) was significantly related to the spawner density downstream of the bypass (x), rather than being primarily a function of (the most upstream) bypass design (hypothesis 5). Separate analyses were performed for all years, odd-years, and even-years, as well as for pre-bypass modification and post modification years.

The effects of bypass modifications on the relative abundance of juvenile pink (incubating) and coho (rearing) salmon in upstream habitat were not analyzed, statistically, due to sparse data sets (hypothesis 2); however, histograms and tables were constructed to indicate trends.

4. Document project progress.

The documentation required by the Trustee Council included writing quarterly progress reports and this final report.

5. Comply with supplementation criteria and guidelines.

The supplementation criteria and guidelines developed by the Trustee Council were followed during implementation of this project (Honnold 1996). In addition, all permit requirements for this project were adhered to, including land use approval by Afognak Joint Ventures, habitat impact assessment by ADF&G, and NEPA compliance requirements.

RESULTS

1. Estimate the number of salmon spawning in habitat upstream and downstream of the improved bypass.

The average pink salmon escapement into Little Waterfall Creek was 6,824 fish prior to installation of three bypasses (1968-1980; Table 2; Figure 9). The escapements were entirely distributed in the spawning habitat of the lower reaches of the stream and intertidal area during this period. The installation and operation of the three bypasses increased the average pink salmon escapement ~ ten-fold during 1981-1995 (71,130); average odd-year (94,968) and even-year (43,888) escapement increased approximately 13-fold and 8-fold, respectively. The bypasses increased the utilization of upstream spawning habitat during this period; however, only 21% (14,659) of the escapement, on average, were observed in spawning habitat upstream of the largest bypass. There was little variation in this average proportion between odd (21%) and even-year (18%) runs. The utilization of upstream spawning habitat varied between years, ranging from a high of 45% in 1993 to a low of 2% in 1981. In addition, the distribution of observed spawners varied considerably within the upstream habitat from year to year; however, fish migrations further upstream (sections 3-5; Appendix A) appear to have occurred more frequently since 1989.

The largest bypass was modified in 1995 to improve salmon passage. Post-modification escapements were 13,624, 24,339, and 151,655 pink salmon in 1996, 1997, and 1998, respectively (Table 2; Figure 9). The proportion of the escapement observed upstream of the largest bypass was 41% (5,578) in 1996, 59% (14,442) in 1997, and 49% (74,845) in 1998.

Coho salmon escapement data are available during 1981-1998, but they are sporadic due to enumeration deficiencies as result of high water events (Table 3). Escapements have been small, ranging from a high of 480 in 1986 to a low of 0 in 1993, 1995, and 1997. The average coho escapement from 1981-1995 was 97 fish. Approximately 38 (39%) coho salmon, on average, were observed in habitat upstream of the largest bypass, but the average proportion upstream was 50% of the overall escapement.

Post-modification escapements were 218, 0, and 254 coho salmon in 1996, 1997, and 1998, respectively (Table 3). The proportion of the escapement observed upstream of the largest bypass was 16% (36) in 1996, 0% (0) in 1997, and 50% (127) in 1998.

Annual harvests of Little Waterfall Creek pink salmon were estimated during 1968-1998 (Appendix B). Pre-bypass (1968-1980) harvests ranged from a high of 5,937 (1980) to a low of 0 (several years) and averaged 1,022 pink salmon from (Table 4). By contrast, post-bypass (1981-1998) harvest ranged from a high of 381,679 (1995) to a low of 183 (1996), and averaged 51,264 pink salmon (not including 1989 when the EVOS prevented fishing). Odd-year harvests averaged 71,712 compared to average even-year harvests of 30,817 pink salmon during 1981-1998. Harvests were extremely low during 1996-1998 due to poor runs (1996,1997), and limited fishing effort (1998).

Total runs averaged less than 8,000 pink salmon prior to installation of the bypasses and increased, on average, to over 121,000 fish once the bypasses were installed and operational (Table 4). The largest run was in 1995 when 482,000 pink salmon returned. The average return-per-spawner (RPS) also increased from 1.7 to 3.1 and exploitation rate (ER) from 13% to 42% as a result of the bypasses. The largest RPS was 11.3 as a result of 1998 returns from the 1996 brood year.

The 1981-1998 Little Waterfall Creek pink salmon runs returned, on average, beginning in late July, peaked in early to mid-August, and ended by early to mid-September (Figure 10). Peak harvests were during the week ending 15 August. Escapement timing paralleled harvest timing; however, both appeared somewhat dependent upon fishery effort, as reflected by declines during peak harvest periods. Peak escapements to upstream habitat (upstream of largest bypass) occurred from the 22-31August for most years (Appendix A). Data from a tagging study, in 1991 and 1992, indicate that the majority of pink salmon observed upstream of the pre-modified bypass entered Little Waterfall Creek (escapement at most downstream bypass) from 02-15 August (Appendix C).

2. Determine the relative abundance of juvenile salmon in habitat upstream of the improved bypass as compared to downstream areas.

Little Waterfall Creek was sampled in March or April in 1982, 1986, 1987, 1992, 1994, 1996, and 1997 to estimate pre-emergent salmon fry relative abundance (Table 5). High flows and poor weather prevented sampling in other years during 1981-1997. Budget limitations prevented sampling in 1998. The indexed number of pink salmon fry per m^2 for the system ranged from a high of 586 (1982) to a low of 66 (1997), averaging 288 fry. The majority of the fry were estimated downstream of the largest bypass for all years and fry were only observed upstream of the bypass in 1992 and 1994. Approximately, 30% of the fry captured were found in upstream habitat for these years. The only post bypass modification sampling occurred in 1997 and revealed low numbers of pink salmon fry in the system and none in upstream habitat. Pre-emergent coho salmon have not been captured at any sample locations for any sample years.

Pink salmon egg-to-fry survival estimates for 1981-1996 brood years (where data are available) ranged from a high of 21.9% (1981 escapement) to a low of 1.7 % (1993 escapement), averaging 9.1% (Table 6). Upstream egg-to-fry survivals ranged from a high of 9.0% (1991 escapement) to a low of 0.0% (four years), averaging 1.4%. Downstream (of the bypass) survivals ranged from a high of 9.0% (1981 escapement) to a low of 0.2% (1993 escapement), averaging 3.8%.

Minnow trapping in Little Waterfall Creek resulted in a total catch of 68 juvenile coho salmon in 1996 (Table 7; Appendix D). Of these, 40 were caught in baited traps and 28 in unbaited traps. Approximately, 63% (43) were captured at downstream sites and 37% (25) from upstream sites. Baited traps caught similar numbers of coho salmon in downstream (22; 55%) and upstream (18; 45%) sites, while unbaited traps caught more in downstream (21; 75%) locations than upstream (7; 25%) locations.

The total catch in 1997 was 159 coho salmon, of which 90 were caught in baited traps and 69 in unbaited traps (Table 7; Appendix D). Downstream sites represented 55% (88) of the total catch compared to 45% (71) at upstream sites. Baited traps captured substantially more juvenile coho at downstream (59; 66%) sites than upstream sites (31; 34%), while unbaited traps captured fewer coho at downstream (29; 42%) than at upstream sites (40; 58%).

Upstream catches of coho salmon increased almost three-fold from 1996 (25) to 1997 (71); however, the proportion of the overall catch (downstream and upstream sites combined) increased only slightly from 37% in 1996 to 45% in 1997 (Figure 11). Upstream coho salmon CPUE increased substantially in 1997 (0.99) compared to 1996 (0.35). Coho salmon CPUE increased from 0.25 in 1996 to 0.43 in 1997 for baited traps and from 0.10 to 0.56 for unbaited traps fished in upstream habitat.

3. Conduct statistical analysis of pre- and post-bypass improvement data.

The results of a single-factor ANOVA comparing the mean proportion of the annual pink salmon escapements to use the largest bypass and migrate upstream prior to modification (1981-1995) to the mean proportion after modification (1996-1998) indicate significant differences (Table 8; Figure 9). The test statistic (F) was computed to be 23.79 and the critical value (F*crit*) was 4.6 at a significance (P-value$_{.05}$) of < 0.001. In addition, single-factor ANOVA of even-year proportions, as described above, indicate significant differences between pre and post-bypass modification data. The test statistic (F) was computed to be 23.79 and the critical value (F*crit*) was 5.98 at a significance (P-value$_{05}$) of 0.003. Therefore, the null hypothesis - *bypass modifications will not significantly increase the proportion of the overall pink and coho salmon annual escapement to use the bypass and spawn in upstream habitat* - was rejected (for pink salmon) for all years and when only even years were analyzed. Insufficient data were available to conduct analysis of the proportional use of the bypass by pink salmon in odd-years only, and for coho salmon.

A single-factor ANOVA statistics comparing average pink salmon production (escapement) prior to (1968-1980) and after (1981-1998) the installation of all bypasses resulted in significant differences when all years and only even years were tested (Table 8; Figure 9). The all year test statistic (F) was 13.38, F*crit* was 4.24, and P-value$_{05}$ was .001. The even-year year test statistic (F) was 8.99, F*crit* was 4.60, and P-value$_{05}$ was .009. There were only two pre-bypass years of odd-year escapement data to compare to the series of post-bypass escapement data; thus, the

ANOVA statistics, which indicate no significant difference (Table 8), are weak, compared to those for all and even-years. These statistical data support rejection of the null hypothesis - *there is not a significant difference in average pink salmon production prior to and after the installation of all bypasses* – for all and even-year pink salmon escapements.

A total of eleven different simple linear regression analyses were computed to test the null hypothesis - *there is not a significant relationship between escapement and resulting adult returns for Little Waterfall Creek pink salmon* (Table 9; Figures 12-15). The results indicate that, in most cases (9), the null hypothesis would not be rejected; however, exceptions were indicated for the regressions of all and odd-year upstream escapements (x) for 1981-1996 parent years compared to overall returns (y). These results show a strong positive linear relationship between upstream escapement and overall returns (R=0.77 all years; R=0.81 for odd-years). Also, upstream escapement explains 59% and 66% of the variation in overall returns for all years and odd-years data, respectively. The regression lines were significant for both data sets ($P < 0.001$ for all years and $P = 0.014$ for odd-years. However, graphic representation of these latter regressions (Figure 14) indicate that the 1993 escapement and resultant return exert large leverage on these analyses. Regressions of all and odd-year upstream escapements (x) for 1981-1996 parent years compared to overall returns (y) that exclude the 1993 escapement and resultant return were much different (Table 9; Figure 15). These results show no linear relationship between upstream escapement and overall returns (R=0.08 all years; R=0.19 for odd-years). The regression lines were not significant for either data sets ($P = 0.774$ for all years and $P = 0.676$ for odd-years). Thus, the null hypothesis is not rejected.

Simple linear regression analyses were also computed to test the null hypothesis - *the proportion of the annual escapement upstream is not a function of spawner density downstream of the bypass*. The results of these analyses were also used as an indirect measure to test the null hypothesis - *the proportion of the annual escapement upstream is not a function of bypass (the most upstream) design*. Statistics were computed for 11 different data sets (1981-1998) of downstream pink salmon escapements (x) regressed against the proportion of the overall escapement observed upstream (Table 9; Figures 16-20). None of the analyses indicated strong linear relationships (R values ≤ 0.49) with the exception of even-year downstream escapements from 1981-1995 and excluding 1988 (R=0.80). This linear correlation suggests that downstream escapement explains 64% of the variation in the upstream proportion of the overall escapement for these years. The regression line was only marginally significant ($P = 0.055$). Other than the preceding data set, the results were consistent and would indicate the null hypothesis - *the proportion of the annual escapement upstream is not a function of spawner density downstream of the bypass* would not be rejected. Furthermore, from these results it appears reasonable to reject the hypothesis - *the proportion of the annual escapement upstream is not a function of bypass (the most upstream) design.*

4. Document project progress and results.

Quarterly reports were submitted on schedule as outlined by the Trustee Council. This final report was due September 30, 1998; however, was delayed by other work commitments.

5. Comply with supplementation criteria and guidelines.

This project was designed to provide improved spawning habitat for pink and coho salmon, as well as additional rearing habitat for coho salmon. The barrier bypasses in place at Little Waterfall Creek have been operational since the late 1970s (Honnold 1991); thus, the populations of pink and coho salmon have had ~ 20 years to adapt to initial system changes. The genetic variation or compositions of these populations have not been assessed; however, have likely remained static throughout the years of improved production. Hybridization is also unlikely, since new stocks have not been introduced to the system.

Resident species, such as Dolly Varden (*Salvelinus malma*), rainbow or steelhead trout (*O. mykiss*), three-spine stickleback (*Gasterosteus aculeatus*), freshwater sculpin (*Cottus aleuticus*) and sockeye salmon (*O. nerka*) have also remained intact and healthy (Honnold 1996). In fact, improved spawning habitat access and increased salmon fry production (forage) has probably benefited resident species. Interspecific competition (pink and coho salmon) has also, likely, been minimal, although there is some overlap in habitat use by pink and coho salmon. Temporal and spatial separation minimizes competition. Both species have equal opportunity to utilize the improved bypass, thus spawn in upstream habitat.

This project has provided additional pink and coho salmon for harvest in Little Waterfall Bay and other area waters. Mixed-stock fisheries problems appear to have not occurred and are not anticipated as result of this project. Harvest regulations have been in place to harvest surplus pink salmon produced at Little Waterfall Creek since the early 1980s (Honnold 1996, 1997; Brennan 1998). The results of this project have not and are not expected to require changes to these regulations. Coho harvest regulations have also been maintained for Perenosa Bay fisheries (Figure 2), and have allowed adequate management of the increased area coho salmon runs. Little Waterfall Creek coho salmon runs have not increased to harvestable sizes; however, the regulations in place will provide proper management to sustain the stock if abundance increases.

DISCUSSION

The data presented indicate that the null hypotheses: 1) *bypass modifications will not significantly increase the proportion of the overall pink salmon annual escapement to use the bypass and spawn in upstream habitat*; and 3) *there is not a significant difference in average pink salmon production prior to and after the installation of all bypasses* should be rejected. Also, initially the data suggested that the null hypothesis - 4) *there is not a significant relationship between escapement and resulting adult returns for Little Waterfall Creek pink salmon* should be rejected when upstream escapement for all years and odd-years are the dependent (x) variables. Further analyses, excluding data that exerted large leverage on these regressions, indicated failure to reject the null hypothesis for both the all years and odd-years data sets. All other data tested (dependent variables overall or downstream escapement for all years, odd-years, or even-years; Table 9) indicate failure to reject the null hypothesis. The data analyzed also indicate failure to reject null hypothesis 5) - *the proportion of the annual escapement upstream is not a function of spawner density downstream of the bypass*. Results from the analyses of null hypothesis 5) suggest that null hypothesis 6) - *the proportion of the annual escapement upstream is not a function of (the most upstream) bypass design* should be rejected. Insufficient data were available to statistically test the null hypothesis - 2) *bypass* *modifications will not significantly increase the relative abundance of juvenile pink (incubating) and coho (rearing) salmon in upstream habitat*; however, data suggest that more coho salmon were rearing after the bypass modification (1997) than prior to bypass modification (1996).

The historical pink salmon (and coho salmon to a lesser degree) escapement and distribution data indicate that inadequate passage through the bypass at the largest barrier falls at Little Waterfall Creek limited utilization of spawning habitat upstream. The original design of the bypass did not provide proper slope or water velocity conducive to salmon use. Smaller bypasses located downstream of the bypass in question are readily used by pink salmon and have slopes of 20% (Honnold 1991). Similarly, the Portage Creek fish pass (Figure 2) has a 13% slope and is used without difficulty by pink salmon (Honnold 1991). Other fishway evaluations indicate that sockeye, coho and chinook salmon pass readily through bypasses with 13%-28.7% slopes (Gauley 1960; Gauley and Thomson 1963; Slatick 1975). Steeppasses with gradients of 22-25% assure water discharge sufficient to attract fish to enter a bypass (A. Antonnikov, 1964, unpublished manuscript, USSR) and ascend easily as observed for sockeye and chinook salmon at the Frazer Lake fish pass (22% slope) on Kodiak Island (Blackett 1987). Pink salmon, a physically less vigorous fish, appear to need slopes in the 13-20% range, for optimum passage through bypasses, as observed at Little Waterfall Creek (Honnold 1996, 1997).

It is also necessary to provide consistent flow patterns in bypasses to allow for head increases, and stable water velocity. The design of the Alaska -type fish pass accounts for these head changes with baffles reducing water velocity (Zeimer 1962). Fishway (bypass) designs must also account for the normal cruising and burst swimming speeds of target species (Clay 1995). That is, a fishway must be designed so that water velocities do not exceed the swimming capabilities of the target species (Zeimer 1962). The velocity of the water through the orifices or slots must be less than the burst speed, and the velocity in the pools must be less then the cruising speeds. Beach *(*1984*)* suggests that a gradual transition between cruising and burst speeds is optimal in terms of utilization of the fish's anaerobic (white) and aerobic (red) muscle. Larger sockeye, coho and chinook salmon can withstand high water velocity (13.4-15.8 fps); however, smaller fish of these species may not successfully negotiate similar flows rates (Weaver 1962). Most salmonids are capable of negotiating a water velocity of approximately eight feet per second (fps) (A. Antonnikov, 1964, unpublished manuscript, USSR); but for short durations, velocities slightly greater than 8 fps are not excessive (Zeimer 1962). Flows should also be sufficient to provide a minimum discharge from the bypass entrance of 3 fps to attract fish and resting areas should have a velocity not greater than 1 fps for every 10 feet of vertical rise, depending on shape and length (Zeimer 1962). Insufficient number and poor location of resting pools also reduces salmon passage (B.A. McCurtain, ADF&G retired, Anchorage, personal communication). Coho salmon are highly susceptible to fatigue and adequate resting facilities are necessary in fishways with water velocities exceeding 1.1 meters per second (3.61 fps) for any considerable distance (Paulik et al 1957). Resting tanks at Frazer Lake fish pass are beneficial for holding slower or descending salmon without blocking passage of other salmon (Blackett 1987).

Pink salmon swimming ability had been observed to be poor in the most upstream bypass at Little Waterfall Creek during high flow events (Honnold 1997). The original design of this bypass did not appear to provide proper water velocities for consistent pink salmon passage. Water velocity appeared to exceed the optimum for larger salmonid species during most conditions, and baffles may not have been effective because of the excessive slope. Resting pool water velocity likely exceeded the recommended level (1 fps) due to the long steeppass section runs and pools not being staggered to impede the water velocity. The literature does not adequately address the limitations of pink salmon swimming ability with regards to bypass use, instead focusing on other salmonid species. The affected bypass was designed and constructed in the late 1970s when most performance parameters were gleaned from successful chinook, coho, and steelhead projects.

This project provided for modifications to the bypass to correct deficiencies in slope, water velocity, and number and location of resting pools. Slopes for all sections are now at 20% (Figure 7) or less, compared to 27% prior to the project (Figure 4). Observations from 1996-1998 indicated a constant water velocity in the steeppass runs and greatly reduced velocity in resting pools, as a result of staggering of steeppass runs. The addition of two resting pools and the modification of the previous entrance tank into an additional resting pool also appear to have increased fish endurance and improved passage through the bypass. The outflow at the new entrance tank also provided the required attraction for salmon; however, the tank was placed too high, making entry difficult. Also, the substrate in front of the entrance tank did not initially provide a pool for pink salmon to stage prior to entering the bypass. Field modifications to the entrance tank and construction of a temporary sandbag pool alleviated these problems in 1996 and 1997. A permanent 0.6-1.0 meter deep pool was partially excavated in the substrate in 1998 and is scheduled for completion in 1999.

The escapement distribution data indicate that a larger proportion (50%) of coho salmon migrated by way of the bypass (prior to modification) to upper habitat compared to pink salmon (21%). The limitations of the bypass, previously discussed, appear to have affected pink salmon migrations to a greater extent than coho migrations. However, the Little Waterfall Creek coho salmon escapements have, historically, been low, which limited the assessment of passage through the pre-modified bypass. The larger proportion of coho salmon observed upstream of the pre-modified bypass may be due to their swimming speed (cruising and burst; Bell 1984). Coho salmon, being larger than pink salmon, would be assumed to swim faster in the short-term (burst) and long-term (cruising). Post-modification escapement data do not indicate any substantial improvement in bypass use by coho salmon. However, bypass modifications would be predicted to assist the migration to upper habitat, since slope and water velocity criteria of the pre-project bypass were at upper limitations for coho salmon. The precision and reliability of pre and post-modification coho salmon escapement data is questionable due to survey techniques and associated variability. Comparison of escapement estimates from year to year should be used with caution when visual surveys are employed (Waldichuk 1984; Serbic 1991; Irvine et al. 1992.

Pink salmon utilization of spawning habitat upstream of the original bypasses at Little Waterfall Creek was greatly improved by the installation of the three bypasses, as indicated by a ten-fold increase (7,000 to 70,000) in the mean escapement post-bypass completion. Mean escapements for all years and even-years were significantly different ($P<0.001$ and $P=0.009$, respectively) when comparing pre and post-bypass periods. Odd-year escapements were not significantly different; however, only two years of pre-byass data were available, which may have limited the statistical analysis. The spawning habitat upstream of the largest bypass was not substantially utilized by pink salmon prior to modification of the largest bypass (1981-1995). Generally, data indicate variable use of the upper habitat prior to modification of the largest bypass and only one year (45% in 1993) in which the proportion of pink salmon upstream was within the post-modification range (41%-59%).

