The Keogh and Waukwaas Rivers Paired Watershed Study for B.C.'s Watershed Restoration Program: Juvenile Salmonid Enumeration and Growth 1997

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D.J.F. McCubbing and B.R. Ward

Watershed Restoration Project Report No. 6
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ABSTRACT

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The effectiveness of stream habitat rehabilitation was evaluated in year one of an initiative requiring several years. The study used a staircase design in the treated (rehabilitated) watershed, the Keogh River, and an untreated (logged) watershed, the neighbouring Waukwaas River. The study examined anadromous salmonid density, growth, smolt yield and survival rates associated with a variety of stream habitat structures and whole-river fertilization. Other activities in the drainage include hillslope rehabilitation, road de-activation, and, eventually, riparian area restoration. Based on samples (electroshocking) to obtain fish population estimates, complex lateral debris jams had highest coho fry (*Oncorhynchus kisutch*) densities ($\bar{x} = 80$ fry•100m^{-2}), while boulder clusters had greatest steelhead parr (*O. mykiss*) abundance ($\bar{x} = 6$ parr•100m^{-2}, or ca. one parr per boulder). However, results were not significantly different statistically among habitat structures, as a result of large variance among fish densities in structures, particularly steelhead fry and parr, due to the reduced and patchy recruitment among treatment reaches coincident with extremely depressed steelhead adult run size over the past few years; additional monitoring is therefore essential. Stream flow and habitat type affected fish response to habitat structures. Typically, riffles were associated with higher steelhead parr numbers and shallow pools with higher coho fry numbers. Growth data, in summer and early fall size, indicated improved length (5 to 10mm) and weight (greater than 30%) of both coho fry and steelhead fry in fertilized areas compared to untreated areas ($p<0.01$). Differences in salmonid densities and distribution between the Keogh and Waukwaas Rivers were apparent in both steelhead and coho juveniles. A total of 145 steelhead parr from the range of habitats were marked with PIT tags for future recovery at the Keogh River fish fence as smolt migrants. We recommend project continuation to more reliably evaluate the relative effectiveness of structure designs for fish use, and to determine the smolt yield benefits from stream fertilization, structure placements, and their combined impact compared to before treatment and the external control. This information will support training in stream restoration techniques at this demonstration watershed and improve delivery of B.C.'s Watershed Restoration Program.

ACKNOWLEDGEMENTS

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INTRODUCTION

Advances in the understanding of forest ecosystems and watershed geomorphology have resulted in a new Forest Practices Code for regulating future forest harvesting in British Columbia. The need to rehabilitate hillslopes and streams in watersheds deforested under past logging practices has been recognized and implemented because of the slow rate of natural recovery to a mature forest, particularly in the riparian zone (Meehan 1991; Slaney and Martin 1997), and the reported effects that such historical practices have had on valuable aquatic resources within impacted aquatic ecosystems (Slaney et al. 1977a, 1977b; Tripp and Poulin 1986; Hall et al. 1987; Cederholm et al. 1980; Hartman and Scrivener 1990). Under the auspices of Forest Renewal BC (FRBC), and in connection to the Forest Practices Code, considerable resources have and will be used to undertake Watershed Restoration Program (WRP) projects. One component of such rehabilitation work is the restoration of aquatic habitat through in-stream treatments until the riparian zone eventually provides large wood for in-stream structures as well as fluvial-resistant root systems. These rehabilitation projects are complex and varied in nature, requiring detailed planning and co-ordination if future benefits are to be fully achieved (in particular to commercial and recreationally important salmonid species in B.C.). In large, new programs such as WRP, assurance through effectiveness evaluations that program goals and benefits have been attained is fundamental, and thereby facilitates a form of adaptive management in the Program.

Key to evaluating the success of WRP projects will be the ability to adequately measure changes in the aquatic environment as a result of the various treatments of habitat and productivity restoration (Keeley and Walters 1994). Many large programs have failed to adequately address evaluation and have therefore received external criticism (Kondolf and Micheli 1995). While evaluation may be conducted at many levels (e.g., financial, physical, employment, and biological) migratory salmonids are a suitable indicator species, or response variable at the resource level, for several reasons. They are at the upper end of the aquatic food chain and have complex habitat requirements for food, survival, reproduction and migration that reflect a culmination of watershed processes and impacts. Salmonid production and carrying capacity, as measures of the watershed status, can be ascertained by yield of smolts during their relatively brief spring migration.

Detailed knowledge of the habitat requirements of anadromous salmonids in their juvenile life stages has been documented elsewhere. This includes quantitative measurements of habitat requirements (reviewed by Keeley and Slaney 1996) and information on nutrient effects on fish production (Larkin et al. 1997). Accordingly, stream habitat restoration programs in both the USA and Canada are expanding (Koski 1992; Duff et al. 1995), with fish rehabilitation procedures now well documented (e.g., Slaney and Zaldokas 1997). Keeley et al. (1996) reviewed the response of salmonids to changes in habitat through restoration works. There are many detailed examples of successful studies, and physical failures, the latter noted by Frissel and Nawa (1992), but most of those examined describe changes in salmonid population densities at a site level, and not how these changes related to watershed productivity over time; there is little information on the impact to fish populations at the watershed scale.

This study aims to assess the effectiveness of restorative techniques on one watershed, using population dynamics data gathered from over 20 years of salmonid juvenile abundance in-stream, smolt enumerations, and adult steelhead run size estimates (Ward 1988; Irvine and Ward 1989; Ward and Slaney 1993a; Ward 1996). In-river treatments, habitat restoration and fertilization, will be applied to the target watershed over a five-year period, during which intensive juvenile salmonid density, growth, smolt yield and adult escapement data will be collated and analyzed for change, in a staircase-type experiment (Walters et al. 1988). To strengthen the analysis, a neighbouring (paired) watershed will also be monitored but will not undergo any stream rehabilitation treatments during the course of the experiment.