Little Waterfall Creek upstream spawning habitat represents the largest proportion of overall system habitat and is considered of higher quality than downstream habitat (Willette et al. 1994). The use of the upstream habitat contributes substantially to overall production of pink salmon at Little Waterfall Creek for some years. For example, in 1993, the large escapement (~75,000) upstream certainly must have accounted for a substantial portion of the large return (482,000) in 1995. Initial analyses including all brood years from 1981-1996 also indicated that the relationship between spawners and resultant recruits was significant ($P<0.001$; $R^2 = 0.59$). A similar significant relationship ($P=0.014$; $R^2 = 0.66$) was found when comparing upstream escapement to resulting runs for odd-years only. These analyses, however, break down when the 1993 escapement and 1995 return data are excluded ($P>0.60$; $R^2<0.05$) and strongly illustrates (Figures 14 and 15) the strong leverage of the outlying data points on the regressions. The analysis of even-year upstream escapements and resulting runs also did not reveal a significant relationship. These results may be due to the low upstream escapements for most brood years. Spawner-recruit relationships as described above may change in the future as escapements upstream increase as a result of improved bypass passage.

Pre-modification bypass use may have been influenced by pink salmon run timing. The earliest portion of the pink salmon run in some years were observed to use the bypass in larger proportions. In 1991, pink salmon were tagged at a weir located near salt water at Little Waterfall Creek. Approximately 45.3% of tag recoveries were found upstream of the bypass from samples tagged 25 July- 02 August compared to 21% recovered in upstream habitat from fish tagged 09-16 August. In 1992, when tagging was replicated, 28% of fish tagged during the early period were recovered upstream of the bypass compared to 19% for later tagging. The escapement in 1991 was 115,000 of which 19,000 were observed upstream of the bypass while in 1992 the escapement was 43,000 and 6,000 pink salmon were observed upstream of the bypass. This may indicate that density as well as escapement timing might have influenced the tagging results in 1991 and 1992.

Peer reviewers of the 1996 annual report (Honnold 1997) also suggested that the use of the original bypass may have been influenced by downstream fish density. Density, however, does not appear to explain the variation in bypass use, as indicated by regression analyses, which resulted in poor relationships between downstream escapement (independent variable) and the proportion of the pink salmon escapement observed upstream (dependent variable) of the bypass (Hypothesis 5; Table 9).

The proportion of pink salmon utilizing the modified bypass from 1996-1998 was significantly ($P<0.001$) higher than pre-modification use, which indicates that the original bypass design was probably the limiting factor in proportional use of the upstream habitat and that the design improvements were effective.

Pre-construction pre-emergent fry data indicate the habitat downstream of the bypass has historically produced more juvenile pink salmon than upstream habitat. This is not suprising, since larger proportions of the escapements have spawned in downstream habitat. Little Waterfall Creek often has one of the highest annual indices of pink salmon fry/m^2 on Afognak Island (Kevin Brennan, ADF&G, Kodiak, personal communication); however, the system index declined by ~five- fold from 1982 to 1994. Furthermore, fry indices declined by ~thirty -fold in downstream spawning habitat during this period. The brood year escapements were over 100,000 for most years that the fry index declined and the majority of spawning occurred in downstream habitat. This trend may indicate habitat degradation due to the uneven distribution of pink salmon that spawn in the system. Approximately 80% of the overall spawning habitat in Little Waterfall Creek is located upstream of the largest barrier bypass (Honnold 1995); however, average pink salmon distribution to this area prior to 1996 was only 21% of the total escapement. This indicates that 79% of the escapement utilized only 20% of the spawning habitat and may, in part, explain the declining index of pre-emergent fry. Previous Kodiak Island studies suggested significant density dependent relationships for pink salmon populations for both egg retention and pre-emergent fry response (Donnelly 1983; Eggers et al 1991). Swanton et al (1993), however, reported no conclusive evidence that the depression of pink salmon indices (fry/m^2) for Kodiak Island systems, overall, was directly caused by high spawner densities as a result of the 1989 overescapements. The latter conclusion is supported by pre-emergent data collected in 1996 at Little Waterfall Creek. The total fry index, as well as the downstream index increased substantially to the highest level since 1982, although in 1995, over 100,000 pink salmon escaped and over 80,000 spawned in downstream habitat. By contrast, the overall index of fry/m^2 in 1994 was the lowest on record; however the upstream index was higher than the downstream index. The escapement in 1993 was also over 100,000, but 45% of the pink salmon spawned upstream.

The relationship between spawner density and resultant fry produced may be highly influenced by environmental conditions for Kodiak pink salmon systems (Charles O. Swanton, ADF&G, Fairbanks, personal communication). Frequent freshet events occur at Little Waterfall Creek, which may scour redds and account for declining fry/m^2 indices.

Regardless of the reason for declining fry/m^2 indices, the improved passage through the bypass may lessen negative impacts by providing a more even distribution of spawners in Little Waterfall Creek.

The absence of coho salmon fry in pre-emergent samples is not unexpected with the low escapements observed in the system. Additional samples in different locations may be necessary to document emergent coho salmon fry abundance indices.

Coho salmon fry CPUE in Little Waterfall Creek was higher in 1997 than in 1996 for upstream, downstream, and all combined minnow trapping locations. The 1997 total and downstream CPUEs were about double the 1996 total and downstream CPUEs, while the 1997 upstream CPUE was about triple the 1996 upstream CPUE. This suggests that a larger proportion of adult coho salmon reproduced upstream after the bypass was modified in 1996 than prior to modification in 1995.

The factors discussed indicate that much of the variation in pre-modification escapement distribution to upper and lower habitat was probably a result of design limitations that inhibited consistent migrations through the bypass. The problems identified with the design of the barrier bypass were corrected in 1995 and data presented here suggest that pink and coho salmon passage to upstream habitat has increased during years of varying levels of overall escapement (1996-1998).

The upstream habitat (~17,000 m^2) is estimated to support 24,000 pink and 2,700 coho salmon (Willette et al 1994; Honnold 1997). At this seeding level, an additional harvestable surplus of 24,000 pink and 4,000 coho salmon is projected. The harvest of Little Waterfall pink salmon has averaged (1981-1998) approximately 51,000 annually. Thus, the full utilization of habitat may result in almost 50% more pink salmon for harvest. Coho salmon harvest at Little Waterfall has been minimal, thus new harvest opportunity may be afforded. The seeding of spawning habitat by coho salmon at current escapement levels (~250 in 1998) is expected to be slow. For example, if 100 additional fish reach the upper spawning area, only 800 coho salmon would be predicted to be produced (Table 1). Assuming a 75% exploitation rate, that would leave 200 for escapement. This increase would, then be expected to continue slowly until optimum levels are reached in approximately ten years.

SUMMARY AND CONCLUSIONS

Little Waterfall Creek pink salmon have had limited access to upstream spawning habitat, which has resulted in a larger proportion of spawners distributed in downstream habitat. The steep slope, limited number of resting pools, and resultant high water velocity of the largest barrier bypass were identified as the primary reasons for poor utilization of upper habitat. Bypasses with slopes of 13-20% and evenly spaced (one/10 foot rise) resting pools, providing flows of 8 fps or less, enable consistent pink salmon passage. Coho salmon have similar requirements, however they can negotiate bypasses with steeper slopes. The original bypass design was insufficient due to slopes of 27%, irregularly spaced resting pools and resultant high water velocity, especially during freshet events. This project provided for modifications to correct the original bypass design, including reducing slopes to 20% or less, and adding three properly spaced staggered resting pools. Juvenile and adult production assessment prior to bypass modification reflects the poor passage to upper habitat, as indicated by spawner distribution, low pre-emergent fry abundance, and rearing coho abundance. Prior to modification of the bypass, the escapement to upstream habitat by pink salmon varied, regardless of the overall escapement trends. The overall system or downstream pink salmon escapement density did not appear to explain this variation and appears more likely a result of steeppass limitations and water velocity fluctuations in response to season hydrological changes in Little Waterfall Creek. Coho salmon adult data are sparse and limit the assessment of the use of the modified bypass. However, juvenile coho salmon data indicate increased abundance post-modification, which also suggests improved adult escapement. Pink salmon proportional use of the bypass and distribution to upstream habitat improved substantially from 1996-1998 as result of bypass improvements. Full seeding of upstream habitat can potentially provide, on average, ~ 34% more pink salmon for harvest. Coho salmon will also be available to harvest when escapement levels reach optimum levels; however, this is not expected to occur in the near-term.

In conclusion, the improvements made to the largest, most upstream, bypass at Little Waterfall Creek appear to have been successful, as reflected by the significant increase in the proportion of the pink salmon escapement and, to a lesser extent, increased juvenile coho salmon abundance observed upstream of the barrier.

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TABLES

Table 1. Assumptions of spawner density, fecundity, survivals, and exploitation rate used to forecast pink and coho salmon production benefits for the Little Waterfall Creek restoration project.

Parameter	Pink Salmon	Source (Area)	Coho Salmon	Source
Optimum female density (no./m2)	0.7	Heard (1978)	0.08	Sheng et al. (1990)
Average fecundity	1,858	Prince William Sound Aquculture Association (1991)	4,835	Alaska (unpublished ADF&G data)
Egg-to-fry survival (%)	6.4	SE Alaska (unpublished ADF&G data)	2.0	Bradford (1994) [a]
Marine survival (%)	3.1	Alaska (Sharr et al. 1993)	4.1	Washington, California (Willette et al. 1994)
Exploitation rate (%)	54	Barrett et al. (1990); Kodiak (unpublished ADF&G data)	75	Chapman (1986)

[a] egg-to-smolt survival

Table 2. Pink salmon peak survey counts, bypass counts, and escapement estimates downstream of bypass, upstream of bypass, and for the total *Little Waterfall Creek system, 1968-1998* (means only for 1968-1980; bold indicates years after bypass modification).

Year[a]	Downstream of Bypass			Upstream of Bypass			Total System			
	Peak Count	Escapement Estimate	%	Peak Count[b]	Escapement Estimate	%	Peak Count	Bypass Count[c]	Escapement Estimate	%
Mean 68-80:	3,592	6,824	100	0	0	0	3,592	nd	6,824	100
Mean 68-80 (OY):	3,550	6,745	100	0	0	0	3,550	nd	6,745	100
Mean 68-80 (EY):	3,616	6,870	100	0	0	0	3,616	nd	6,870	100
1981	nd	60,122	98	1,125	1,125	2	nd	55,447	61,247	100
1982	35,800	41,554	87	4,200	6,275	13	40,000	47,829	47,829	100
1983	10,045	18,883	88	955	2,677	12	11,000	21,560	21,560	100
1984	34,614	30,165	75	5,386	9,851	25	40,000	36,016	40,016	100
1985	69,643	107,131	90	10,357	12,080	10	80,000	119,211	119,211	100
1986	22,622	46,865	92	2,378	4,019	8	25,000	50,884	50,884	100
1987	nd	nd	nd	nd	nd	nd	26,000	29,093	29,093	100
1988	nd	nd	nd	nd	nd	nd	14,500	nd	27,550	100
1989	88,558	132,989	90	7,743	14,027	10	96,301	nd	147,016	100
1990	11,121	38,925	83	3,044	8,075	17	14,165	42,060	47,000	100
1991	53,400	95,654	83	10,083	19,346	17	63,483	99,136	115,000	100
1992	22,540	36,691	85	3,569	6,309	15	26,109	35,763	43,000	100
1993	63,224	91,339	55	45,799	75,052	45	109,023	nd	166,391	100
1994	15,750	37,292	73	6,974	13,645	27	22,724	nd	50,937	100
1995	28,885	82,135	82	8,328	18,088	18	36,690	nd	100,223	100
1996	**3,081**	**8,046**	**59**	**2,428**	**5,578**	**41**	**5,509**	**nd**	**13,624**	**100**
1997	**6,059**	**9,897**	**41**	**8,861**	**14,442**	**59**	**14,920**	**nd**	**24,339**	**100**
1998	**42,975**	**76,810**	**51**	**51,693**	**74,845**	**49**	**94,668**	**nd**	**151,655**	**100**
Mean 81-98:	33,888	57,156	82	10,808	17,840	26	42,358	53,700	69,810	100
Mean 81-98 (OY):	45,688	74,769	86	11,656	19,605	23	54,677	64,889	87,120	100
Mean 81-98 (EY):	23,563	39,544	75	9,959	16,075	31	31,408	42,510	52,499	100
Mean 81-95:	38,017	63,057	89	8,457	14,659	21	43,214	53,700	71,130	100
Mean 81-95 (OY):	52,293	84,036	88	12,056	20,342	21	60,357	64,889	94,968	100
Mean 81-95 (EY):	23,741	38,582	88	4,259	8,029	18	26,071	42,510	43,888	100

OY - Odd Year; EY - Even Year; nd - no data.

[a] First two barriers bypassed with fish passes in 1979; third bypassed in 1980 ; 1981-1998 escapements were enhanced as a result.

[b] Bypass count in 1981.

[c] Salmon counted as they exit most downstream bypass.

Table 3. Coho salmon peak survey counts, bypass counts, and escapement estimates downstream of bypass, upstream of bypass, and for the total Little Waterfall Creek system, 1981-1998 (bold indicates years after bypass modification).

Year[a]	Downstream of Bypass			Upstream of Bypass			Total System			
	Peak Count	Escapement Estimate	%	Peak Count	Escapement Estimate	%	Peak Count	Bypass Count[b]	Escapement Estimate	%
1981	4	10	40	6	14	60	10	3	24	100
1982	nd	nd	nd	nd	nd	nd	nd	16	16	100
1983	40	96	100	0	0	0	40	5	96	100
1984	18	43	28	47	113	72	65	15	156	100
1985	0	0	0	2	5	100	2	0	5	100
1986	195	468	98	5	12	3	200	2	480	100
1987	nd	nd	nd	nd	nd	nd	1	1	2	100
1988	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
1989	0	0	0	16	38	100	16	nd	38	100
1990	7	17	39	11	26	61	18	18	43	100
1991	9	22	29	22	53	71	31	31	74	100
1992	0	0	0	34	82	100	34	3	82	100
1993	0	0	0	0	0	0	0	nd	0	0
1994	95	228	67	47	113	33	142	nd	341	100
1995	0	0	0	0	0	0	0	nd	0	0
1996	**76**	**182**	**84**	**15**	**36**	**16**	**91**	**nd**	**218**	**100**
1997	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**nd**	**0**	**0**
1998	**53**	**127**	**50**	**53**	**127**	**50**	**106**	**nd**	**254**	**100**
Mean 81-98:	33	80	36	17	41	44	47	9	108	100
Mean 81-95:	31	74	33	16	38	50	43	9	97	100

OY - Odd Year; EY - Even Year; nd - no data.

[a] First two barriers bypassed with fish passes in 1979; third bypassed in 1980 ; 1981-1998 escapements were enhanced as a result.

[b] Salmon counted as they exit most downstream bypass.

Table 4. Little Waterfall Creek pink salmon run reconstruction, return per spawner (RPS), and exploitation rate (ER), 1968-1998.

Year [a]	Escapement	Harvest	Total Run	RPS [b]	ER [c]
1968	950	0	950	nd	0%
1969	0	0	0	nd	nd
1970	3,800	113	3,913	4.1	3%
1971	nd	nd	nd	nd	nd
1972	950	162	1,112	0.3	15%
1973	nd	nd	nd	nd	nd
1974	11	0	11	0.0	0%
1975	13,300	443	13,743	nd	3%
1976	9,506	0	9,506	864.2	0%
1977	0	0	0	0.0	0%
1978	6,840	1,965	8,805	0.9	22%
1979	13,680	2,622	16,302	nd	16%
1980	26,030	5,937	31,967	4.7	19%
Mean:	6,824	1,022	7,846	1.7	13%
Mean (OY):	6,745	766	7,511	0.0	10%
Mean (EY):	6,870	1,168	8,038	2.0	15%
1981	61,247	58,284	119,531	8.7	49%
1982	47,829	53,862	101,691	3.9	53%
1983	21,560	4,220	25,780	0.4	16%
1984	40,016	6,832	46,848	1.0	15%
1985	119,211	48,751	167,962	7.8	29%
1986	50,884	38,387	89,271	2.2	43%
1987	29,093	15,718	44,811	0.4	35%
1988	27,550	112,010	139,560	2.7	80%
1989	147,016	0	147,016	5.1	0%
1990	47,000	48,978	95,978	3.5	51%
1991	115,000	7,619	122,619	0.8	6%
1992	43,000	1,109	44,109	0.9	3%
1993	166,391	126,832	293,223	2.5	43%
1994	50,937	13,328	64,265	1.5	21%
1995	100,223	381,679	481,902	2.9	79%
1996	13,624	183	13,807	0.3	1%
1997	24,339	2,302	26,641	0.3	9%
1998	151,655	2,668	154,323	11.3	2%
Mean (1981-1998):	69,810	51,264	121,074	3.1	42%
Mean (OY):	87,120	71,712	158,832	3.2	45%
Mean (EY):	52,499	30,817	83,317	3.0	37%

[a] First two barriers bypassed with fish passes in 1979; third bypassed in 1980 (improvements made in 1995).

[b] Mean RPS for 1968-1980 does not include 1976 data.

[c] Mean ER calculated from mean harvest and run data.

Table 5. Little Waterfall Creek pink salmon fry captured and index number per m^2 for upstream and downstream pre-emergent sampling sites, 1982 - 1997.

Year	Date	Digs		Number of Pink Fry [a]				Indexed Number of Pink Fry/m^2 [b]		
		No.	% w/fry	U.stream	%	D. stream	%	U.stream	D. stream	Total
1982	6-Apr	20	50	0	0.0	2,177	100.0	0.00	1171.23	585.61
1986	25-Mar	20	55	2	0.2	1,259	99.8	0.54	338.10	339.21
1987	1-Apr	20	80	0	0.0	458	100.0	0.00	246.40	123.20
1992	28-Mar	20	100	353	29.2	856	70.8	95.50	224.90	325.22
1994	7-Apr	20	55	147	31.7	316	68.3	39.50	37.40	124.55
1996	21-Mar	20	50	0	0.0	1,695	100.0	0.00	911.91	455.96
1997	28-Mar	20	15	0	0.0	244	100.0	0.00	131.27	65.64
Mean:		20	58	72	8.7	1,001	91.3	19.36	437.32	288.48

[a] Actual number of pink fry enumerated from all digs.

[b] (Number of fry/(number of digs x 2)) x 10.76 (K.Brennan,ADF&G,personal communication).

Table 6. Little Waterfall Creek viable pink salmon escapement, potential egg deposition, indexed fry per m^2, indexed fry and egg-to-fry survival estimates, 1981-1998 (years associated with use of modified bypass are shaded).

	Escapement			Potential Egg Deposition [a]			Indexed Fry/ m^2 [b]			Indexed fry [c]			Egg to fry survival (%)		
Year	Total	Upstream	Downstream	Total	Upstream	Downstream	Total	Upstream	Downstream	Total	Upstream	Downstream	Total	Upstream	Downstream
1981	61,247	1,125	60,122	56,898,463	1,045,125	55,853,338	585.61	0.00	1171.23	12,473,493	0	5,036,289	21.9	0.0	9.0
1982	47,829	6,275	41,554	44,433,141	5,829,475	38,603,666	nd	nd	nd						
1983	21,560	2,677	18,883	20,029,240	2,486,933	17,542,307	nd	nd	nd						
1984	40,016	9,851	30,165	37,174,864	9,151,579	28,023,285	nd	nd	nd						
1985	119,211	12,080	107,131	110,747,019	11,222,320	99,524,699	339.21	0.54	338.10	7,225,173	9,180	1,453,830	6.5	0.1	1.5
1986	50,884	4,019	46,865	47,271,236	3,733,651	43,537,585	123.20	0.00	246.40	2,624,160	0	1,059,520	5.6	0.0	2.4
1987	29,093	nd	nd	27,027,397			nd	nd	nd						
1988	27,550	nd	nd	25,593,950			nd	nd	nd						
1989	147,016	14,027	132,989	136,577,864	13,031,083	123,546,781	nd	nd	nd						
1990	47,000	8,075	38,925	43,663,000	7,501,675	36,161,325	nd	nd	nd						
1991	115,000	19,346	95,654	106,835,000	17,972,434	88,862,566	325.22	95.50	224.90	6,927,186	1,623,500	967,070	6.5	9.0	1.1
1992	43,000	6,309	36,691	39,947,000	5,861,061	34,085,939	nd	nd	nd						
1993	166,391	75,052	91,339	154,577,239	69,723,308	84,853,931	124.55	39.50	37.40	2,652,915	671,500	160,820	1.7	1.0	0.2
1994	50,937	13,645	37,292	47,320,473	12,676,205	34,644,268	nd	nd	nd						
1995	100,223	18,088	82,135	93,107,167	16,803,752	76,303,415	455.96	0.00	911.91	9,711,948	0	3,921,213	10.4	0.0	5.1
1996	13,624	5,578	8,046	12,656,696	5,181,962	7,474,734	65.54	0.00	131.27	1,396,002	0	564,461	11.0	0.0	7.6
1997	24,339	14,442	9,897	22,610,931	13,416,618	9,194,313	nd	nd	nd						
1998	151,655	74,845	76,810	140,887,495	69,531,005	71,356,490	nd	nd	nd						
Mean:	69,810	19,029	60,967	64,853,232	17,677,879	56,637,909	288.47	19.36	437.32	6,144,411	329,169	1,880,458	9.1	1.4	3.8

[a] 50:50 sex ratio; fecundity of 1858 (Willette et al. 1994).