Data on salmon escapement enumeration in the Keogh River will be used with steelhead data, where possible, to evaluate the effectiveness of restorative techniques on pink (*O. gorbuscha*) and coho salmon production, and to calibrate smolt yield to adult escapement, and to further identify the freshwater and marine components of salmonid recruitment.

Within the broad evaluation of salmonid production, a study investigating the relative success of introduced nutrients and habitat structures will also be conducted, where we will evaluate the structural durability, species selectivity, fish densities and their survival rates in the various boulder and log designs, under nutrient replenished and untreated conditions. In this report, we report the fish response to stream rehabilitation from the first year of summer and early-fall investigations, and provide recommendations for project continuation, including improvements in study design and rehabilitation techniques.

STUDY AREA AND METHODS

Study Area

The Keogh and Waukwaas Rivers, two third-order coastal streams, are at the northern end of Vancouver Island. The Keogh River flows northeast for 33km from Keogh Lake headwaters and drains into Queen Charlotte Strait (127.4^o W, 50.6^o N) south of Port Hardy, B.C. Annual discharge ranges from 0.1 to an estimated 254$m^3 \bullet s^{-1}$ with a mean annual flow of ca. 5.3 $m^3 \bullet s^{-1}$. A more detailed description of the watershed was provided in Ward and Slaney (1979, 1988, 1993a,b), and previous research and steelhead population dynamics were summarized in Ward (1996). The adjoining Waukwaas River watershed, has a stream length of 24km and flows into Rupert Inlet (127^{o}21' W, 50^{o}35' N) near Coal Harbour, B.C. These watersheds of similar climate and geomorphology drain neighbouring hillslopes that have been exposed to comparable forest practices, but differ slightly in the distribution and abundance of lakes (6 in the Keogh, 4 smaller lakes in the Waukwaas), tributaries (19 on the Keogh, compared to two extensive main tributaries in the Waukwaas, each with several second-order branches), and may also have salmon populations that are exposed to slightly different oceanographic conditions and commercial salmonid exploitation (Queen Charlotte Strait and Johnstone Strait versus Quatsino Sound and Rupert Arm). Salmonid species in both watersheds include steelhead and cutthroat (*O. clarki*) trout (mainly resident fish), coho, pink and chum (*O. keta*) salmon, as well as Dolly Varden (*Salvelinus malma*) and kokanee (*O. nerka*) in lakes. A description of Keogh habitat structures installed in 1996 was provided by Potyrala (1997), according to previous plans and submissions detailing objectives and expected benefits (data on file ;Ward 1994, Riley 1995). Salmonid smolt yields from the two watersheds appear to be parallel, based on comparisons of 1995, 1996 and 1997 smolt yields (Fig.1).

Fertilization was carried out on reaches X and W in 1997 with slow release briquettes available from IMC Vigoro Inc., Winter Haven, Florida (see Ashley and Slaney 1997) at a target of concentration of 5μg soluble reactive phosphate per litre of water (K. Ashley, pers. comm.).

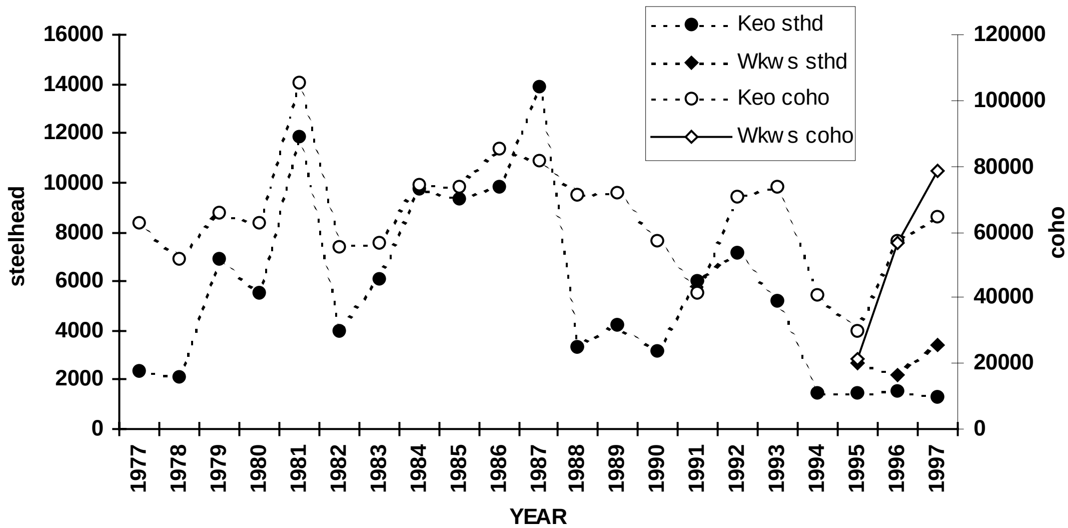

Figure 1. Steelhead trout and coho salmon smolt yields from the Keogh (1977 to 1997) and Waukwaas (1995 to 1997) Rivers based on results of fish fence operations reviewed in Ward and McCubbing (1998).

Experimental Design

The experimental design considers the two treatment types, the construction of habitat structures and stream fertilization. Representative structures are sampled (electroshocked) for salmonid use. To evaluate the success of watershed rehabilitation techniques, two methods are utilized. The first of these is an assessment of salmonid juvenile densities in freshwater over time, as sampled by mark-recapture techniques using electroshocking techniques. The second technique considers the steelhead parr response to treatments, using mark and recapture methods via a counting fence to assess smolt yield, survival and growth rates within the treated sections.