[b] (Number of fry/(number of digs x 2)) x 10.76 (K.Brennan,ADF&G,personal communication).

[c] Index of fry/m^2 x useable spawning habitat.

nd no data

Table 7. Coho salmon catch and CPUE for baited and unbaited traps proportioned by upstream and downstream (of modified bypass) at trapping sites at Little Waterfall Creek, 1996 -1997.

		Downstream Coho Catch			Upstream Coho Catch			Total Coho Catch		
Year		Number	% Total	CPUE [a]	Number	% Total	CPUE [a]	Number	% Total	CPUE [a]
1996	Baited	22	55.0%	0.31	18	45.0%	0.25	40	100.0%	0.56
	Unbaited	21	75.0%	0.30	7	25.0%	0.10	28	100.0%	0.39
	Total	43	63.2%	0.61	25	36.8%	0.35	68	100.0%	0.96
1997	Baited	59	65.6%	0.83	31	34.4%	0.43	90	100.0%	1.26
	Unbaited	29	42.0%	0.41	40	58.0%	0.56	69	100.0%	0.97
	Total	88	55.3%	1.23	71	44.7%	0.99	159	100.0%	2.22

[a] CPUE = Catch (coho)-per-unit (hours of trapping)-effort.

Table 8. Summary of single-factor ANOVA statistics for null hypotheses (one and three) tested for Little Waterfall Creek pink salmon.

Hypothesis 1: Bypass modifications will not significantly increase the proportion of the overall pink salmon annual escapement to use the bypass and spawn in upstream habitat.

Groups	Years	Source of Variation	df	MS	F	P-value	F crit
1981-1995	all	Between Groups	1	2,670	23.79	0.0002	4.60
1996-1998	all						
1981-1995	even	Between Groups	1	1,157	23.79	0.0027	5.98
1996-1998	even						

Hypothesis 3: There is not a significant difference in average pink salmon production prior to and after the installation of all bypasses.

Groups	Years	Source of Variation	df	MS	F	P-value	F crit
1968-1980	all	Between Groups	1	22,670,586,787	13.38	0.0011	4.24
1981-1998	all						
1968-1980	odd	Between Groups	1	8,871,344,018	3.31	0.1022	5.12
1981-1998	odd						
1968-1980	even	Between Groups	1	8,198,205,780	8.99	0.0095	4.60
1981-1998	even						

Table 9. Summary of regression statistics for null hypotheses (four and five) tested for Little Waterfall Creek pink salmon.

Hypothesis 4: There is not a significant relationship between escapement and resulting adult returns for Little Waterfall Creek pink salmon.

Variables		Brood	Multiple	R	Standard	Observations	df	MS	F	P-value	F crit
x	y	Years	R	Square	Error						0.05
Tot.Escapement	Return	1981-1996 - All	0.48	0.23	108973	16	1	4.95E+10	4.17	0.0605	4.60
Tot.Escapement	Return	1981-1996 - Odd	0.43	0.18	152845	8	1	3.18E+10	1.36	0.2877	5.99
Tot.Escapement	Return	1981-1996 - Even	0.63	0.39	40742	8	1	6.46E+09	3.89	0.0959	5.99
DS Escapement	Return	1981-1996 - All	0.22	0.05	121075	16	1	1.05E+10	0.71	0.4112	4.60
DS Escapement	Return	1981-1996 - Odd	0.08	0.005	168796	8	1	1.00E+09	0.04	0.8575	5.99
DS Escapement	Return	1981-1996 - Even	0.42	0.18	47465	8	1	2.90E+09	1.29	0.2996	5.99
US Escapement	Return	1981-1996 - All	0.77	0.59	79494	16	1	1.27E+11	20.14	0.0005	4.60
US Escapement	Return	1981-1996 - All [a]	0.08	0.01	77152	15	1	4.96E+08	0.08	0.7774	4.67
US Escapement	Return	1981-1996 - Odd	0.81	0.66	98344	8	1	1.14E+11	11.78	0.0139	5.99
US Escapement	Return	1981-1996 - Odd [a]	0.19	0.04	104058	7	1	2.13E+09	0.2	0.6759	6.61
US Escapement	Return	1981-1996 - Even	0.59	0.35	42136	8	1	5.77E+09	3.25	0.1215	5.99

-Continued-

Table 9. (page 2 of 2)

Hypothesis 5: The proportion of the annual escapement upstream is not a function (the most upstream) bypass design, but a function of spawner density downstream of the bypass.

Variables		Years	Multiple R	R Square	Standard Error	Observations	df	MS	F	P-value	F crit 0.05
x	y										
DS Escapement	US %	1981-1998 - All	0.02	0	17	18	1	1.61E+00	0.005	0.9446	4.49
DS Escapement	US %	1981-1995 - All	0.29	0.08	11	15	1	1.58E+02	1.18	0.2955	4.67
DS Escapement	US %	1996-1998 - All	0.03	0	13	3	1	1.10E-01	0.0006	0.9836	161.40
DS Escapement	US %	1981-1998 - all w/o 87-88;93;97-98	0.49	0.24	9	13	1	2.78E+02	3.38	0.0928	4.84
DS Escapement	US %	1981-1998 - all w/o 87-88;93;96-98	0.31	0.1	35412	12	1	1.36E+09	1.08	0.3222	4.96
DS Escapement	US %	1981-1998 - odd	0.14	0.02	21	9	1	5.80E+01	0.13	0.7285	5.59
DS Escapement	US %	1981 -1995 - odd	0.35	0.12	14	8	1	1.67E+02	0.83	0.3972	5.99
DS Escapement	US %	1981-1995 - odd w/o 93 and 87	0.08	0.006	7	6	1	1.00E+00	0.03	0.88	7.71
DS Escapement	US %	1981-1998 - even	0.41	0.17	15	9	1	3.33E+02	1.42	0.2717	5.59
DS Escapement	US %	1981 -1995 - even	0.48	0.23	8	7	1	1.20E+02	1.53	0.2708	6.61
DS Escapement	US %	1981-1995 - even w/o 88	0.8	0.64	5	6	1	1.64E+02	7.22	0.0548	7.71

DS = downstream of modified bypass

US=upstream of modified bypass

US%= proportion of overall escapement upstream of modified bypass

[a] Excluding 1993 data

FIGURES

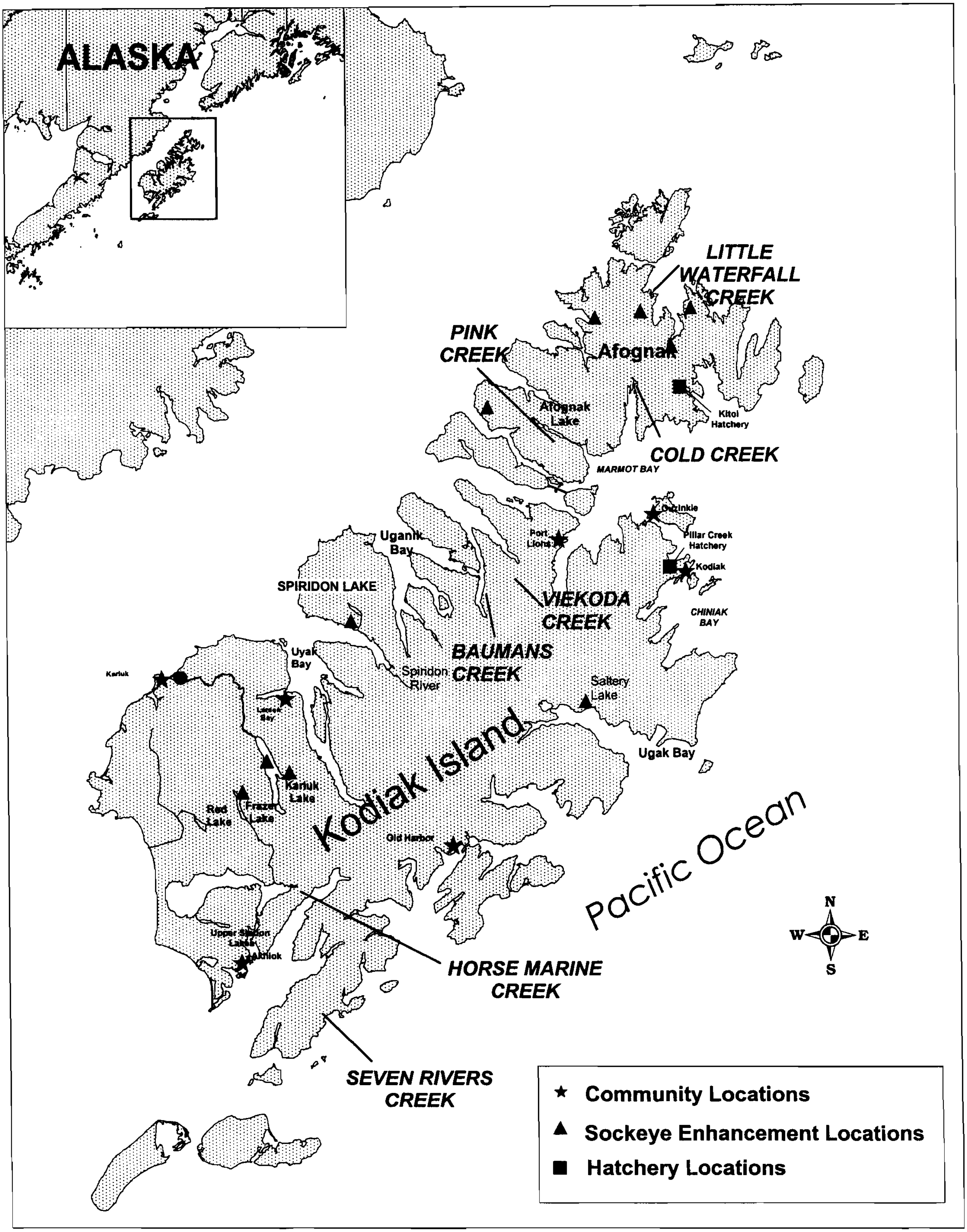


Figure 1. Location of salmon systems investigated for restoration potential; Little Waterfall Creek restoration began in 1994.

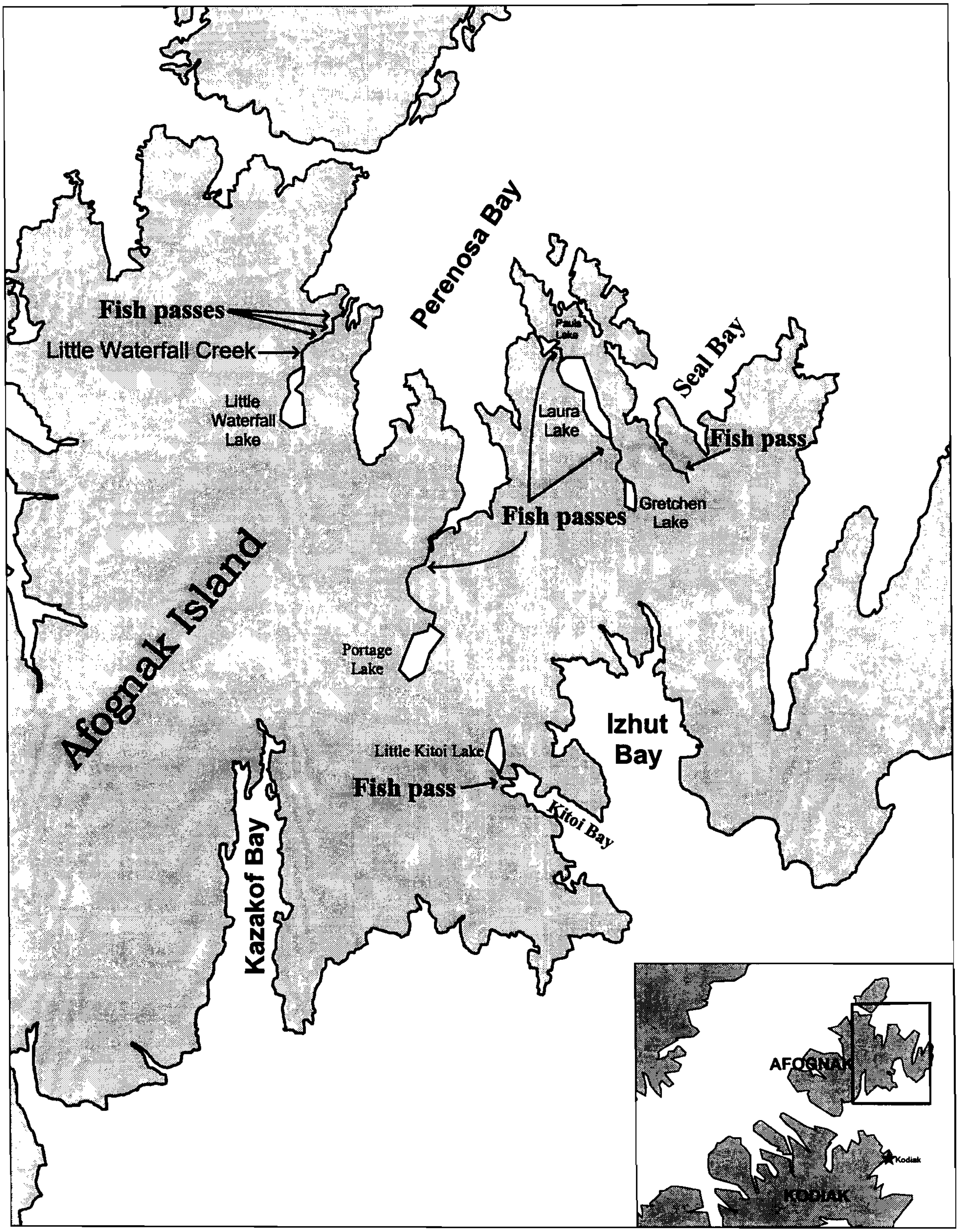


Figure 2. Location of fish passes (barrier bypasses) on Little Waterfall Creek and other salmon systems on Afognak Island.

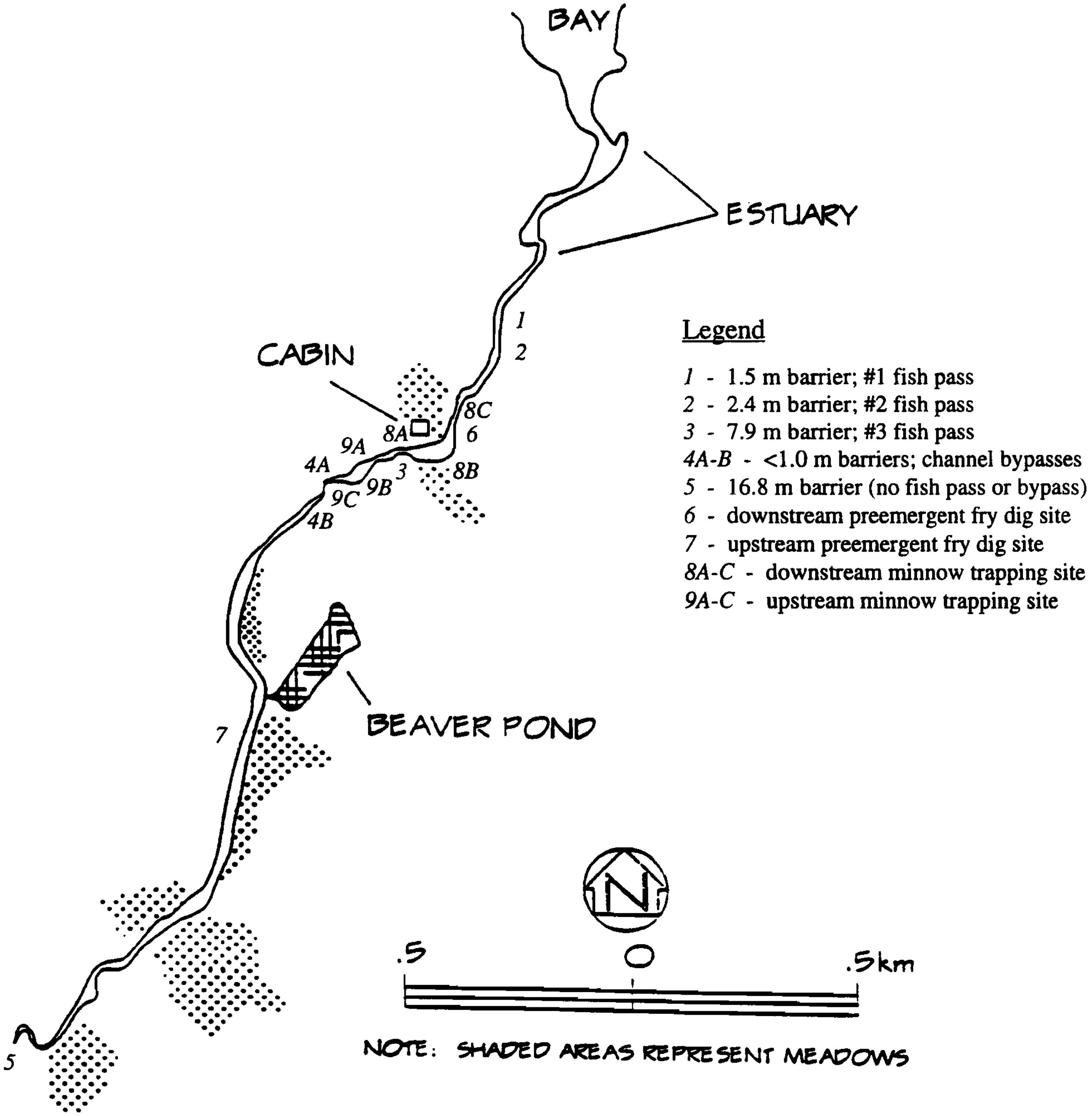


Figure 3. Location of barriers, fish passes, preemergent fry dig sites, and minnow trapping sites on Little Waterfall Creek, Afognak Island.

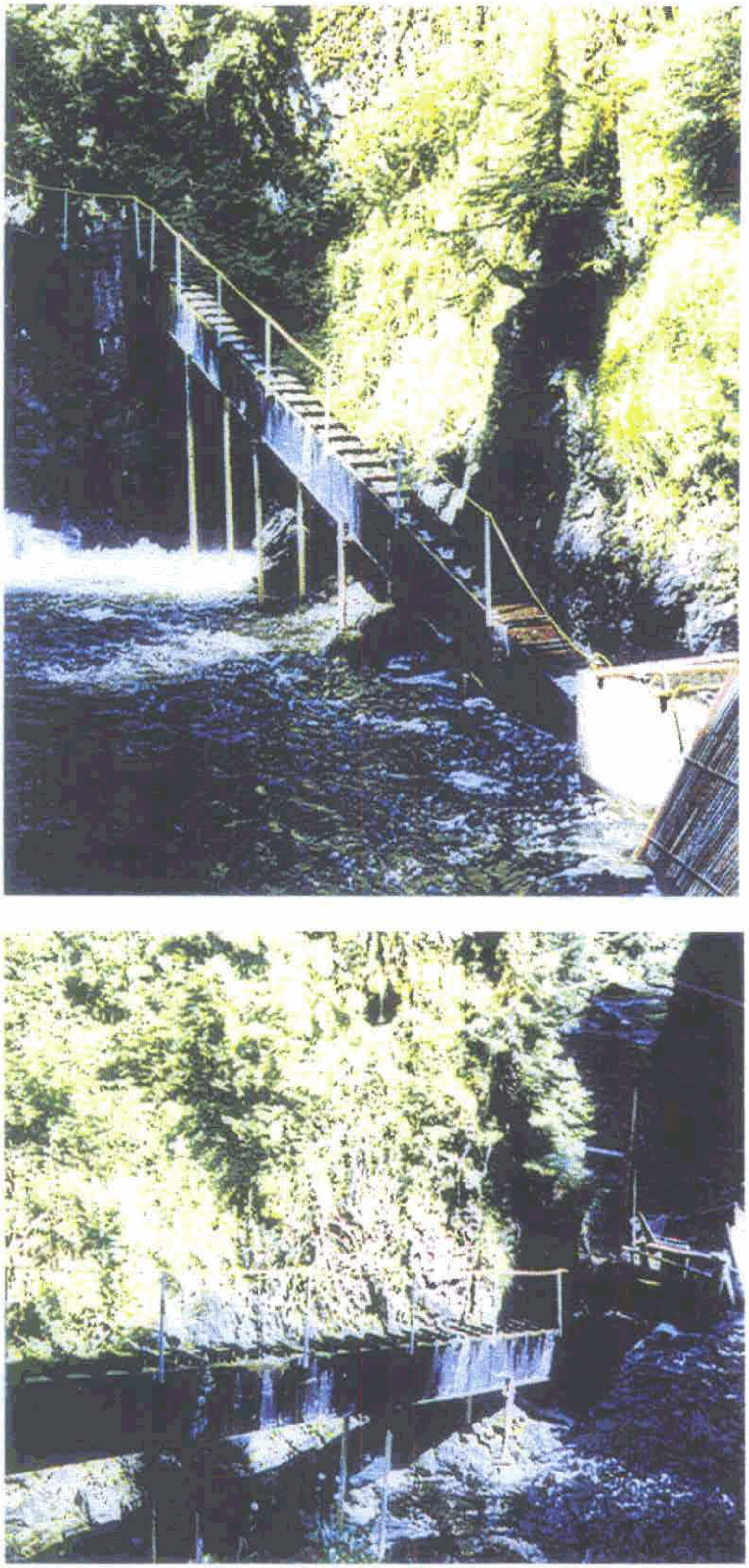


Figure 4. Photos of the most upstream bypass (third bypass) at Little Waterfall Creek, prior to 1995 modifications to improve salmon passage.