Four stream reaches of the Keogh River, (Fig. 2) were identified based on gradient and width, and to coincide with data collection in previous studies (e.g., Ward and Slaney 1993a): Reach W, River mouth (fish fence) to Rupert Main (11 km); Reach X, Rupert Main to Cub Creek (11 km); Reach Y1, Cub Creek to Muir Lake (4.8 km); and Reach Z1, Muir Lake to Keogh Lake (5 km). Similar reaches based on gradient and width were selected on the Waukwaas River (Fig. 3): Reach 1, River mouth to logging road immediately downstream of the Port Alice Highway (11 km); Reach 2, Port Alice Highway to West Main (8 km); Reach 3, upstream of West Main on tributary 1, (5 km); and Reach 4, upstream of West Main on tributary 2 (4 km).

On all reaches (other than reach W) 100m of river was sampled for all fish species present. Sampling length on reach W was increased to 200m as this reach is significantly larger in area and more diverse in habitat types than the other reaches. Sample sites were selected to represent typical sections of flat, pool, riffle and run in the proportion in which these habitats were shown to be present within the whole reach, as in Ward and Slaney (1993a) and Hankin and Reeves (1988).

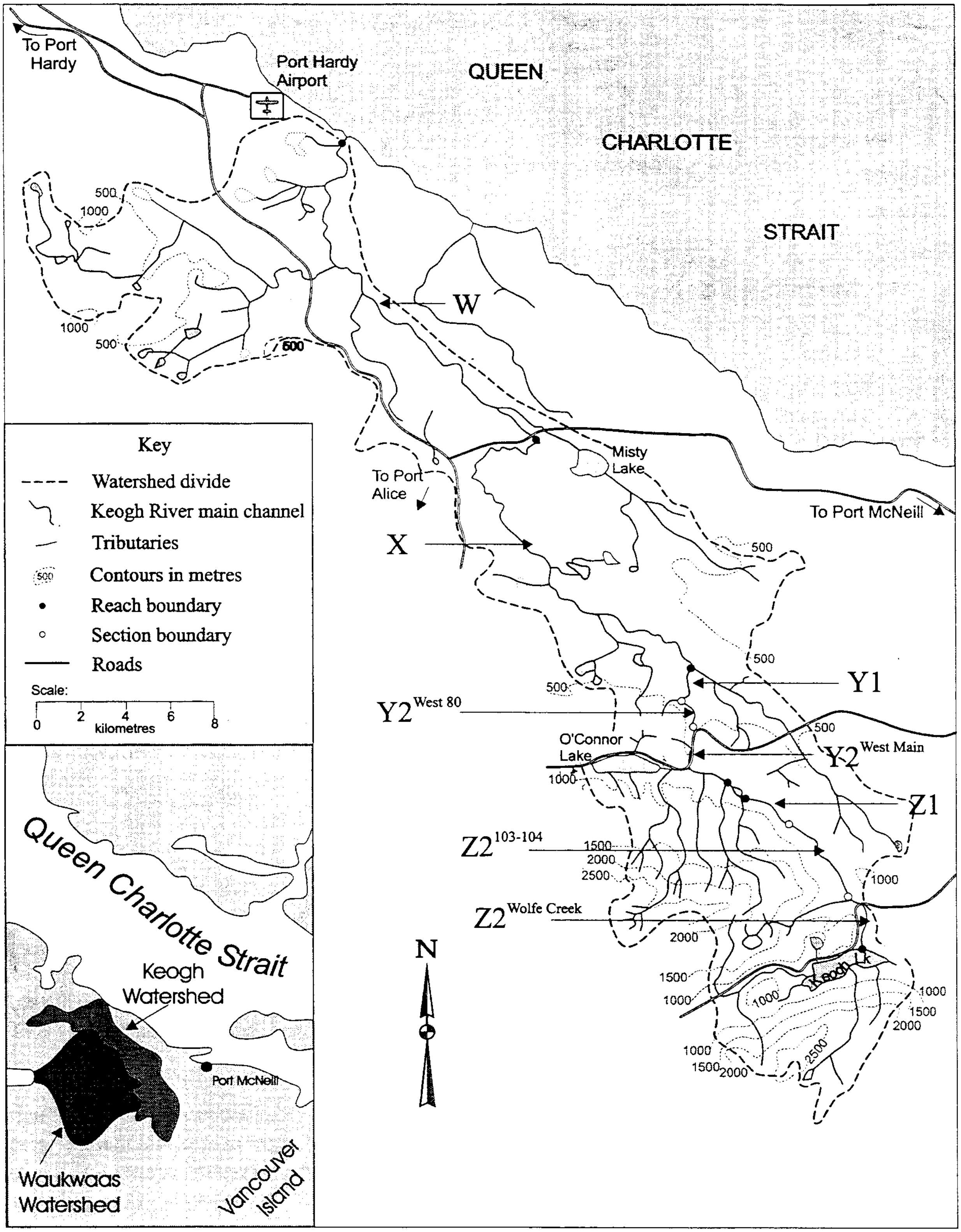

Figure 2. Map of the Keogh River watershed.