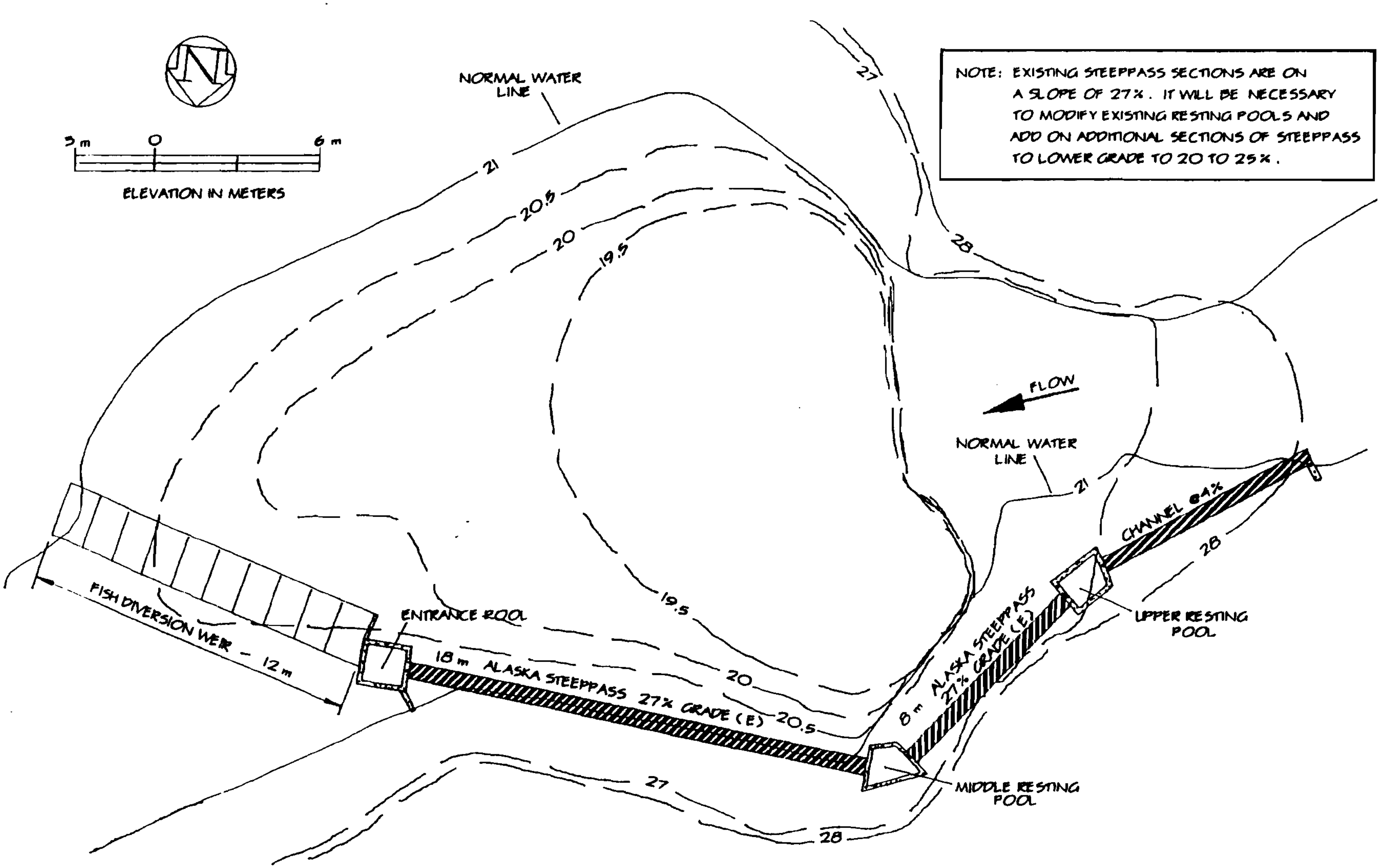


Figure 5. Design of original barrier bypass at 7.9 meter falls and recommended modifications to improve salmon passage.

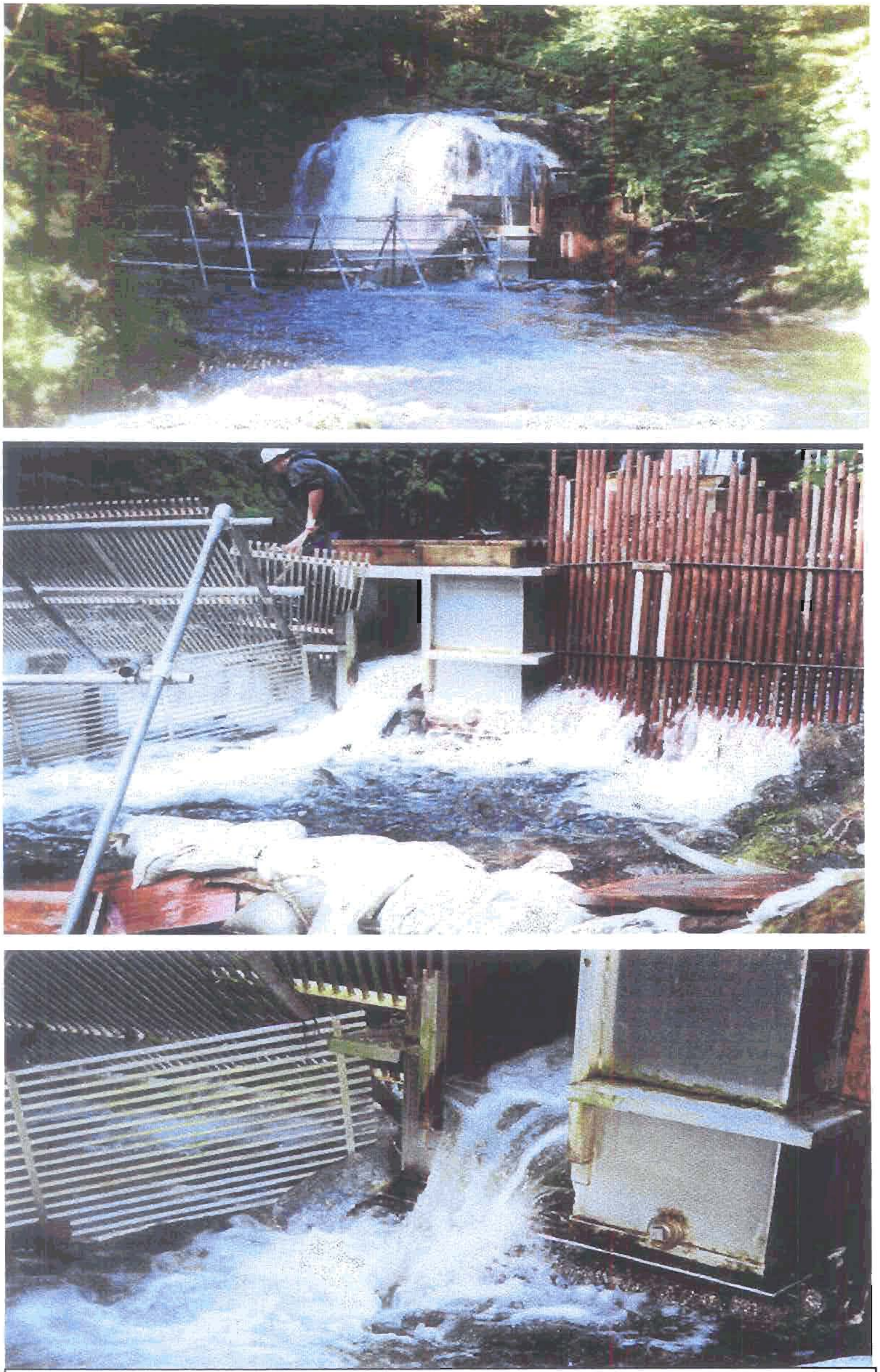


Figure 6. Photos of the third bypass entrance tank and diversion weir at Little Waterfall Creek, after 1995 modifications to improve salmon passage. Note pink salmon entering the entrance tank in the middle photo.

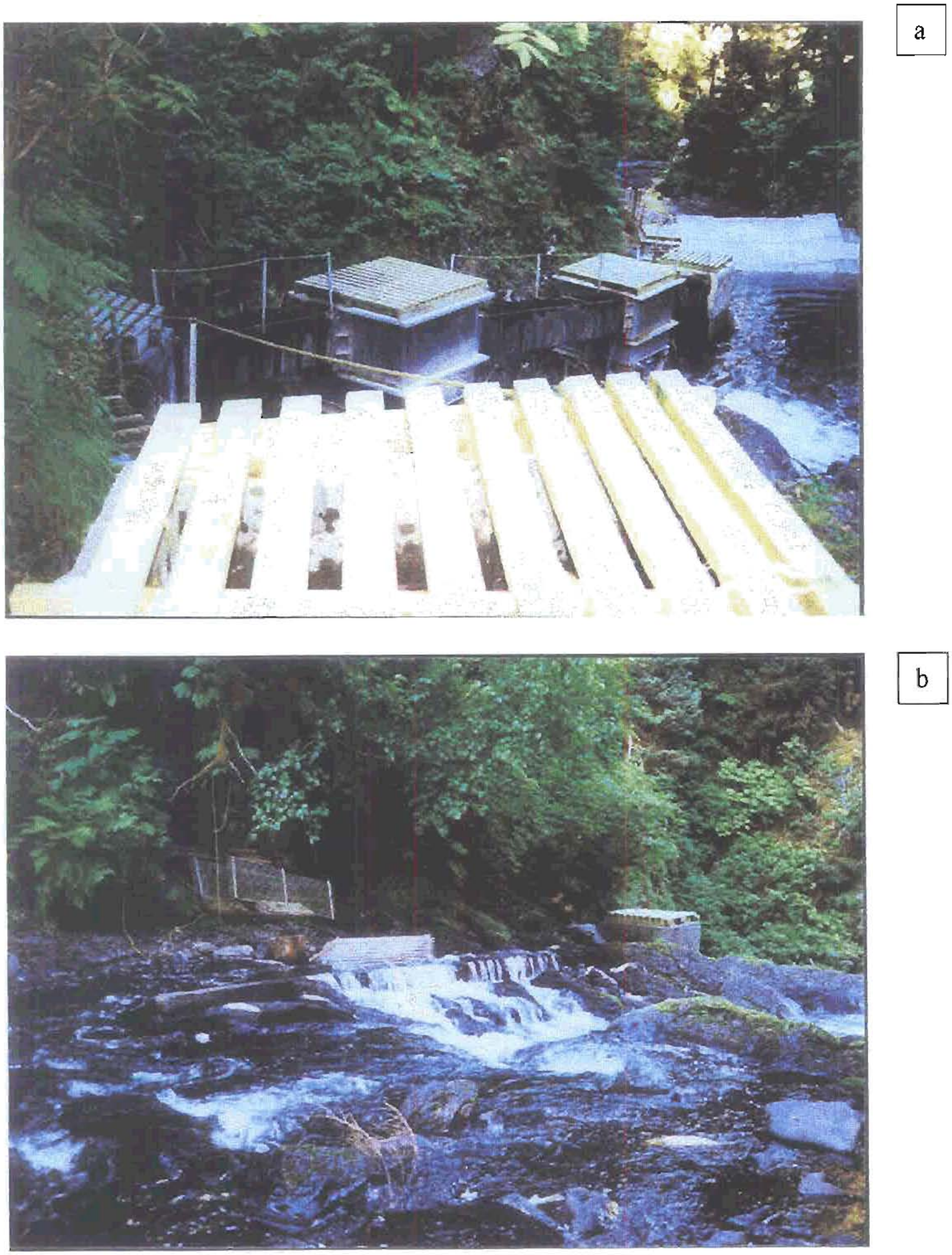


Figure 7. Photos of the third bypass at Little Waterfall Creek, with addition of aluminum resting tanks, reduced steeppass grades (a), and also showing exit channel diversion wall (b), which prevents salmon from being washed over falls.

Figure 8. Series of photos showing the entire post-modification configuration of the third bypass at Little Waterfall Creek.

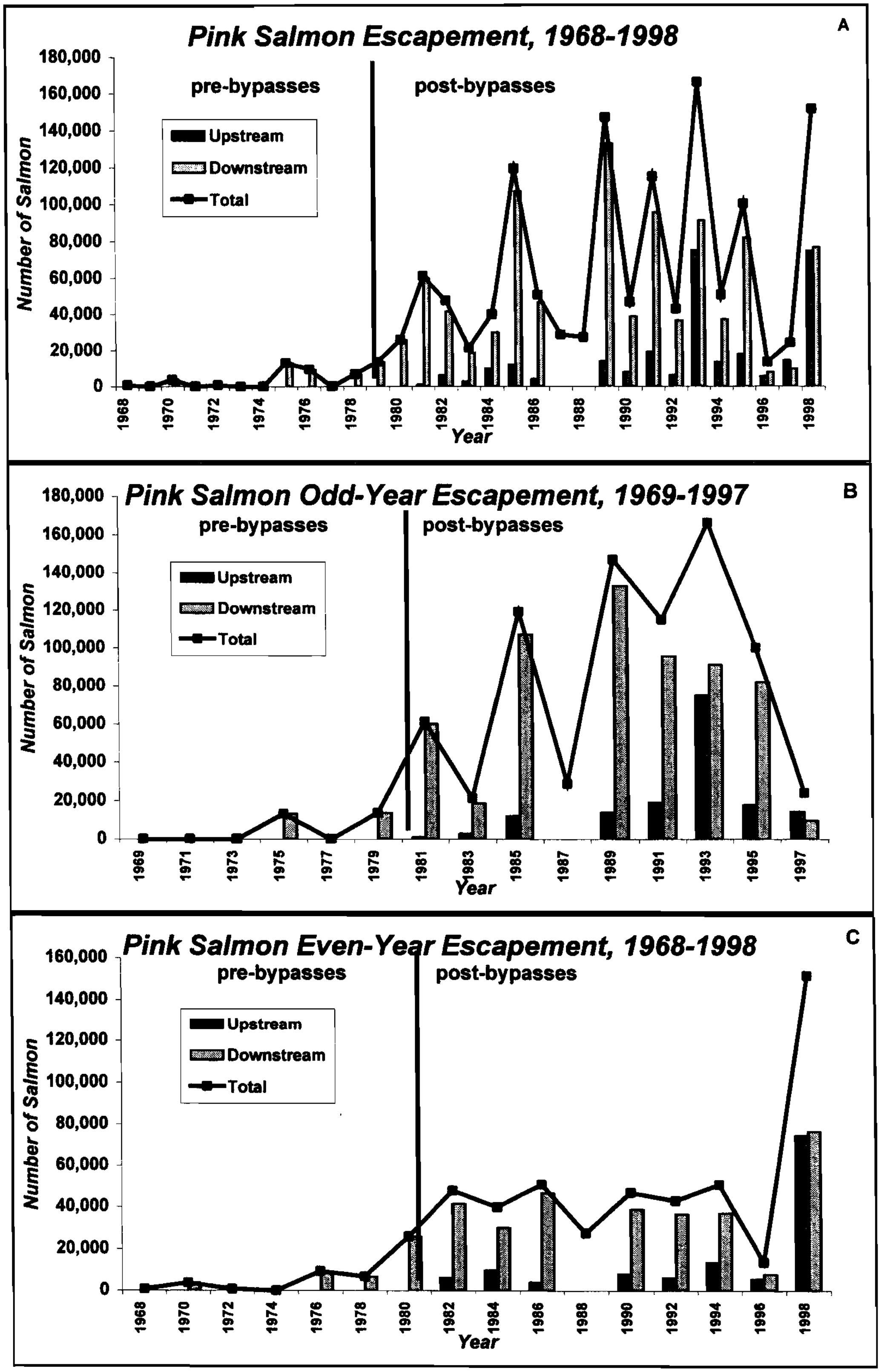
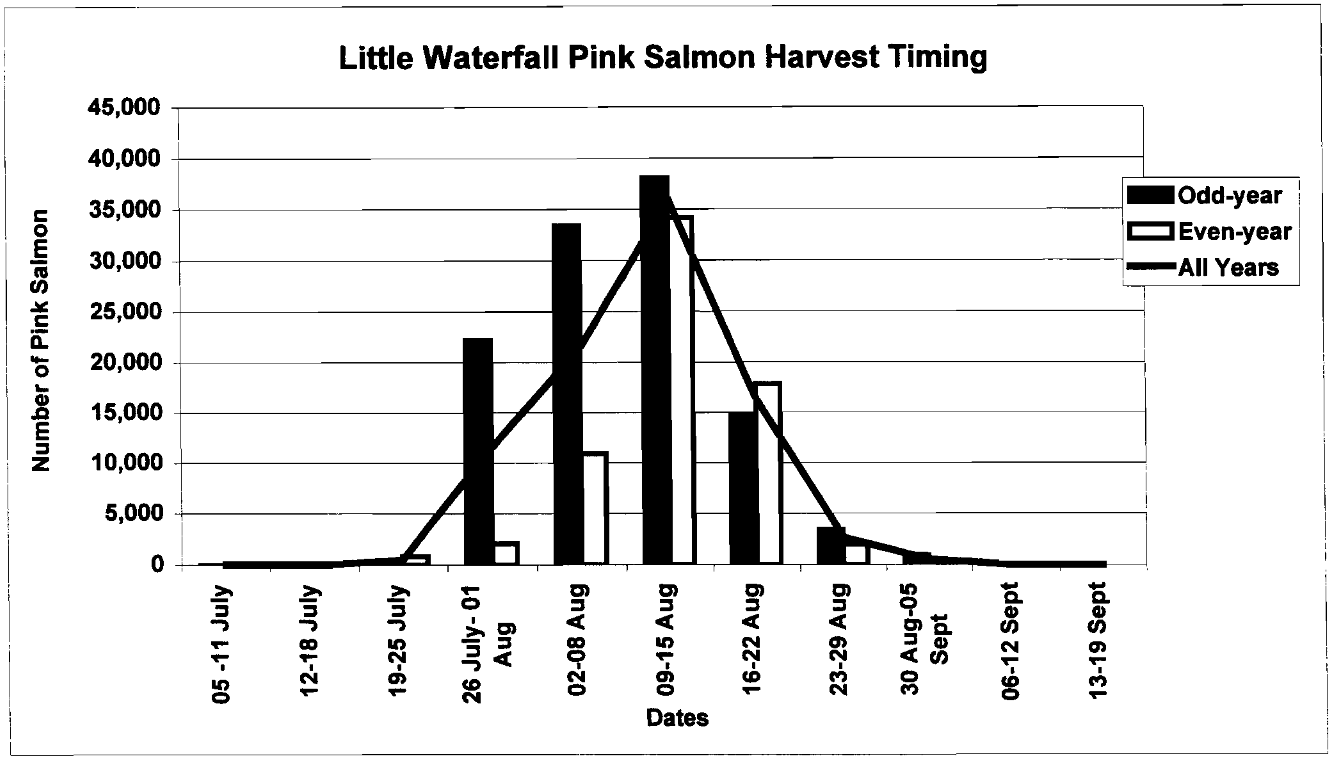


Figure 9. Little Waterfall Creek pink salmon all year (A), odd-year (B), and even-year (C) escapements, including annual total, and distribution downstream and upstream of modified bypass, 1968-1998 (post-modification escapements - 1996-1998).