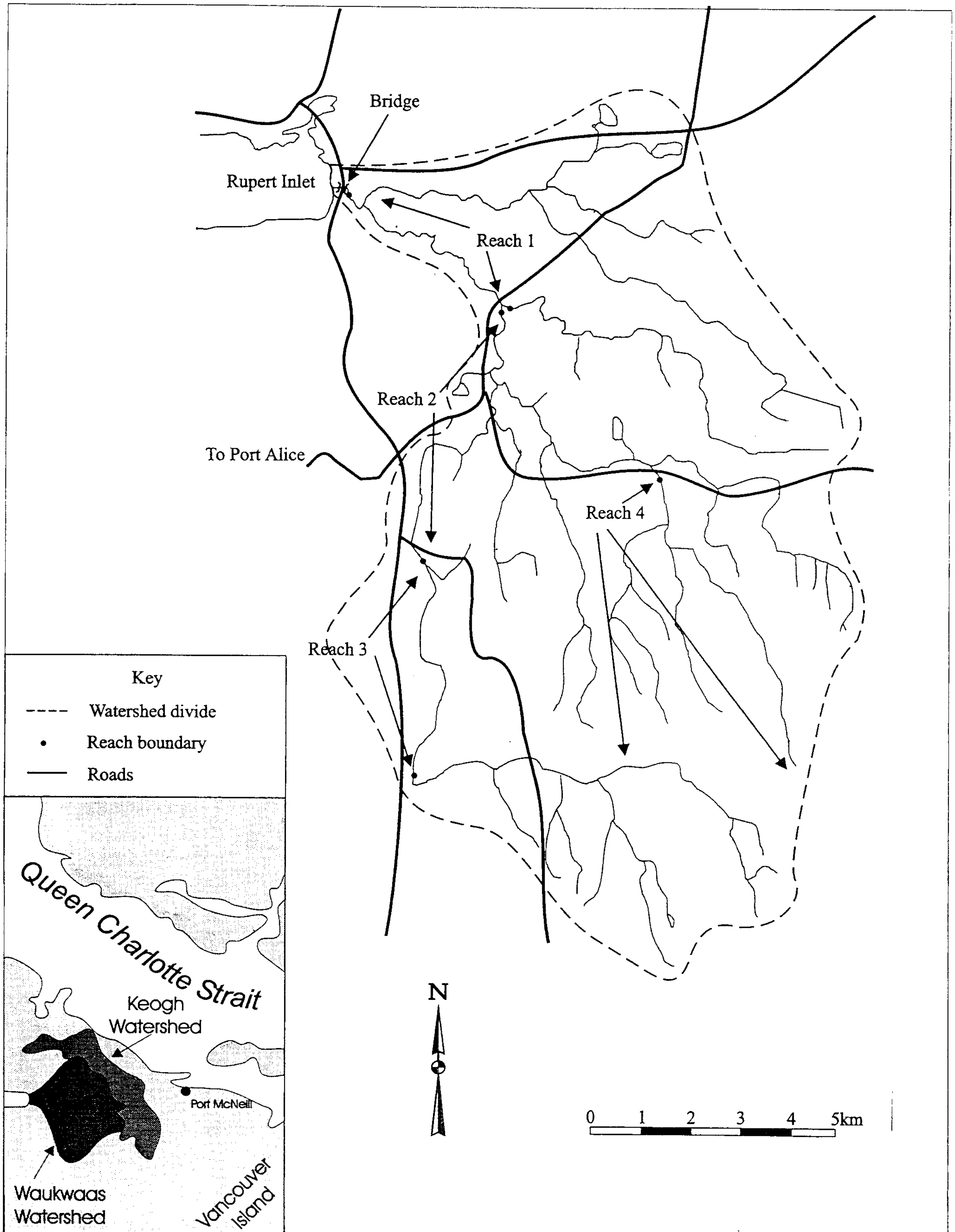

Figure 3. Map of Waukwaas River watershed.

In each of the four reaches on the Keogh River, steelhead parr were tagged with passive integrated transponder (PIT) tags implanted into the body cavity by hypodermic needle. These tags, about the size of a grain of rice, allow for individual fish identification by electronic scanning (Quinn and Peterson 1996). Within sections W and X, up to 200 parr if available, will be tagged yearly from 1997 to the year 2000, in areas of simple habitat (unrestored, little large woody debris (LWD)). Within reaches Y and Z, up to 400 parr (again, if available) will be tagged yearly, the numbers being equally split between areas of complex habitat, already treated with structures, denoted as section Y2 and Z2, and areas of simple habitat type, Y1 and Z1, and with a sufficient buffer zone (at least 500m) to avoid contamination. During the course of the experimental period, rehabilitation treatments will be undertaken throughout these reaches (Table 1), allowing for growth and survival estimates to be observed as a function of the treatment type.

Table 1. Treatment plan and reaches used for fish density, growth, survival, and smolt yield assessment in the Keogh and Waukwaas Rivers for evaluation of WRP stream habitat rehabilitation techniques.

Unit	1994-1996	1997	1998	1999/2000	Reach
1		s	s	fs	Z2
2		s	fs	fs	Y2
3		f	fs	fs	X
4		f	f	fs	W
5			fs	fs	Y1
6				fs	Z1
7					Waukwaas

Note: blank = no treatment, f = fertilized, s = structures and fs = fertilized and structures

Site Selection

Prior to sampling, each reach on both watersheds was assessed for relative habitat frequency. In the case of the Keogh River, data was adapted from work reported in Potyrala (1997), which used methods for habitat assessment as set out in Watershed Restoration Program (WRP) Technical Circular No.8 (Johnston and Slaney 1996). The habitat classes of pool, flat, riffle and run were combined to give total lengths of each for all reaches. The relative frequency was calculated from the total habitat length and the total reach length. As no habitat assessment data existed for the Waukwaas River, 500m sections of the river within each reach (selected to be representative), were measured for habitat frequency by the methods described for the Keogh River (Potyrala 1997). Differences in the relative frequency of habitat types were evident between reaches and rivers (Table 2).

Table 2. Relative frequency (expressed as m of bank length per 100m) of habitat types, by reach in the Keogh and Waukwaas Rivers, 1997.

Reach	Flat	Pool	Riffle	Run
Keogh				
W	25	41	13	21
X	25	10	49	16
Y1	23	22	31	23
Z1	24	11	50	15
Waukwaas				
1	35	32	23	10
2	40	18	32	10
3	38	11	51	0
4	20	26	54	0

Sampling was undertaken at a number of sites within each reach, in the proportion by bank length, to the frequency of occurrence of that habitat type within the reach (for example, on Reach 1 on the Waukwaas, 35% of the habitat by bank length is flat, thus as close to 35m of flat was sampled as practicable). This method of stratified sampling corrects for variance in the population distribution of species within the sample reaches (Elliot 1972). Where possible replicates of habitat types were sampled (Table 3), and the mean of these replicates was used in calculating fish densities and biomass for each habitat type within a reach.

Table 3. Numbers of replicate sample sites of habitat, by reach in the Keogh and Waukwaas Rivers, 1997.

Reach	Flat	Pool	Riffle	Run
Keogh				
W	3	2	3	1
X	1	1	2	1
Y1	2	1	2	1
Z1	2	1	2	1
Waukwaas				
1	1	1	2	2
2	1	1	2	1
3	2	1	3	0
4	2	2	3	0

Data on species distribution and density was also collected on a representative sample of the established (pre-1997) structures at four locations (covering two reaches) on the mainstem of the Keogh River. Where possible structures were sampled individually with sufficient river area adjoining, to target fish that may be using the structure as a refuge. Steelhead parr were PIT-tagged as part of this work within structure sites and by further electroshocking in the immediate area.

Data collection

Physical site data was recorded on a pre-printed proforma. Details included habitat length, mean width, bed type and load, water depth, shading, riparian species, velocity and LWD cover.

Population data was obtained by electroshocking representative habitat units, screened from the surrounding river by impassable net barriers, using the mark-recapture methodology (Riley and Fausch 1992). All fish caught during the first sampling run were marked (by an upper caudal fin clip) and returned to the site, following identification and recording of numbers. The site was rested for one hour before the recapture run was undertaken. Upon re-sampling, if insufficient recaptures of any species occurred (less than 20% of sample), or any new salmonid species was recorded, the second run was also treated as a marking run and a third run was undertaken. Otherwise data on recaptures was recorded along with, lengths of all salmonids (to a maximum of 30 individuals), weights of all parr, mean fry weights from a representative sub-sample and scale samples for aging purposes. Numbers, lengths and mean weights of all non-salmonid species were also recorded, as were any mortalities.

Additional sampling by reach was undertaken in late autumn. Growth prior to summer sampling was assessed by comparison to untreated sections and data published in Johnston et al. 1990. A representative sample (at least 30 of each species) was sampled from each reach and the four structure locations (where time and conditions allowed). Length, weight and species data were recorded and further steelhead parr were tagged.

Further sampling was undertaken in winter flow conditions using minnow traps to assess differential use of structures and habitat types within the range of salmonid species that overwinter in the mainstem of the Keogh River. Results are expressed as the average number of fish caught per trap per set (a set being an overnight period of 8-10 hours), by habitat type and complexity.

Population Calculations

Population estimates were calculated using the mark-recapture equation, (Riley and Fausch 1992):

(1) $N=\{(M+1)(C+1)/(R+1)\}+\text{ mortalities},$

where N = estimate, M= number marked, C = total number captured in the recapture run and R = recaptures.

Coho and steelhead juveniles were split into age classes of fry (0+) and parr (>0+) based on length frequency distributions. For example, steelhead of lengths exceeding 80mm were estimated to be parr from a length frequency histogram (Fig. 4). A similar exercise on coho juveniles was undertaken with a length of 75mm showing the transition between fry and parr, although more overlap of size classes was evident. Scale samples will be analysed to improve the accuracy of these estimates.

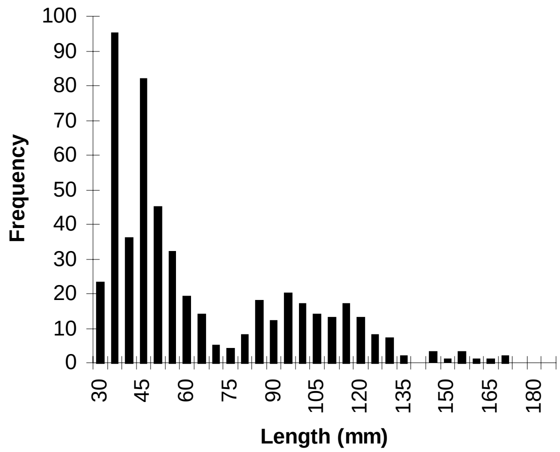

Figure 4. Steelhead length frequency distribution, Keogh River, summer 1997.

RESULTS

Reach Data

Salmonid population results from the Keogh and Waukwaas Rivers were described in three ways (Appendix 2): as mean population densities (nos.•$100m^{-2}$) by habitat type (adjusted for replicate habitat sites but ignoring reach, Table 4); as mean population, numbers•$100m^{-1}$ of representative bank length by reach (adjusted for replicate habitat sites and relative habitat frequency, Table 5); and mean densities•$100m^{-2}$ of reach (adjusted for replicate habitat sites but not for relative habitat frequency).

Arguably the best comparison of numerical differences in stream fish populations is based on bank length, as this allows for variations in flow and width, within the sampling season, where as densities described by area will change over time as width alters with flow (assuming no immigration or emigration of fish). Data for the Keogh and Waukwaas Rivers, when examined as densities per bank length, were different among the reaches sampled both within and between rivers. For example, steelhead fry are found in greatest densities in the lower reaches of the Keogh, but were highest in the middle reaches of the Waukwaas River (Table 4).

Table 4. Mean populations (numbers•100m^{-1} bank length) of salmonid species in the Keogh and Waukwaas Rivers, 1997, by reach (adjusted for replicate site data and stratified habitat frequency).

Reach	Steelhead Fry	Steelhead parr	Coho fry	Coho parr
Keogh				
W	180	15	255	10
X	93	21	436	5
Y1	37	21	291	22
Z1	0	14	425	9
Waukwaas				
1	86	70	27	0
2	488	36	311	69
3	411	136	398	16
4	24	22	99	12

We analyzed the preferred habitat type by species and age class (Table 5). Steelhead parr and fry were most abundant in riffle and run habitat on the Keogh River, coho fry preferring flats and coho parr dominating the pools. On the Waukwaas River steelhead parr were also most abundant in the riffle sections, but fry were found in greatest abundance in the flats. Coho fry similar to the Keogh River results, were most abundant in flat habitat, with coho parr dominant in the pool sections. Observations on sampling suggested the very small size of many steelhead fry (<45mm) may be responsible for their selected habitat on the Waukwaas River in early summer. These small, recently hatched fry were observed in the slow margins of the flat areas, away from strong currents.