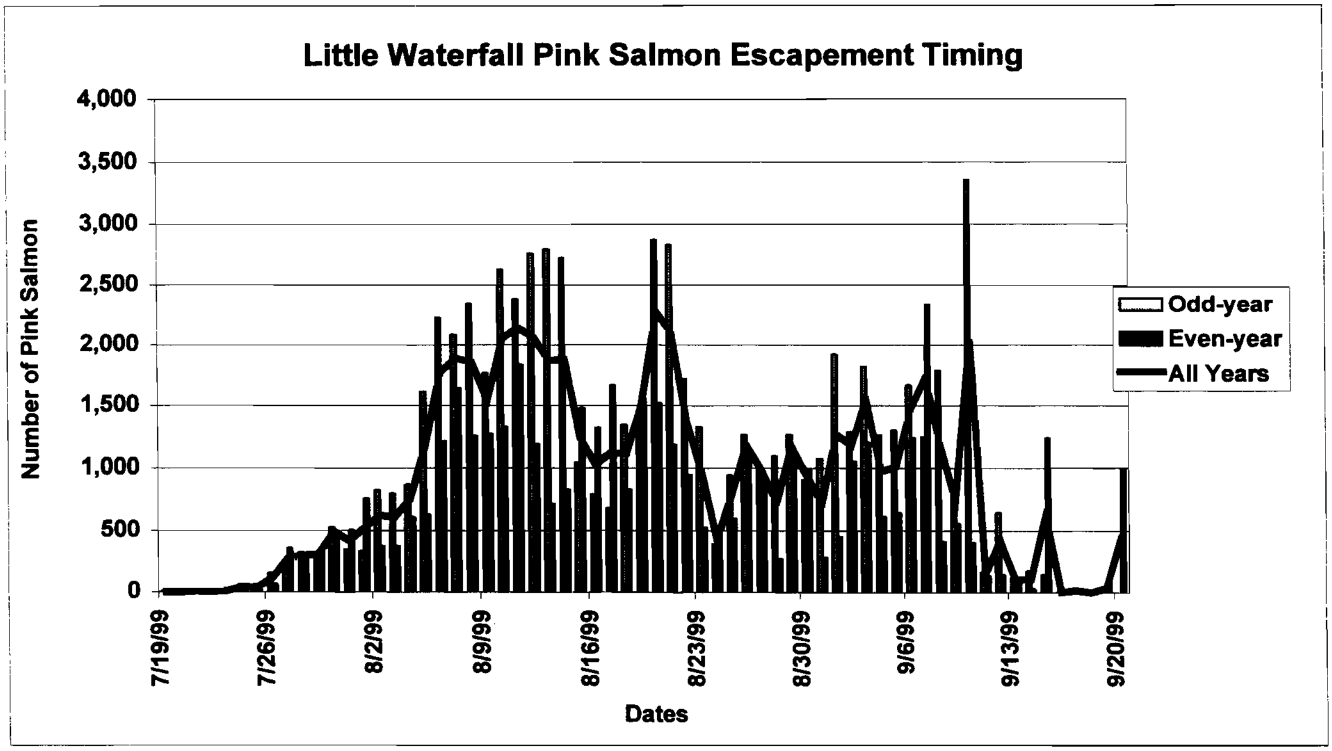


Figure 10. Little Waterfall pink salmon average harvest (A) and escapement (B) by day for all years, odd-years, and even-years, 1981-1998 (weir escapements only and harvest for 251-82, 251-83, 251-84 sections combined).

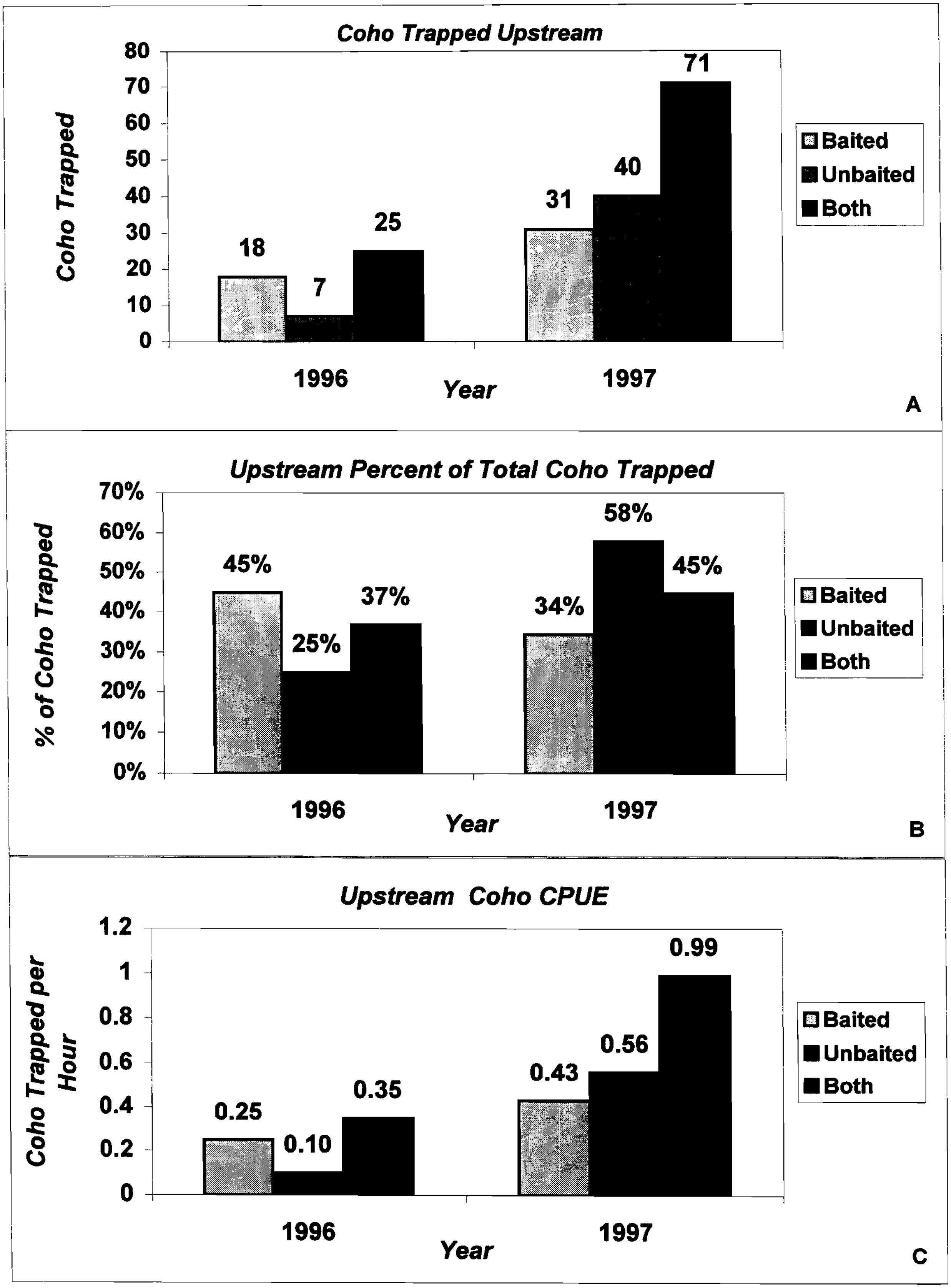


Figure 11. Coho catch (A), proportion of overall catch (upstream plus downstream) (B), and catch-per-unit-effort (CPUE) (C) for minnow traps fished upstream of modified bypass at Little Waterfall Creek, 1996 and 1997.

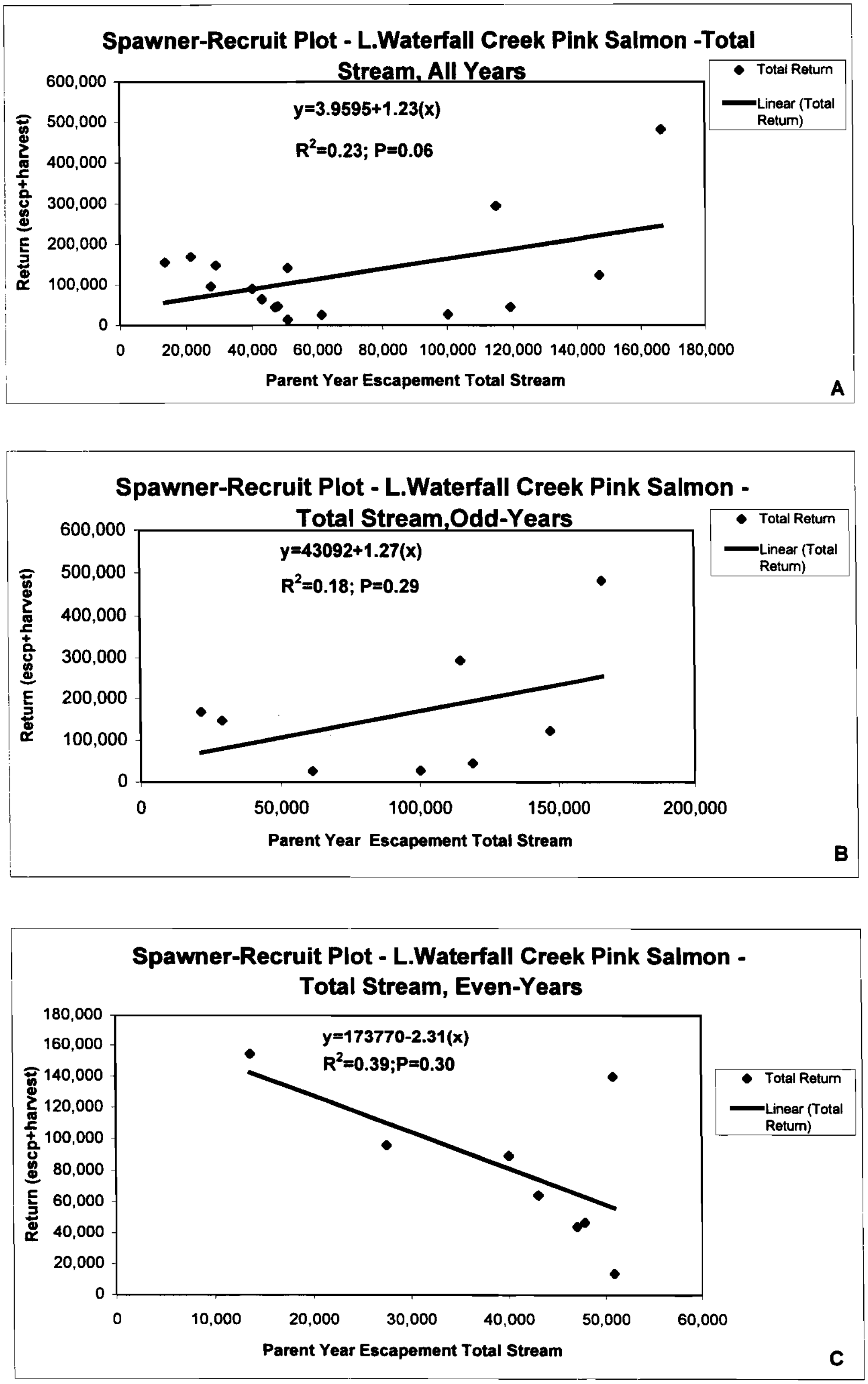


Figure 12. Pink salmon return as a function of parent year total stream escapement, all years (A), odd-years (B), and even-years (C), Little Waterfall Creek, 1981-1996.

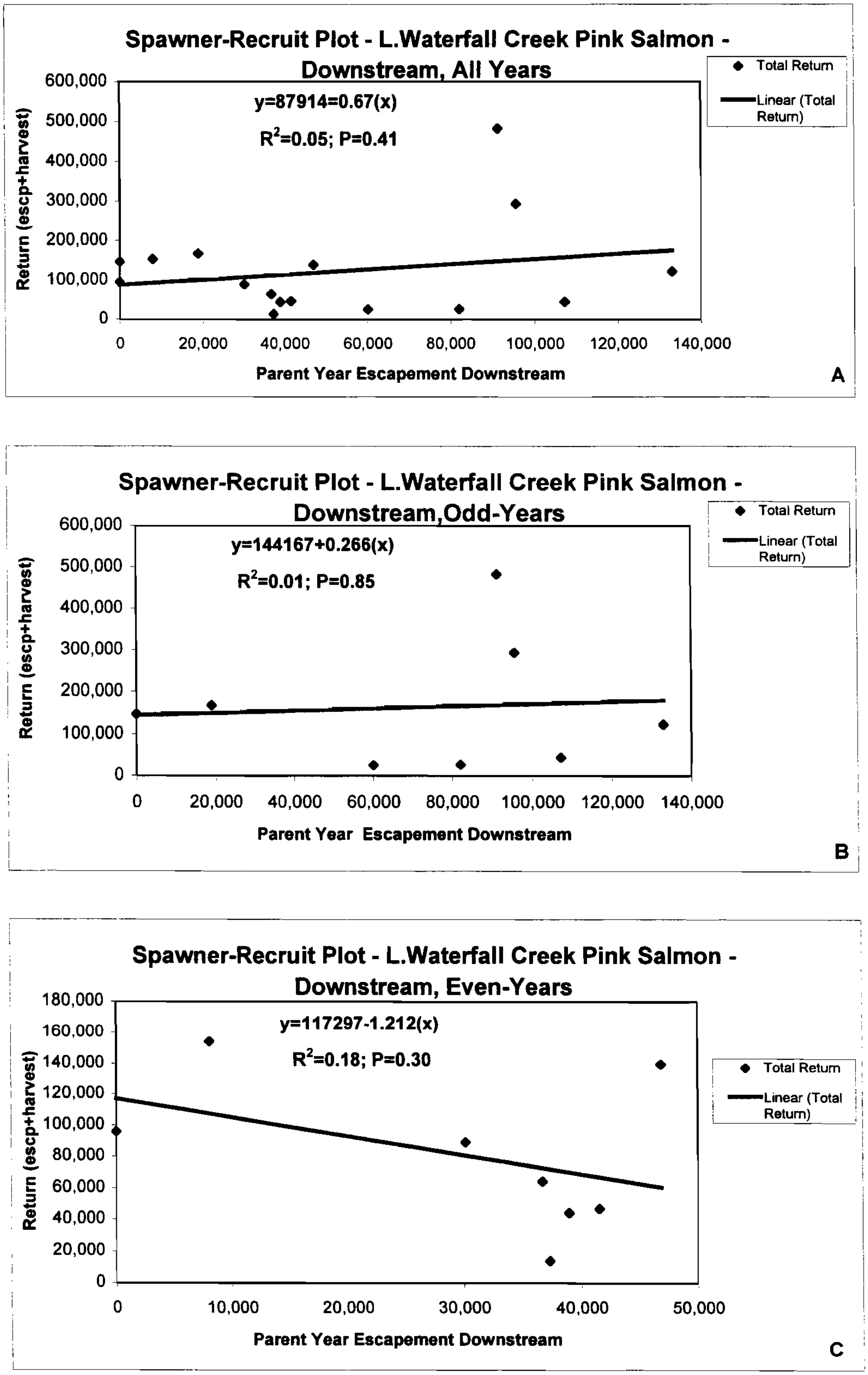


Figure 13. Pink salmon return as a function of parent year downstream escapement, all years (A), odd-years (B), and even-years (C), Little Waterfall Creek, 1981-1996.

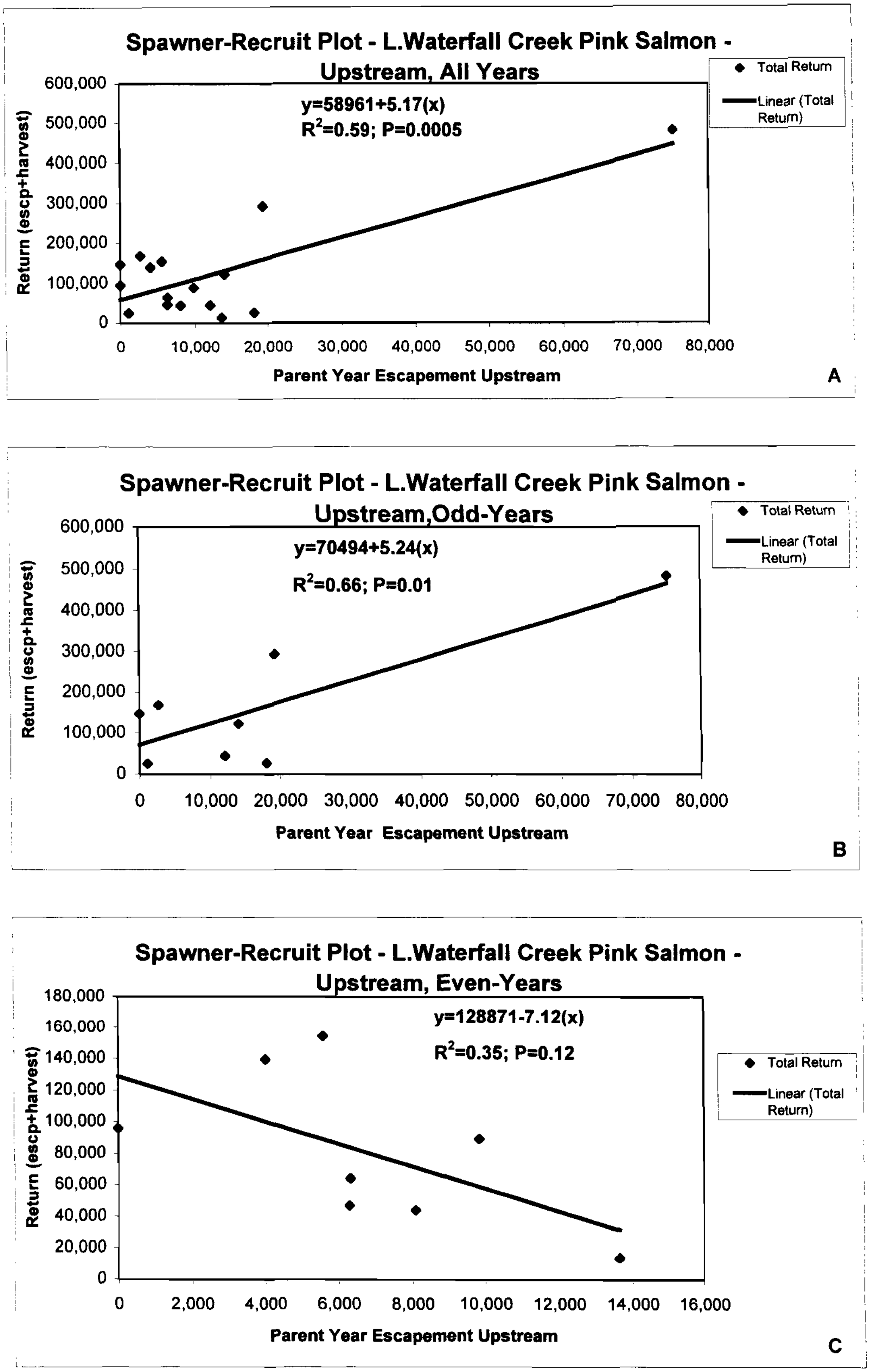
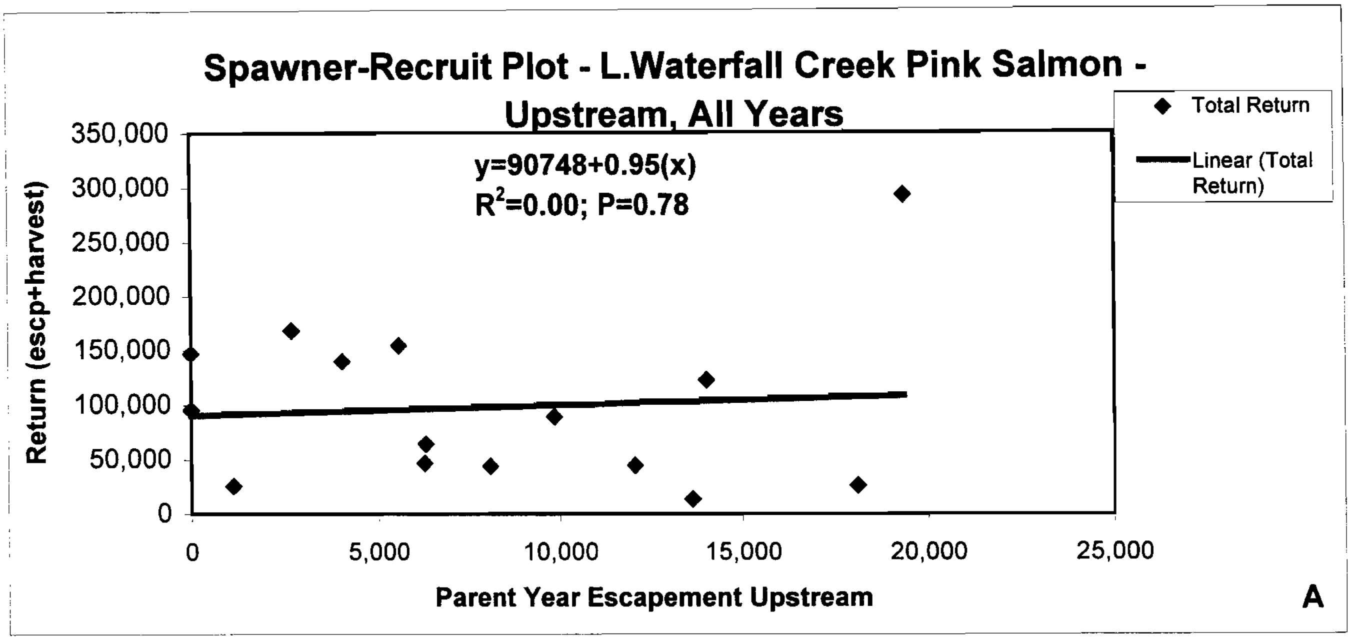


Figure 14. Pink salmon return as a function of parent year upstream escapement, all years (A), odd-years (B), and even-years (C), Little Waterfall Creek, 1981-1996.



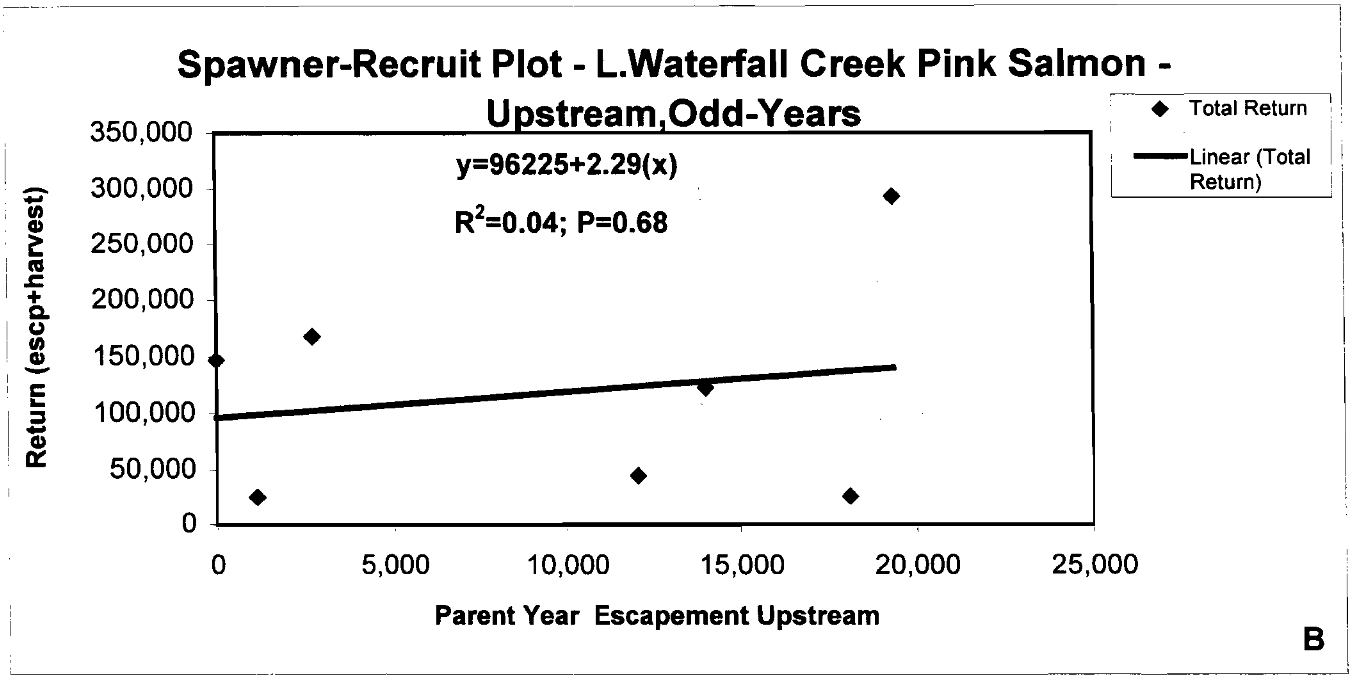


Figure 15. Pink salmon return as a function of parent year upstream escapement, all years (A), and odd-years (B), excluding 1993, Little Waterfall Creek, 1981-1996.

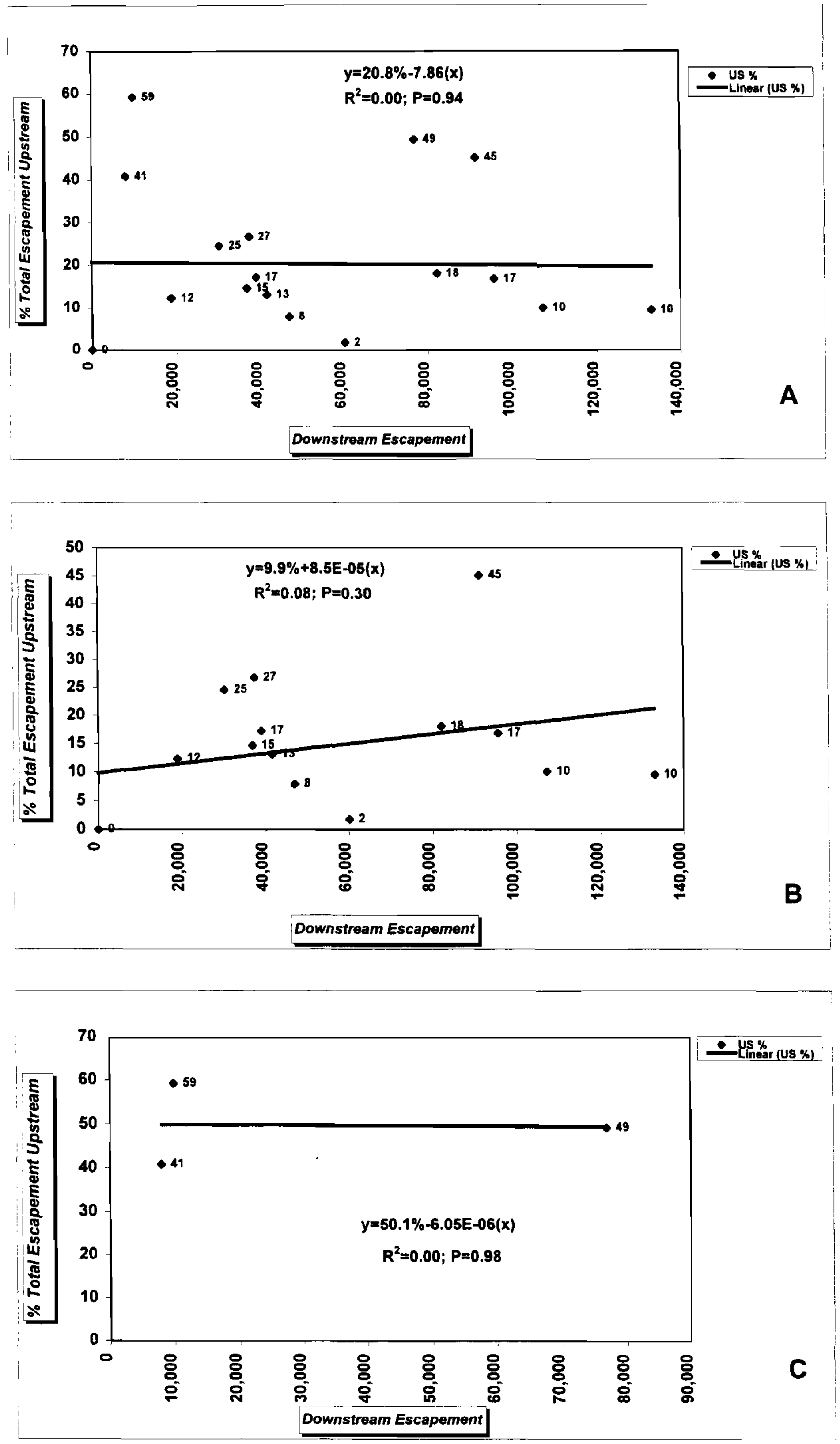


Figure 16. Bivariate scatter plot of pink salmon escapement downstream of bypass and percentage of total escapement upstream of bypass at Little Waterfall Creek, 1981-1998 (A), 1981-1995 (B), and 1996-1998 (C).

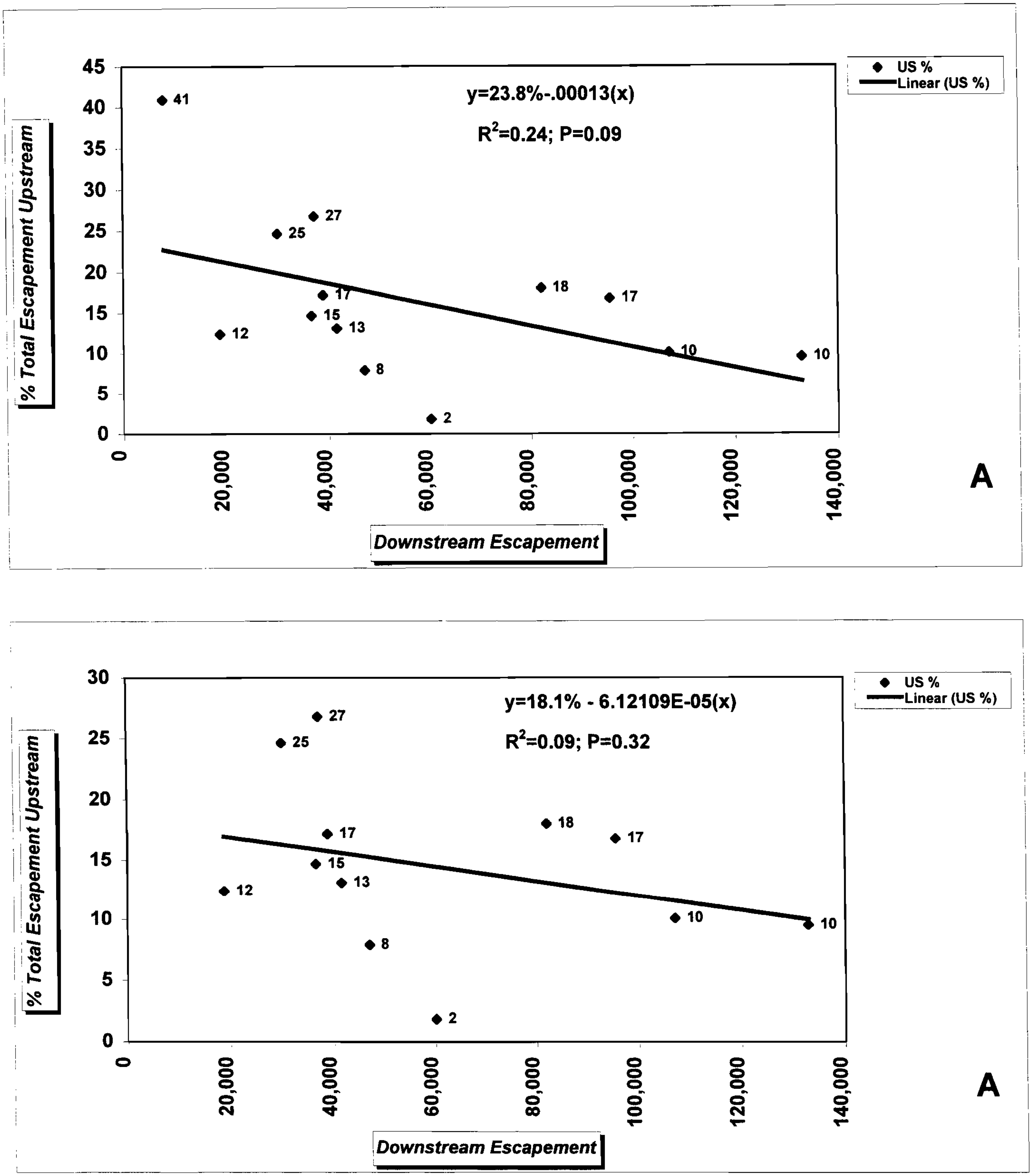
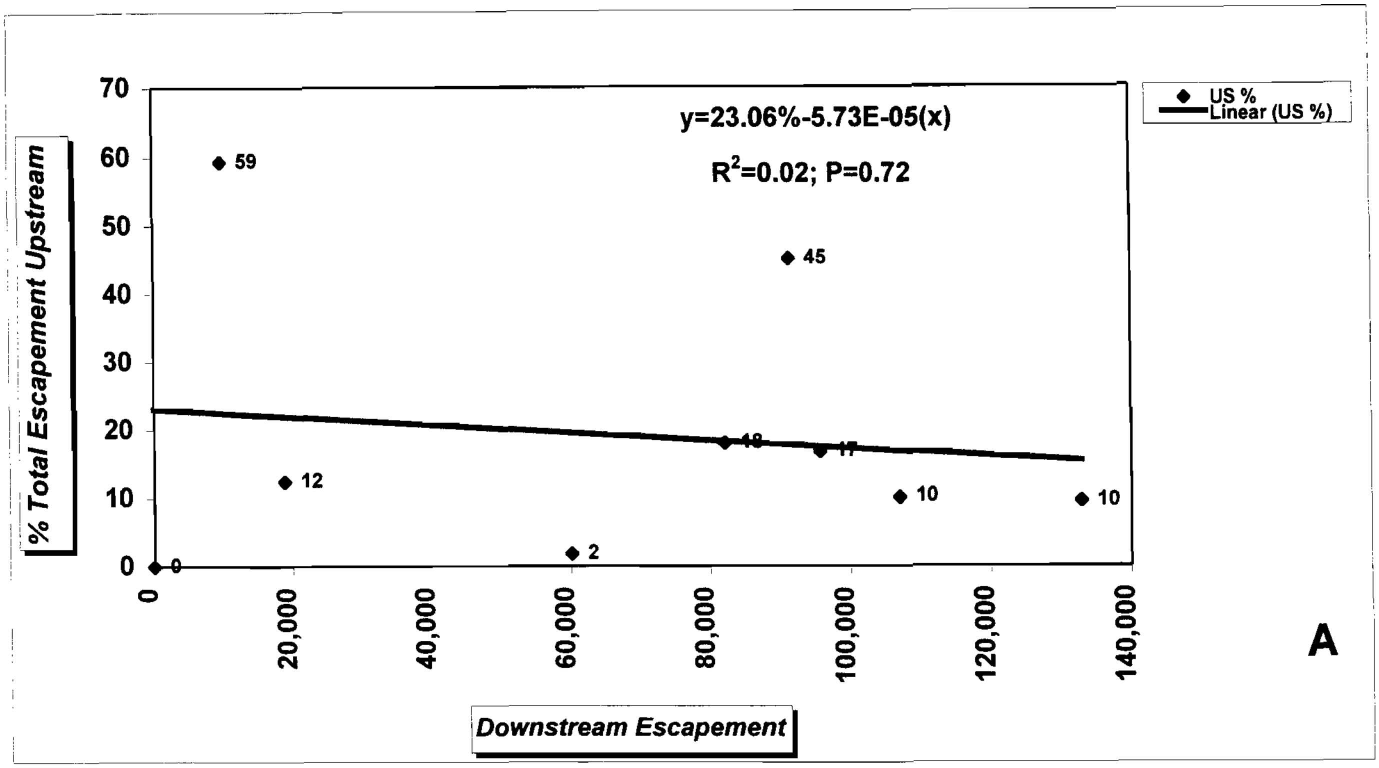


Figure 17. Bivariate scatter plot of pink salmon escapement downstream of bypass and percentage of total escapement upstream of bypass at Little Waterfall Creek, 1981-1998 w/o 1987, 1988, 1997,1998, and 1993 (A), 1981-1998 w/o 1987, 1988, 1996-1998,and 1993 (B).



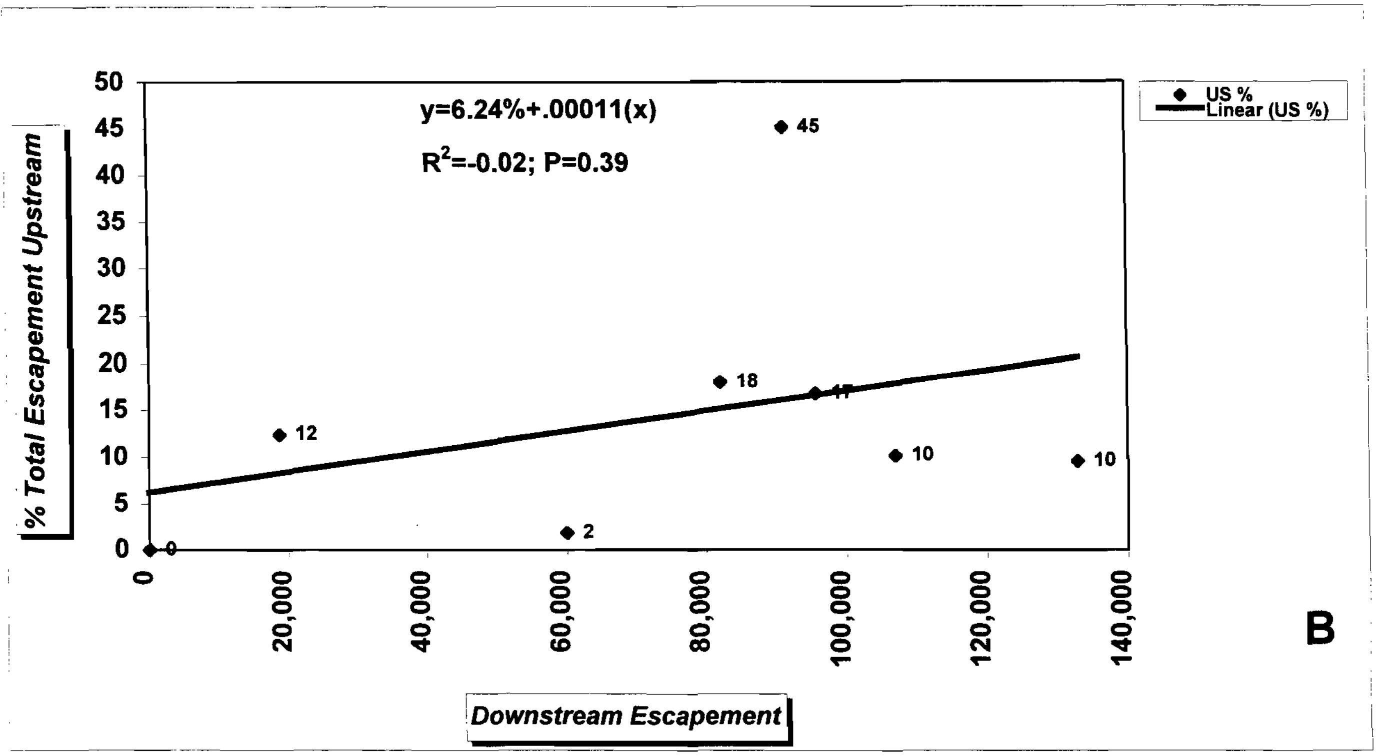
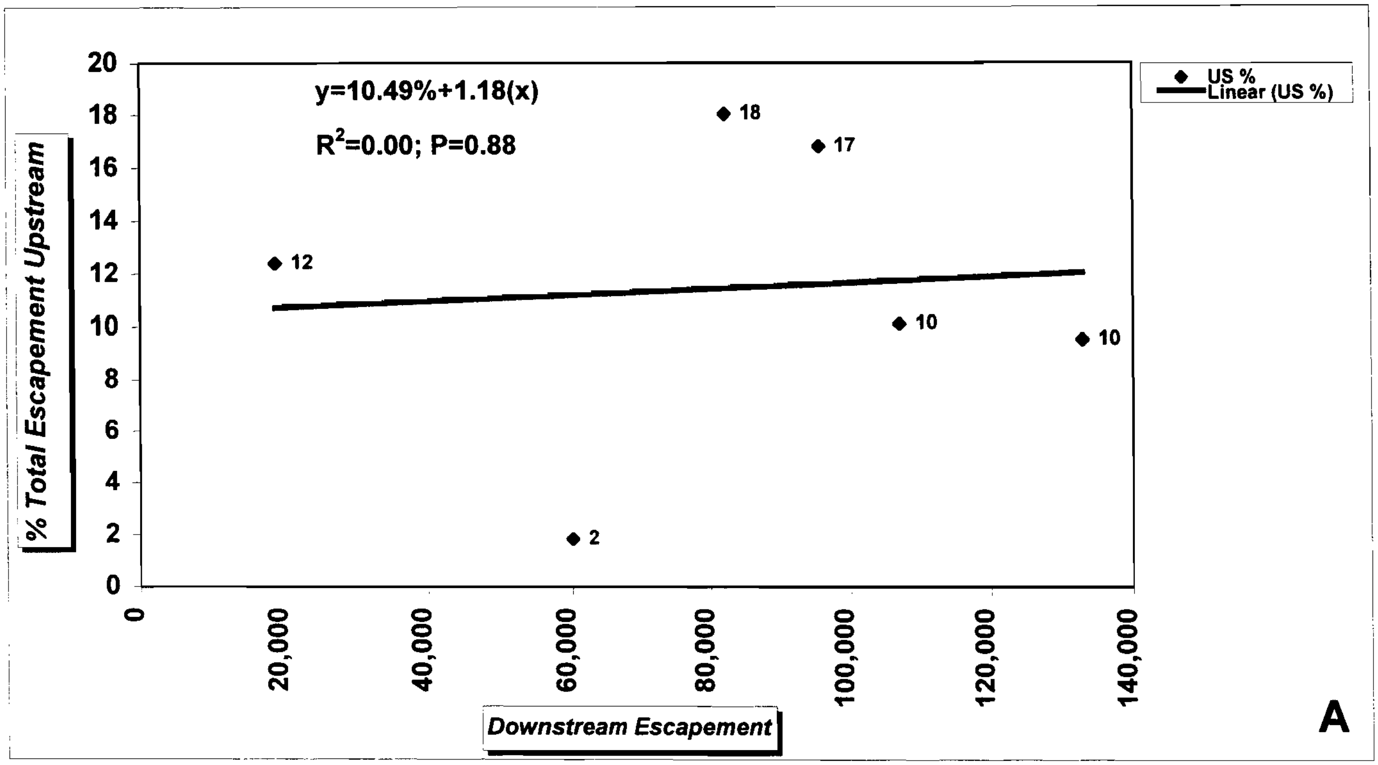


Figure 18. Bivariate scatter plot of pink salmon escapement downstream of bypass and percentage of total escapement upstream of bypass at Little Waterfall Creek, even-years, 1981-1998 (A), and 1981-1995 (B).