Autumn sampling for growth data on the Waukwaas River found steelhead fry concentrated in the riffle areas, suggesting localized migration between habitats after the summer growth period.

Table 5. Mean population (density•100m^{-2}) of key salmonid species in the Keogh and Waukwaas Rivers, 1997, by habitat type (adjusted for replicate habitat site data.) across all sample reaches.

Reach	Steelhead Fry	Steelhead parr	Coho fry	Coho parr
Keogh				
Flat	0.44	3.72	131.46	3.41
Pool	0.62	2.89	68.89	65.30
Riffle	1.08	4.36	65.30	0.21
Run	1.28	6.62	86.20	2.37
Waukwaas				
Flat	3.97	15.99	95.85	4.21
Pool	0.72	13.07	57.88	15.56
Riffle	2.53	36.41	85.88	4.47
Run	2.72	3.61	2.35	0.00

Structure Sampling

A total of 67 structures were sampled in 1997. These were considered by type and location (Table 6, Appendix 3), and were representative of the treatment structures installed in each section and reach in the year prior to sampling. Structures which had been installed in 1997, and had not experienced flood flows and those which had undergone significant alterations to design or size were avoided.

Table 6. Representative introduced habitat structures in the Keogh River 1997, sampled by section and reach.

		Reach			
Structure Type	**Code**	**W80 - Y2**	**West Main - Y2**	**W103-104 - Z2**	**Wolfe Creek - Z2**
Boulder Cluster	BC	2	3	4	0
Lateral Debris Jam	DJ	2	5 (+1)	5 (+1)	2 (+1)
Lateral Debris Catcher	DC	0	1	1	0
Double Deflector Log	DDL	1	1	1	0
Downstream V	DV	0	1	1	0
Downstream U	DU	0	2	0	0
Upstream V	UV	0	1	0	0
Plunge Pool Log	PP	0	0	1	0
Riffle Reconstruction	RR	0	0	2	2 (+1)
Single Deflector Log	SDL	3 (+1)	5 (+3)	2 (+1)	1 (+2)
Root Wad	RW	1 (+1)	1	0	0
A-logs	AL	0	0	0	1
Instream Log	ISL	1	0	0	0
Double Floating log	DFL	0	0	2	0
Combination	COMB	1	2	1	2

Note: Combination structures include more than one structure type sampled as one unit, figures in brackets show composition of combination sites in terms of structures present.

Considerable variation in the distribution and production of some key salmonid species, notably steelhead fry and coho parr was evident from the four structure locations. Steelhead fry were found in only low densities at West Main and West 80, Reach Y (less than 2 fry•$100m^{-2}$) and were absent from West 103-104 and Wolfe Creek, Reach Z, regardless of structure type and habitat. Production of other salmonid species, (cutthroat trout, and Dolly Varden) was very low throughout the structures sampled. For this reason analysis comparing structure effectiveness has necessarily been restricted to steelhead parr and coho fry.

Mean densities for all sites and each structure type was examined for steelhead parr (Fig. 5) and coho fry (Fig. 6). Wide variations in response was observed among structures, for coho fry, 20 to 100 fry•$100m^{-2}$ and steelhead parr, 2 to 12 parr•$100m^{-2}$. Care should be taken in interpretation of these figures as the number of replicates of each structure type sampled was variable.

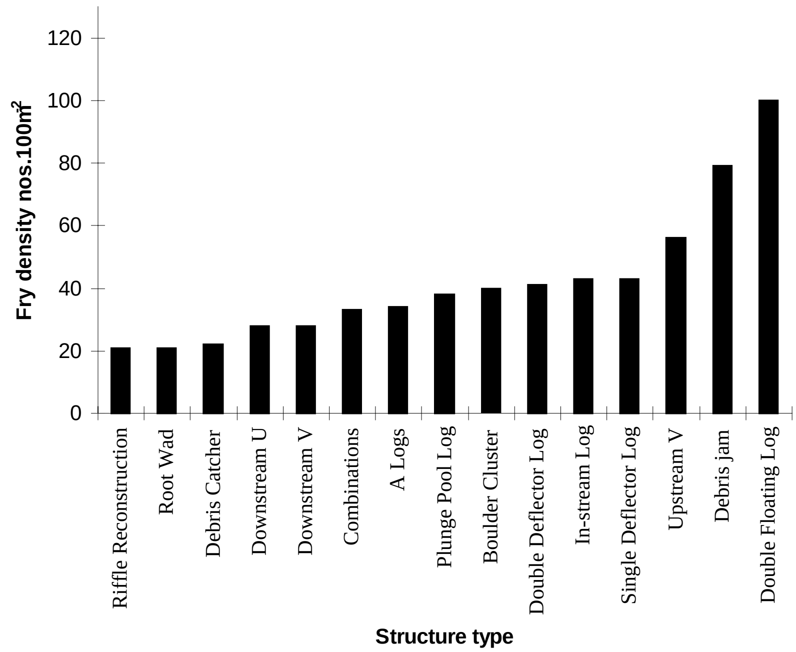

Figure 5. Mean coho fry densities in sampled structures.