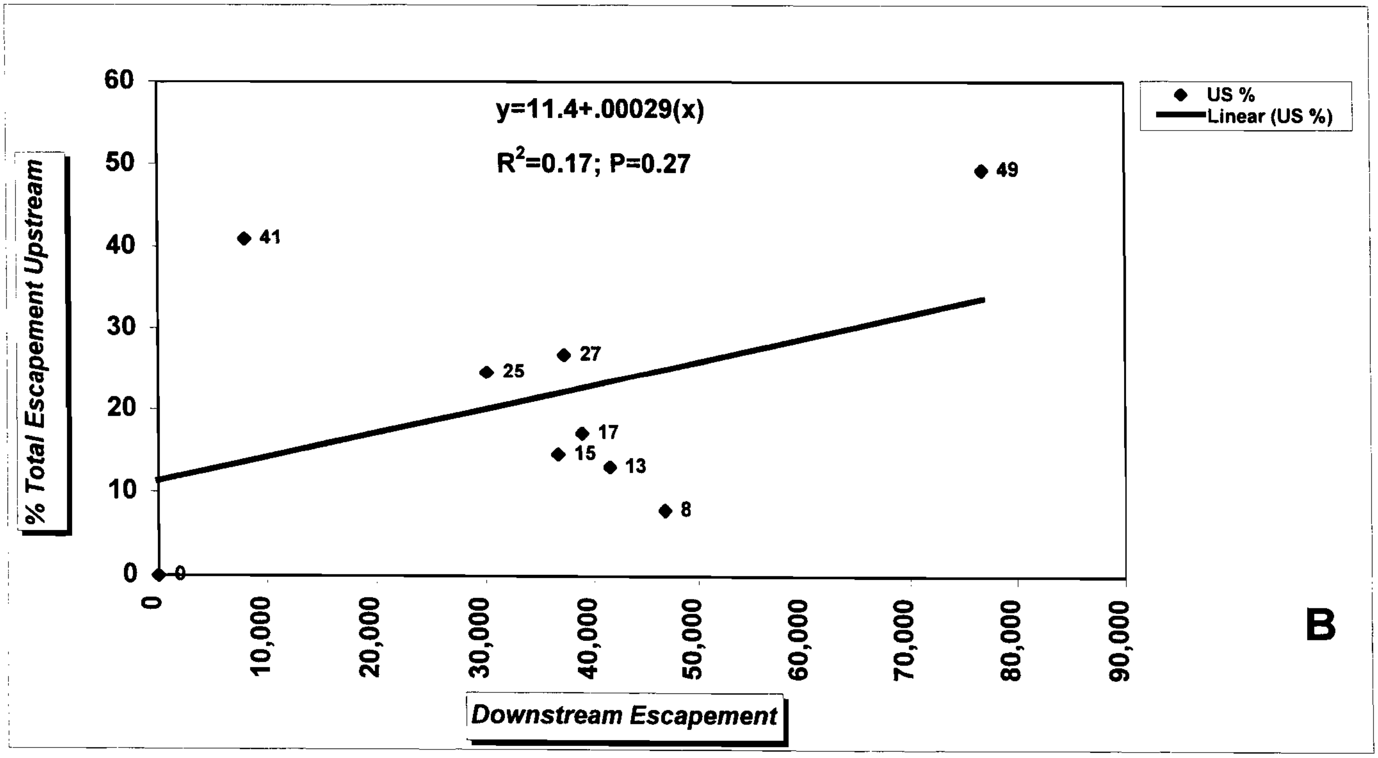


Figure 19. Bivariate scatter plot of pink salmon escapement downstream of bypass and percentage of total escapement upstream of bypass at Little Waterfall Creek, odd-years 1981-1995 w/o 1987 and1993 (A), and even-years 1981-1998 (B).

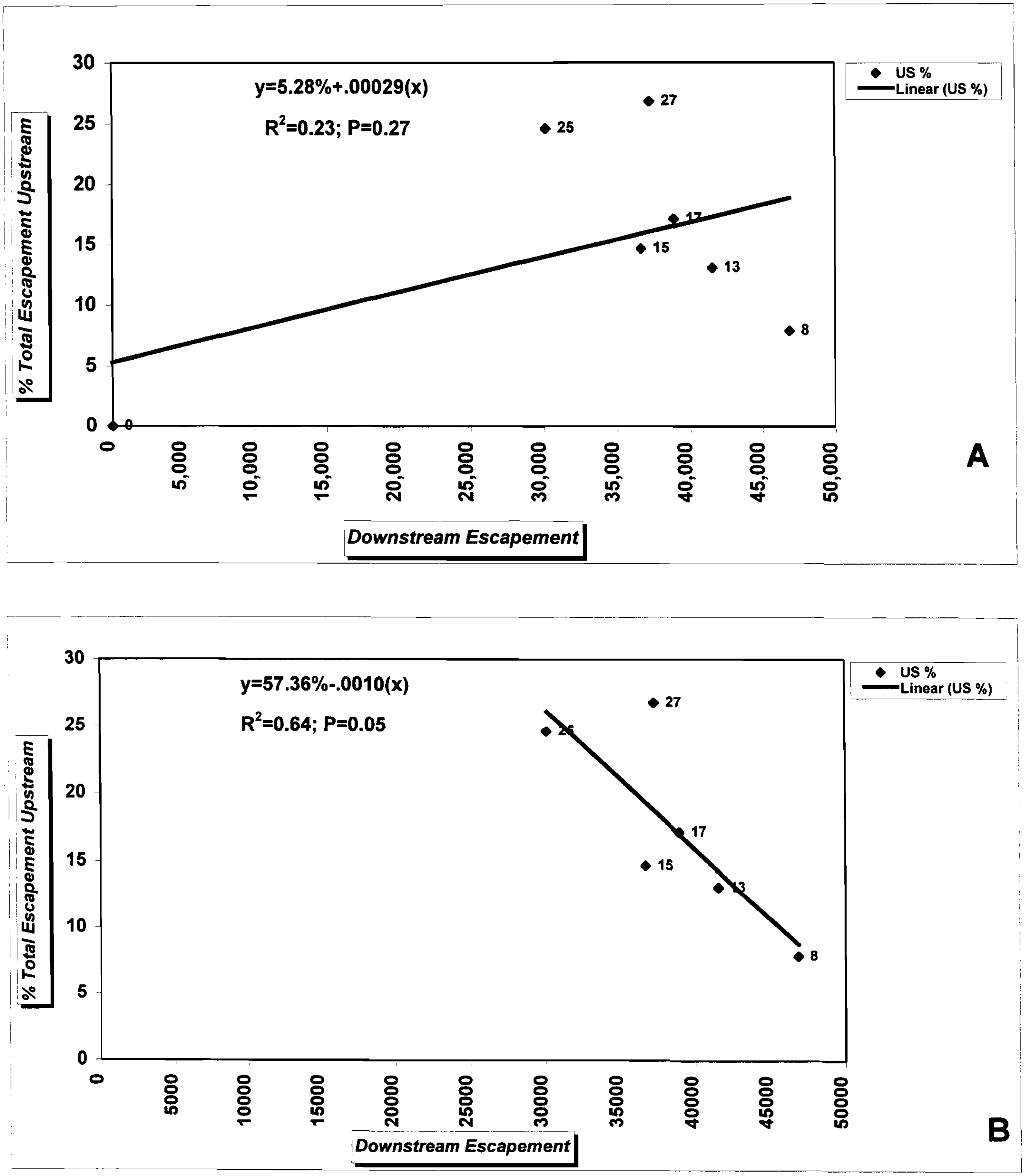


Figure 20. Bivariate scatter plot of pink salmon escapement downstream of bypass and percentage of total escapement upstream of bypass at Little Waterfall Creek, even-years 1981-1995 (A), and even-years 1981-1995 w/o 1988 (B).

APPENDICES

Appendix A.1 Live pink salmon observed upstream of modified bypass by section, downstream of bypass, and for the total Little Watefall Creek system, 1982-1998.

Year	Date	Sections Upstream of Bypass [a]													Downstream of Bypass [a]		Total
		1	%	2	%	3	%	4	%	5	%	1-5	% 1-5	% Total	All	% Total	System
1981	[a]	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	1,125	100%	2%	60,122	98%	61,247
1982	22-Aug	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	2,500	100%	5%	50,000	95%	52,500
	25-Aug	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	3,000	100%	6%	44,000	94%	47,000
	26-Aug	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	3,700	100%	7%	46,000	93%	49,700
	27-Aug	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	4,000	100%	8%	45,500	92%	49,500
	28-Aug	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	4,000	100%	8%	45,500	92%	49,500
	29-Aug	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	4,200	100%	9%	44,000	91%	48,200
	30-Aug	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	3,800	100%	8%	43,000	92%	46,800
	31-Aug	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	3,525	100%	7%	44,000	93%	47,525
	1-Sep	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	3,700	100%	8%	45,000	92%	48,700
1983	4-Aug	20	100%	0	0%	0	0%	0	0%	0	0%	20	100%	nd	nd	nd	nd
	5-Aug	0	0%	10	100%	0	0%	0	0%	0	0%	10	100%	nd	nd	nd	nd
	11-Aug	190	84%	35	15%	1	0%	0	0%	0	0%	226	100%	nd	nd	nd	nd
	17-Aug	552	95%	20	3%	9	2%	0	0%	0	0%	581	100%	nd	nd	nd	nd
	22-Aug	760	91%	56	7%	3	0%	17	2%	0	0%	836	100%	nd	nd	nd	nd
	24-Aug	605	75%	185	23%	2	0%	15	2%	0	0%	807	100%	nd	nd	nd	nd
	26-Aug	700	73%	232	24%	3	0%	20	2%	0	0%	955	100%	9%	10,045	91%	11,000
	31-Aug	595	64%	320	34%	12	1%	6	1%	0	0%	933	100%	nd	nd	nd	nd
	6-Sep	390	79%	105	21%	0	0%	0	0%	0	0%	495	100%	nd	nd	nd	nd
	11-Sep	241	93%	18	7%	0	0%	0	0%	0	0%	259	100%	nd	nd	nd	nd
	15-Sep	50	91%	5	9%	0	0%	0	0%	0	0%	55	100%	nd	nd	nd	nd
	17-Sep	15	83%	3	17%	0	0%	0	0%	0	0%	18	100%	nd	nd	nd	nd
1984	10-Aug	2,040	71%	830	29%	0	0%	0	0%	0	0%	2,870	100%	26%	8,085	74%	10,955
	22-Aug	3,250	67%	1,411	29%	200	4%	0	0%	0	0%	4,861	100%	31%	10,840	69%	15,701
	28-Aug	2,010	66%	820	27%	220	7%	0	0%	0	0%	3,050	100%	20%	12,550	80%	15,600
	6-Sep	600	70%	220	25%	7	1%	36	4%	0	0%	863	100%	6%	13,500	94%	14,363
	18-Sep	2	67%	1	33%	0	0%	0	0%	0	0%	3	100%	nd	nd	nd	nd
1985	9-Aug	2,000	96%	75	4%	0	0%	0	0%	0	0%	2,075	100%	nd	nd	nd	nd
	14-Aug	5,500	69%	2,400	30%	30	0%	0	0%	0	0%	7,930	100%	nd	nd	nd	nd
	18-Aug	7,500	72%	2,800	27%	55	1%	2	0%	0	0%	10,357	100%	13%	69,643	87%	80,000
	22-Aug	5,000	80%	1,200	19%	60	1%	6	0%	0	0%	6,266	100%	nd	nd	nd	nd
	26-Aug	1,200	78%	260	17%	60	4%	10	1%	0	0%	1,530	100%	nd	nd	nd	nd

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Year	Date	Sections Upstream of Bypass [a]													Downstream of Bypass [a]		Total System
		1	%	2	%	3	%	4	%	5	%	1-5	% 1-5	% Total	All	% Total	
1986	4-Aug	0	0%	0	0%	0	0%	0	0%	0	0%	0	100%				
	11-Aug	200	95%	11	5%	0	0%	0	0%	0	0%	211	100%				
	18-Aug	1,286	72%	351	20%	149	8%	0	0%	0	0%	1,786	100%				
	25-Aug	1,504	63%	736	31%	123	5%	15	1%	0	0%	2,378	100%	10%	22,622	90%	25,000
	3-Sep	1,008	93%	24	2%	17	2%	30	3%	0	0%	1,079	100%				
1987	7-Aug	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	26,000
1988	15-Aug	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	14,500
1989	3-Aug	25	100%	0	0%	0	0%	0	0%	0	0%	25	100%	1%	3,700	99%	3,725
	21-Aug	1,115	22%	1,426	28%	1,156	22%	1,301	25%	154	3%	5,152	100%	17%	24,850	83%	30,002
	28-Aug	1,483	19%	1,549	20%	1,931	25%	2,418	31%	362	5%	7,743	100%	8%	88,558	92%	96,301
	4-Sep	899	30%	488	16%	552	18%	964	32%	113	4%	3,016	100%	6%	45,506	94%	48,522
	12-Sep	308	61%	38	8%	68	13%	64	13%	27	5%	505	100%	nd	nd	nd	nd
1990	8-Aug	61	84%	4	5%	8	11%	0	0%	0	0%	73	100%	1%	8,991	99%	9,064
	19-Aug	1,070	56%	351	18%	310	16%	76	4%	118	6%	1,925	100%	18%	8,550	82%	10,475
	26-Aug	1,657	54%	610	20%	565	19%	154	5%	58	2%	3,044	100%	21%	11,121	79%	14,165
	4-Sep	1,264	57%	555	25%	320	14%	64	3%	9	0%	2,212	100%	17%	10,600	83%	12,812
	10-Sep	510	58%	225	26%	119	14%	16	2%	3	0%	873	100%	nd	nd	nd	nd
1991	8-Aug	2,752	75%	386	10%	507	14%	18	0%	14	0%	3,677	100%	20%	14,821	80%	18,498
	15-Aug	1,660	38%	541	12%	1,128	26%	648	15%	430	10%	4,407	100%	11%	37,500	89%	41,907
	24-Aug	3,896	39%	919	9%	2,201	22%	1,596	16%	1,471	15%	10,083	100%	16%	53,400	84%	63,483
	28-Aug	3,613	38%	808	8%	2,141	22%	1,752	18%	1,248	13%	9,562	100%	25%	29,000	75%	38,562
	7-Sep	702	51%	100	7%	354	26%	38	3%	170	12%	1,364	100%	16%	7,027	84%	8,391
1992	13-Aug	867	26%	922	27%	631	19%	359	11%	584	17%	3,363	100%	19%	14,677	81%	18,040
	21-Aug	921	26%	806	23%	818	23%	588	16%	436	12%	3,569	100%	14%	22,540	86%	26,109
	30-Aug	973	48%	294	14%	467	23%	105	5%	191	9%	2,030	100%	13%	14,150	87%	16,180
	5-Sep	474	59%	95	12%	117	14%	41	5%	82	10%	809	100%	13%	5,660	87%	6,469
1993	4-Aug	5,500	28%	496	3%	975	5%	376	2%	11,980	62%	19,327	100%	32%	41,578	68%	60,905
	10-Aug	9,726	41%	1,045	4%	1,710	7%	301	1%	11,060	46%	23,842	100%	28%	59,932	72%	83,774
	23-Aug	5,528	12%	4,150	9%	6,122	13%	10,950	24%	19,049	42%	45,799	100%	42%	63,224	58%	109,023

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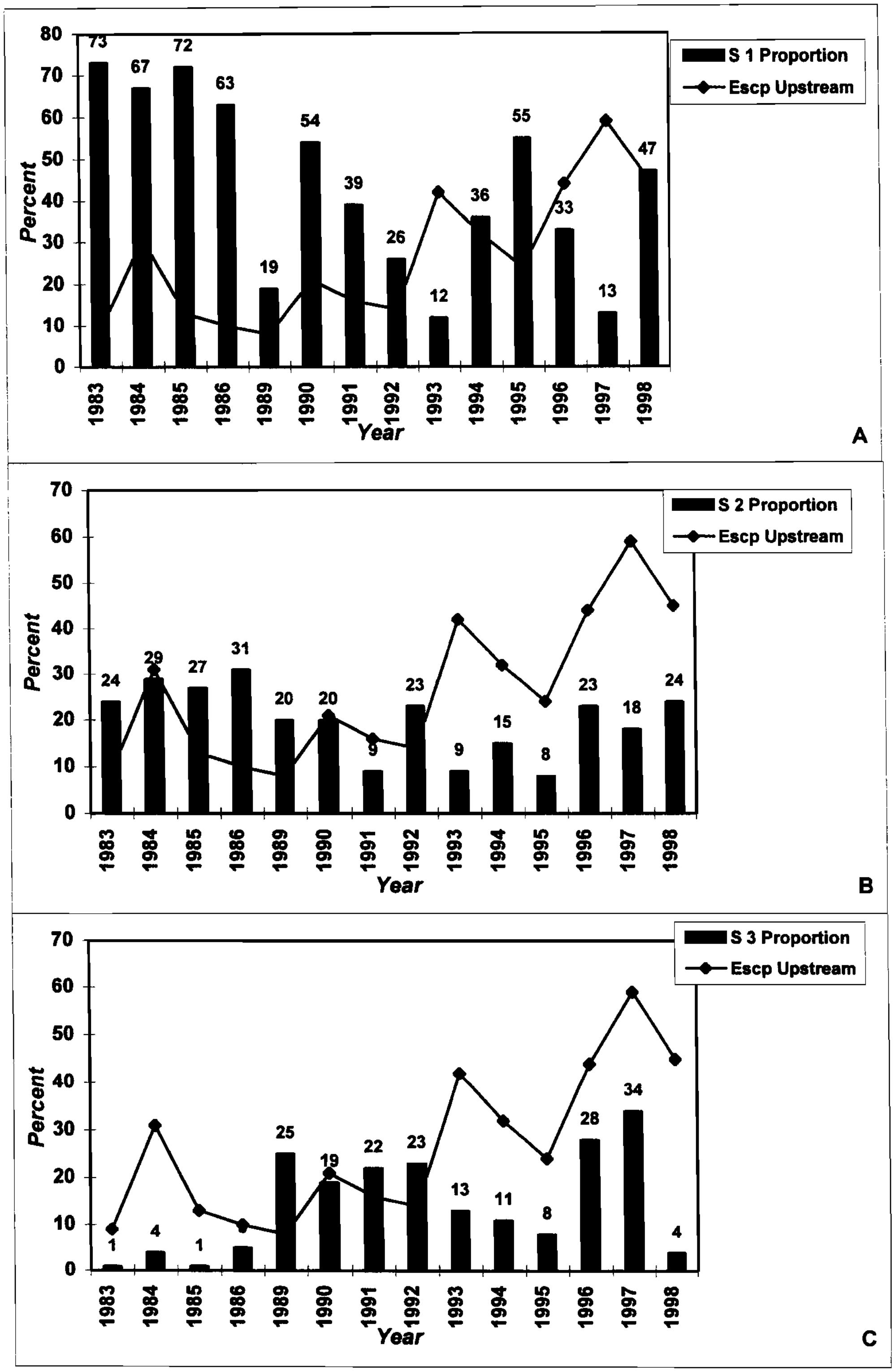
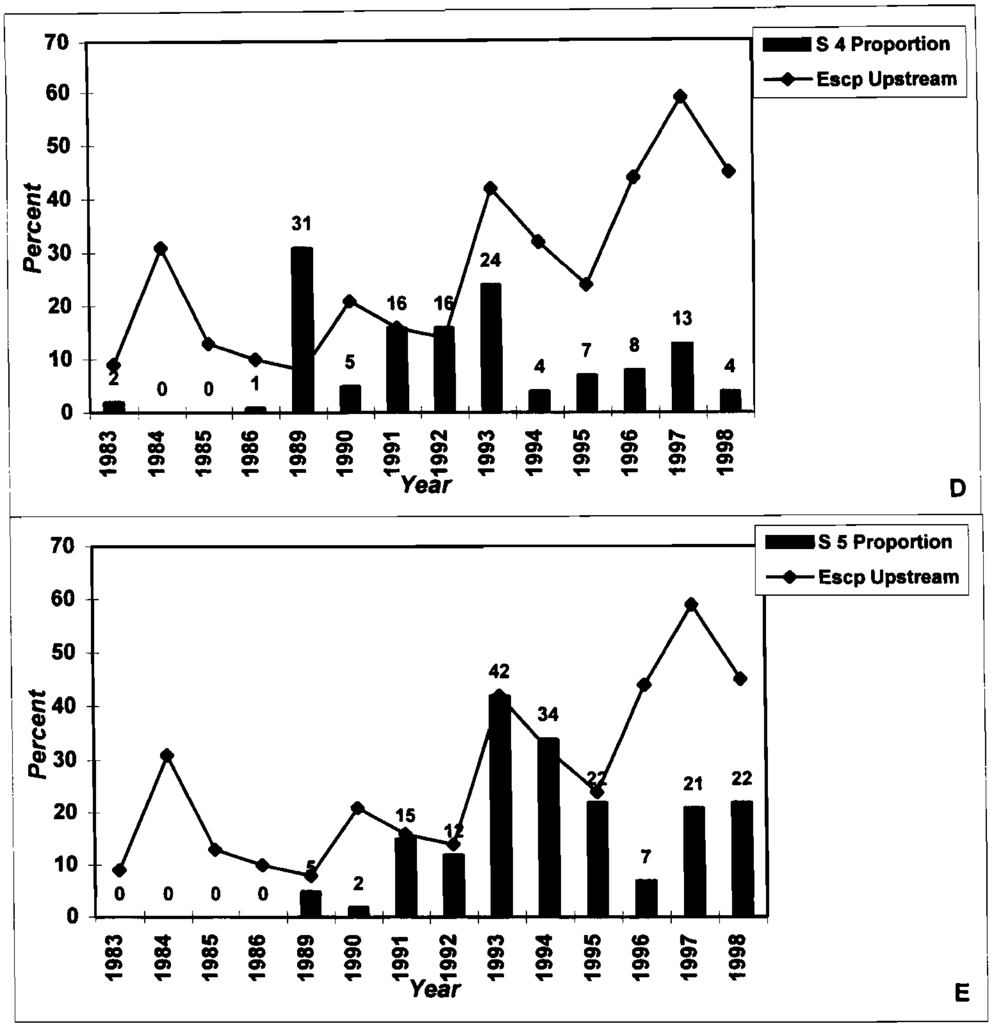
Year	Date	Sections Upstream of Bypass [a]													Downstream of Bypass [a]		Total System
		1	%	2	%	3	%	4	%	5	%	1-5	% 1-5	% Total	All	% Total	
1994	5-Aug	2,431	64%	570	15%	582	15%	75	2%	134	4%	3,792	100%	25%	11,337	75%	15,129
	12-Aug	3,236	47%	811	12%	719	10%	165	2%	1,931	28%	6,862	100%	30%	15,862	70%	22,724
	18-Aug	2,543	36%	1,045	15%	764	11%	263	4%	2,359	34%	6,974	100%	32%	15,115	68%	22,089
	29-Aug	670	43%	233	15%	223	14%	42	3%	382	25%	1,550	100%	16%	8,334	84%	9,884
1995	7-Aug	5,545	67%	648	8%	772	9%	292	4%	2,071	25%	8,328	100%	35%	15,595	65%	23,923
	17-Aug	4,761	55%	730	8%	721	8%	606	7%	1,899	22%	8,717	100%	24%	27,965	76%	36,682
	24-Aug	4,858	62%	979	13%	648	8%	193	2%	1,127	14%	7,805	100%	21%	28,885	79%	36,690
	31-Aug	3,268	69%	459	10%	476	10%	146	3%	416	9%	4,765	100%	14%	29,711	86%	34,476
1996	9-Aug	276	99%	0	0%	3	1%	0	0%	0	0%	279	100%	6%	4,482	94%	4,761
	16-Aug	810	33%	568	23%	682	28%	187	8%	181	7%	2,428	100%	44%	3,081	56%	5,509
	30-Aug	258	19%	170	13%	492	37%	253	19%	163	12%	1,336	100%	37%	2,233	63%	3,569
1997	8-Aug	124	38%	112	35%	70	22%	0	0%	17	5%	323	100%	5%	6,288	95%	6,611
	15-Aug	1,025	16%	876	14%	1,671	26%	617	10%	2,174	34%	6,363	100%	48%	6,794	52%	13,157
	22-Aug	1,184	13%	1,629	18%	2,988	34%	1,170	13%	1,890	21%	8,861	100%	59%	6,059	41%	14,920
1998	28-Jul	1,450	100%	0	0%	0	0%	0	0%	0	0%	1,450	100%	8%	16,500	92%	17,950
	5-Aug	12,868	62%	3,278	16%	643	3%	331	2%	3,784	18%	20,904	100%	37%	34,943	63%	55,847
	12-Aug	24,100	47%	12,160	24%	1,915	4%	2,045	4%	11,473	22%	51,693	100%	55%	42,975	45%	94,668
	19-Aug	12,450	51%	4,975	20%	1,405	6%	1,213	5%	4,425	18%	24,468	100%	44%	31,300	56%	55,768
	25-Aug	4,545	52%	1,717	20%	850	10%	557	6%	1,126	13%	8,795	100%	35%	16,075	65%	24,870