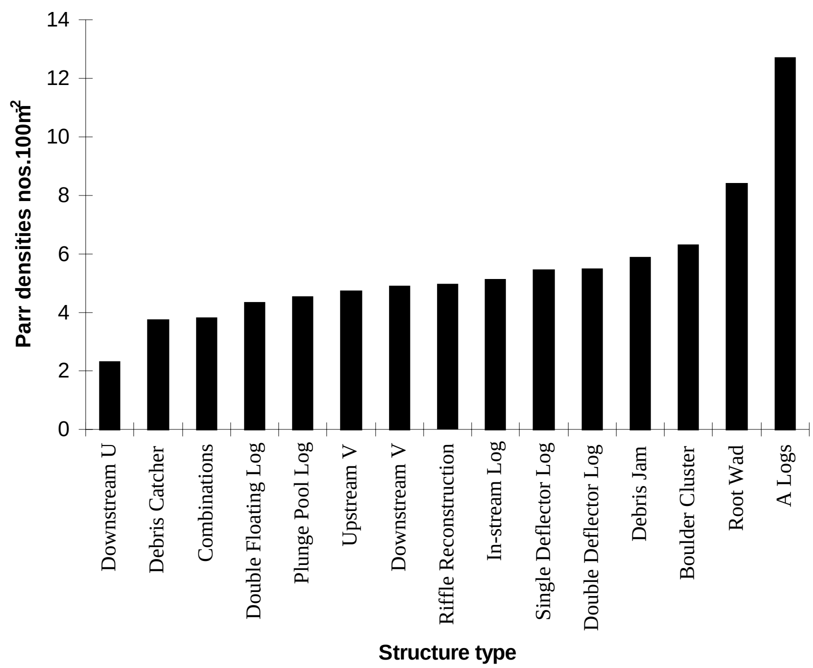

Figure 6. Mean steelhead parr densities in sampled structures.

Mean and standard deviation of fish densities observed for coho fry (Fig. 7) and steelhead parr (Fig. 8), were calculated from replicated structures. Debris jams (DJ, n=14), boulder clusters (BC, n=9), single log deflectors (SDL, n =11) and riffle reconstructions (RR, n= 4), were included in this analysis. No significant difference in the mean abundance for either species across these four structure types could be determined, nor for pooled samples of structures of a similar type.

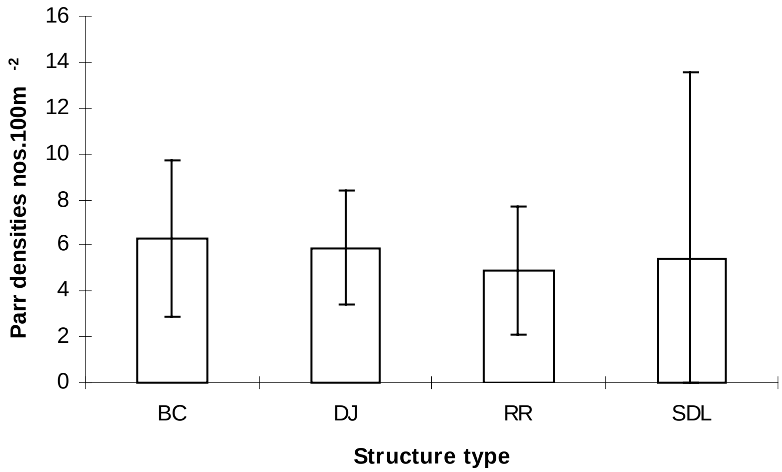

Figure 7. Mean coho fry production (with standard deviation) of four common structure types (BC = boulder cluster, DJ = debris jam, RR = riffle reconstruction and SDL = single deflector log).

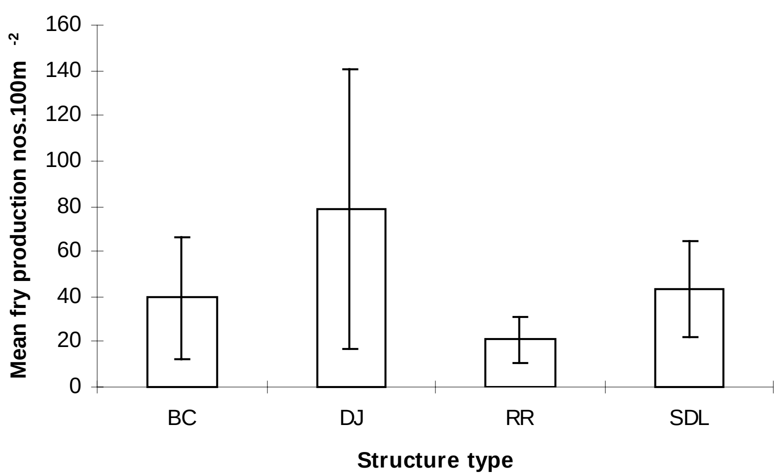

Figure 8. Mean coho fry production (with standard deviation) of four common structure types (BC = boulder cluster, DJ = debris jam, RR = riffle reconstruction and SDL = single deflector log).

Analysis was undertaken on the relationship between the amount of large woody debris in a structure, expressed as a percentage of surface area sampled, (both as instream, overstream and combined cover elements) and salmonid abundance, but no significant relationship could be found for either steelhead parr or coho fry.

Although not statistically significant, an apparent relationship did exist between dominant habitat type and the relative abundance of fish associated with a structure. When the upper quartile of structure sites, based on production densities, was examined for coho fry, a clear relationship existed. Sites where flat was the dominant habitat type showed high abundance (Fig. 9). Conversely, sites dominated by riffles were under-represented. In both cases results were adjusted for sampling bias. When steelhead parr densities were examined, the situation was reversed with greatest abundance of parr found at sites dominated by riffle and the least occurring at sites dominated by flat.