[a] Sections (1-5) are ~ evenly spaced areas beginning just upstream of barrier bypass (number 3); the further upstream the larger the section number; e.g. 1=just upstream of bypass and 5=most upstream section.



Appendix A.2. Pink salmon upstream escapement (peak counts upstream of modified bypass) proportioned by section (1-5; A-C), compared to overall upstream escapement (%), 1983-1998.



Appendix A.3. Pink salmon upstream escapement (peak counts upstream of modified bypass) proportioned by section (1-5; D-E), compared to overall upstream escapement (%), 1983-1998.

Appendix B. Little Waterfall Creek pink salmon harvest apportionment from Perenosa Bay statisical sections (251-82, 251-83, and 251-84) as calculated by escapement percentage.

Year	Escapement by System[a]							Harvest by System			
	L.Waterfall	%	Pauls	%	Portage	%	Total	L.Waterfall	Pauls	Portage	Total
1968	950	3	380	1	34,517	96	35,847	0	0	0	0
1969	0	0	190	0	46,140	100	46,330	0	0	0	0
1970	3,800	12	0	0	28,500	88	32,300	113	0	847	960
1971	0	0	0	0	42,633	100	42,633	0	0	0	0
1972	950	5	0	0	18,227	95	19,177	162	0	3,111	3,273
1973	0	0	0	0	15,500	100	15,500	0	0	676	676
1974	11	0	0	0	11,400	100	11,411	0	0	0	0
1975	13,300	25	0	0	39,900	75	53,200	443	0	1,328	1,771
1976	9,506	31	0	0	21,628	69	31,134	0	0	0	0
1977	0	0	0	0	32,300	100	32,300	0	0	0	0
1978	6,840	10	0	0	58,900	90	65,740	1,965	0	16,920	18,885
1979	13,680	14	0	0	82,991	86	96,671	2,622	0	15,905	18,527
1980	26,030	20	0	0	104,500	80	130,530	5,937	0	23,834	29,771
1981	61,247	43	1,104	1	79,780	56	142,131	58,284	1,051	75,920	135,254
1982	47,829	52	0	0	43,668	48	91,497	53,862	0	49,176	103,038
1983	21,560	45	1,013	2	25,133	53	47,706	4,220	198	4,919	9,337
1984	40,016	55	6,180	8	27,207	37	73,403	6,832	1,055	4,645	12,532
1985	119,211	58	26,904	13	59,176	29	205,291	48,751	11,002	24,200	83,953
1986	50,884	61	1,687	2	30,400	37	82,971	38,387	1,273	22,934	62,594
1987	29,093	70	202	0	12,094	29	41,389	15,718	109	6,534	22,361
1988	27,550	33	434	1	56,475	67	84,459	112,010	1,765	229,611	343,386
1989	147,016	64	4,254	2	79,680	35	230,950	0	0	0	0
1990	47,000	79	775	1	11,547	19	59,322	48,978	808	12,033	61,819
1991	115,000	76	2	0	36,500	24	151,502	7,619	0	2,418	10,037
1992	43,000	47	1,900	2	46,170	51	91,070	1,109	49	1,191	2,349
1993	166,391	92	3,996	2	10,000	6	180,387	126,832	3,046	7,623	137,500
1994	50,937	60	7,002	8	27,550	32	85,489	13,328	1,832	7,208	22,368
1995	100,223	78	6,232	5	22,581	17	129,036	381,679	23,733	85,995	491,408
1996	13,624	61	732	3	8,000	36	22,356	183	10	107	300
1997	24,339	17	1,980	1	119,700	82	146,019	2,302	187	11,320	13,809
1998	151,655	79	12,053	6	28,100	15	191,808	2,668	212	494	3,374

[a] Total escapement estimates from weir enumeration are shaded; others estimated as described in Methods section.

Appendix C.1. Little Waterfall Creek pink salmon spagetti tagging application and recovery surveys (upstream and downstream of pre-modified bypass), 1991.

Tag Application			Weekly Escapement			Weighting	Cumulative Escapement	
Date tagged	Number	Color	Number	% of Cum.	% Tagged	Factor	Number	% of Total
7/26/91	150	Pink	2842	95.0%	5.3%	1.0	2993	2.6%
8/2/91	150	Yellow	11183	78.9%	1.3%	3.9	14176	12.3%
8/9/91	150	Blue	18861	57.1%	0.8%	6.6	33037	28.7%
8/16/91	150	Orange	29999	47.6%	0.5%	10.6	63036	54.8%

		Number of Fish Observed				Tags Observed by Color				
Date	Location	Live	Dead	Total		Pink	Yellow	Blue	Orange	Total
8/8/91	Upstream	3677	4	3681	Number	28	15	0	0	43
					Weighted No.	28	59	0	0	87
					% of Total	32.2	67.8	0.0	0.0	100.0
	Downstream	13701	16	13717	Number	56	108	0	0	164
					Weighted No.	56	425	0	0	481
					% of Total	11.6	88.4	0.0	0.0	100.0
	Total	17378	20	17398	Number	84	123	0	0	207
					Weighted No.	84	484	0	0	568
					% of Total	14.8	85.2	0.0	0.0	100.0
8/15/91	Upstream	4407	8	4415	Number	20	14	8	0	42
					Weighted No.	20	55	53	0	128
					% of Total	15.6	43.0	41.5	0.0	100.1
	Downstream	23500	0	23500	Number	20	41	19	0	80
					Weighted No.	20	161	126	0	307
					% of Total	6.5	52.6	41.1	0.0	100.1
	Total	27907	8	27915	Number	40	55	27	0	122
					Weighted No.	40	216	179	0	436
					% of Total	9.2	49.6	41.1	0.0	99.9

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		Number of Fish Observed			Tags Observed by Color					
Date	Location	Live	Dead	Total		Pink	Yellow	Blue	Orange	Total
8/24/91	Upstream	10083	308	10391	Number	4	8	14	4	30
					Weighted No.	4	31	93	42	171
					% of Total	2.3	18.4	54.3	24.7	99.8
	Downstream	47917	1516	49433						
	Total	58000	1824	59824						
8/28/91	Upstream	9562	621	10183	Number	0	8	6	2	16
					Weighted No.	0	31	40	21	92
					% of Total	0.0	34.2	43.3	22.9	100.4
9/7/91	Upstream	1364	3301	4665	Number	2	0	1	0	3
					Weighted No.	2	0	7	0	9
					% of Total	22.2	0.0	73.7	0.0	96.0
FP 3 weir carcass	Upstream		11492		Number	38	30	17	6	91
					Weighted No.	38	118	113	63	332
					% of Total	11.4	35.6	34.0	19.1	100.1

Appendix C.2. Weekly escapement, proportions weighted by tagging period, distribution upstream and downstream of barrier bypass, and comparative distribution of weir carcasses, 1991.

Date		Weekly Escapement			Weekly Escapement Distribution by Survey Date															
					8-Aug				15-Aug				24-Aug		28-Aug		7-Sep		Total Carcass	
Calendar	St.Wk	Number	Percent	Weighted	Up	%	Down	%	Up	%	Down	%	Up	%	Up	%	Up	%	Up	%
26 Jul -1 Aug	31	2842	2.9%	4.5%	1,185	32.2%	1,597	11.6%	690	15.6%	1,531	7%	243	2.3%	0	0.0%	1,037	23.2%	1,315	11.4%
2 - 8 Aug	32	11183	11.3%	17.8%	2,497	67.8%	12,119	88.4%	1,900	43.0%	12,349	52%	1,913	18.5%	3,484	34.1%	0	0.0%	4,086	35.5%
9 - 15 Aug	33	18861	19.1%	30.0%	0	0.0%	0	0.0%	1,831	41.4%	9,652	41%	5,646	54.5%	4,407	43.1%	3,440	76.8%	3,905	34.0%
16 - 22 Aug	34	29999	30.3%	47.7%	0	0.0%	0	0.0%	0	0.0%	0	0%	2,566	24.7%	2,337	22.8%	0	0.0%	2,192	19.1%
23 - 29 Aug	35	14113	14.3%	NA	NA		NA		NA		NA		NA		NA		NA		NA	
30 Aug - 5 Sep	36	12302	12.4%	NA	NA		NA		NA		NA		NA		NA		NA		NA	
6 - 12 Sep	37	9685	9.8%	NA	NA		NA		NA		NA		NA		NA		NA		NA	
	Totals	98985	100.0%	100.0%	3,682	100.0%	13,716	100.0%	4,421	100.0%	23,533	100%	10,367	100.0%	10,228	100.0%	4,477	100.0%	11,499	100.0%

Appendix C.3. Little Waterfall Creek pink salmon spagetti tagging application and recovery surveys (upstream and downstream of pre-modified bypass), 1992.

Tag Application			Weekly Escapement			Weighting	Cumulative Escapement	
Date tagged	Number	Color	Number	% of Cum.	% Tagged	Factor	Number	% of Total
7/26/92	150	Pink	3847	96.4%	3.9%	1.1	3992	3.5%
8/4/92	150	Yellow	5805	59.3%	2.6%	1.6	9797	8.5%
8/10/92	150	Blue	8994	47.9%	1.7%	2.5	18791	16.3%
8/20/92	150	Orange	3598	16.1%	4.2%	1.0	22389	19.5%

		Number of Fish Observed				Tags Observed by Color - upstream				
Date	Location	Live	Dead	Total		Pink	Yellow	Blue	Orange	Total
8/13/92	Upstream	3363	14	3377	Number	20	11	8	0	39
					Weighted No.	21	18	0	0	39
					% of Total	54.8	45.5	0.0	0.0	100.3
	Downstream	10677	105	10782						
	Total	14040	119	14159						
8/21/92	Upstream	3569	190	3759	Number	4	7	5	1	17
					Weighted No.	4	11	12	0	28
					% of Total	15.3	40.3	44.6	0.0	100.2
	Downstream	12440	520	12960						
	Total	16009	710	16719						
8/30/92	Upstream	2030	639	2669	Number	0	2	0	1	3
					Weighted No.	0	3	0	1	4
					% of Total	0.0	80.7	0.0	25.0	105.7
	Downstream	4150		4150						
	Total	6180	639	6819						
9/5/92	Upstream	809	851	1660	Number	0	0	0	0	0
					Weighted No.	0	0	0	0	0
					% of Total	0.0	0.0	0.0	0.0	0.0
FP 3 weir carcass	Upstream		4108		Number	14	14	14	5	47
					Weighted No.	15	23	35	5	78
					% of Total	19.2	29.0	44.9	6.4	99.4

Appendix C.4. Weekly escapement, proportions weighted by tagging period, distribution upstream of barrier bypass, and comparative distribution of weir carcasses, 1992.

Date		Weekly Escapement			Weekly Escapement Distribution by Survey Date								Total Carcass	
					13-Aug		21-Aug		30-Aug		5-Sep			
Calendar	St. Wk	Number	Percent	Weighted	Up	%	Up	%	Up	%	Up	%	Up	%
26 Jul -1 Aug	31	3847	10.8%	17.3%	1,852	54.7%	574	15.2%	0	0.0%	0	0.0%	788	19.3%
2 - 8 Aug	32	5805	16.3%	26.1%	1,537	45.4%	1,516	40.2%	2,153	76.4%	0	0.0%	1,190	29.1%
9 - 15 Aug	33	8994	25.3%	40.4%	0	0.0%	1,678	44.5%	0	0.0%	0	0.0%	1,843	45.1%
16 - 22 Aug	34	3598	10.1%	16.2%	0	0.0%	0	0.0%	667	23.7%	0	0.0%	263	6.4%
23 - 29 Aug	35	5753	16.2%	NA	NA		NA		NA		NA		NA	
30 Aug - 5 Sep	36	7077	19.9%	NA	NA		NA		NA		NA		NA	
6 - 12 Sep	37	544	1.5%	NA	NA		NA		NA		NA		NA	
	Totals	35618	100.0%	99.9%	3,388	100.0%	3,768	100.0%	2,820	100.0%	0	0.0%	4,084	100.0%

Appendix D. Results of minnow trapping at Little Waterfall Creek, 1996-1997.

		No. Traps	Hours	Coho			Coho CPUE (catch/hour)			Sticklebacks			Dolly Varden		
Year	Date	Fished	Fished	Down	Up	Total	Down	Up	Total	Down	Up	Total	Down	Up	Total
Site A - baited traps															
1996	25-Jun	1	24	1	1	2	0.04	0.04	0.08	0	0	0	0	0	0
1997	10-Jul	1	23.5	20	6	26	0.85	0.26	1.11	2	0	2	0	0	0
1996	17-Jul	1	24	2	2	4	0.08	0.08	0.17	0	0	0	1	0	1
1997	29-Jul	1	24	5	1	6	0.21	0.04	0.25	0	0	0	0	3	3
1996	15-Aug	1	23	1	3	4	0.04	0.13	0.17	2	0	2	0	0	0
1997	21-Aug	1	24	0	11	11	0.00	0.46	0.46	0	0	0	0	0	0
Site A - unbaited traps															
1996	25-Jun	1	24	4	4	8	0.17	0.17	0.33	1	1	2	0	0	0
1997	10-Jul	1	23.5	10	16	26	0.43	0.68	1.11	0	1	1	0	1	1
1996	17-Jul	1	24	3	0	3	0.13	0.00	0.13	0	0	0	0	4	4
1997	29-Jul	1	24	0	0	0	0.00	0.00	0.00	0	0	0	0	0	0
1996	15-Aug	1	23	5	0	5	0.22	0.00	0.22	2	0	2	0	0	0
1997	21-Aug	1	24	0	7	7	0.00	0.29	0.29	0	0	0	0	0	0
Site B - baited traps															
1996	25-Jun	1	24	4	6	10	0.17	0.25	0.42	0	1	1	2	1	3
1997	10-Jul	1	23.5	3	5	8	0.13	0.21	0.34	1	0	1	0	0	0
1996	17-Jul	1	24	3	2	5	0.13	0.08	0.21	0	0	0	0	1	1
1997	29-Jul	1	24	7	0	7	0.29	0.00	0.29	0	0	0	0	0	0
1996	15-Aug	1	23	0	0	0	0.00	0.00	0.00	0	0	0	0	0	0
1997	21-Aug	1	24	2	0	2	0.08	0.00	0.08	0	0	0	0	0	0

-Continued-

Appendix D. (page 2 of 2)

		No. Traps	Hours	Coho			Coho CPUE (catch/hour)			Sticklebacks			Dolly Varden		
Year	Date	Fished	Fished	Down	Up	Total	Down	Up	Total	Down	Up	Total	Down	Up	Total
Site B - unbaited traps															
1996	25-Jun	1	24	2	0	2	0.08	0.00	0.08	1	0	1	1	0	1
1997	10-Jul	1	23.5	3	4	7	0.13	0.17	0.30	0	0	0	0	0	0
1996	17-Jul	1	24	2	0	2	0.08	0.00	0.08	0	0	0	0	0	0
1997	29-Jul	1	24	5	1	6	0.21	0.04	0.25	0	0	0	0	0	0
1996	15-Aug	1	23	2	0	2	0.09	0.00	0.09	0	9	9	0	1	1
1997	21-Aug	1	24	1	0	1	0.04	0.00	0.04	0	0	0	0	0	0
Site C - baited traps															
1996	25-Jun	1	24	3	1	4	0.13	0.04	0.17	0	0	0	4	0	4
1997	10-Jul	1	23.5	10	7	17	0.43	0.30	0.72	0	0	0	0	0	0
1996	17-Jul	1	24	8	3	11	0.33	0.13	0.46	0	0	0	1	0	1
1997	29-Jul	1	24	10	0	10	0.42	0.00	0.42	0	0	0	0	0	0
1996	15-Aug	1	23	0	0	0	0.00	0.00	0.00	0	0	0	0	0	0
1997	21-Aug	1	24	2	1	3	0.08	0.04	0.13	0	0	0	0	0	0
Site C - unbaited traps															
1996	25-Jun	1	24	0	2	2	0.00	0.08	0.08	0	0	0	0	0	0
1997	10-Jul	1	23.5	8	5	13	0.34	0.21	0.55	0	0	0	0	5	5
1996	17-Jul	1	24	3	1	4	0.13	0.04	0.17	0	0	0	0	0	0
1997	29-Jul	1	24	0	4	4	0.00	0.17	0.17	0	0	0	0	3	3
1996	15-Aug	1	23	0	0	0	0.00	0.00	0.00	0	0	0	0	0	0
1997	21-Aug	1	24	2	3	5	0.08	0.13	0.21	0	0	0	0	0	0

Down = sites downstream of modified bypass.
Up = sites upstream of modified bypass.