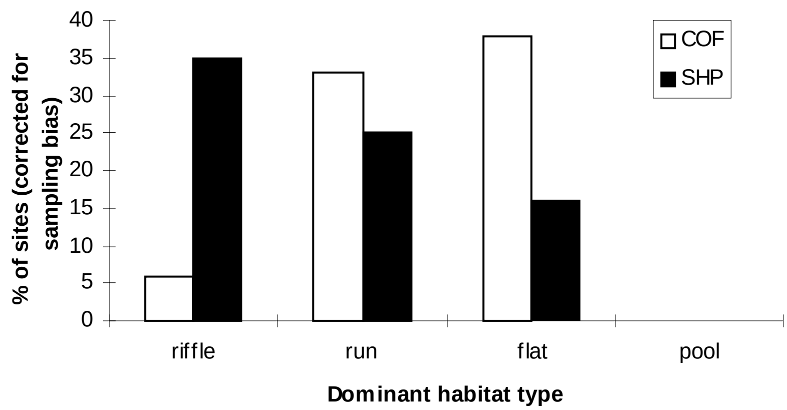

Figure 9. Representation of habitat types in the highest quartile of sampled structures, as expressed by salmonid densities.

A similar analysis was carried out to examine the effect of site location within the river as expressed by salmonid densities. Once more, the data was adjusted for sampling bias. The results showed a slight tendency for structures on West 80 to have highest coho fry and steelhead parr numbers, while sites on the Wolfe Creek section were slightly under-represented for coho fry (Fig. 10).

Mean density of fish among reaches untreated with habitat structures, was also compared to the mean density of fish in structure sites found within the treated reaches. In this analysis densities$\bullet 100m^{-2}$ were used for comparison despite the potential errors associated with this method of describing production. While a less robust method of describing abundance, structure sites were not uniform in the area fished (resulting in uneven bank lengths within sites) so the data derived was unsuitable for bank length calculations. Steelhead parr abundance was greater in reaches treated with structures (Y2, Z2) when compared to the control untreated reaches (Y1, Z1). Coho fry abundance was above average for three locations in the two treated reaches, but lower in the treated areas of Wolfe Creek. Untreated reach Y2 also shows high coho fry abundance (Fig. 11).

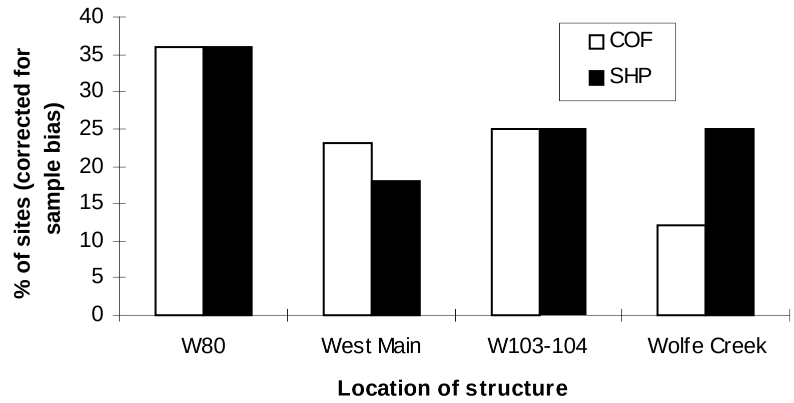

Figure 10. Representation of site location in the highest quartile of sampled structures, as expressed by salmonid densities.

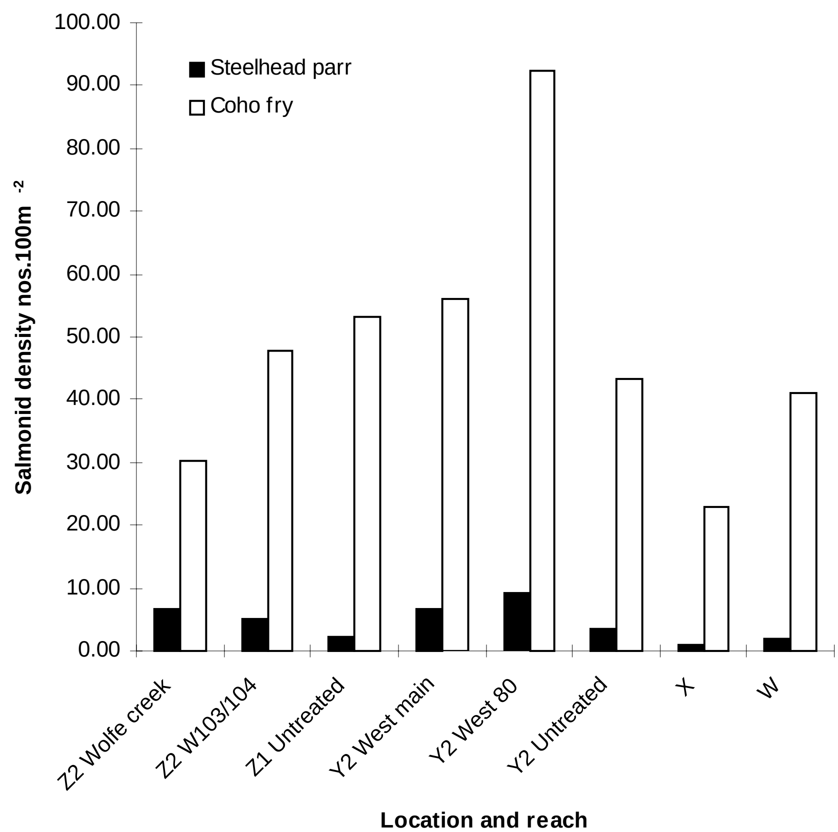

Figure 11. Comparisons of mean salmonid production between treated and untreated reaches, Keogh River 1997.

Total salmonid biomass was also calculated using mean weights of each age class and species of fish within each reach. (Appendix 2). Because of the low densities of cutthroat trout and Dolly Varden sampled, larger errors may occur when calculating the biomass from these results (for example, variations in mean weight of cutthroat trout adults were large between sites, giving rise to high variance on the mean weight of cutthroat adults in any reach). The biomass data has thus been expressed as weight of target species for 100m of bank length by reach and weight of other salmonid species (Fig. 12).

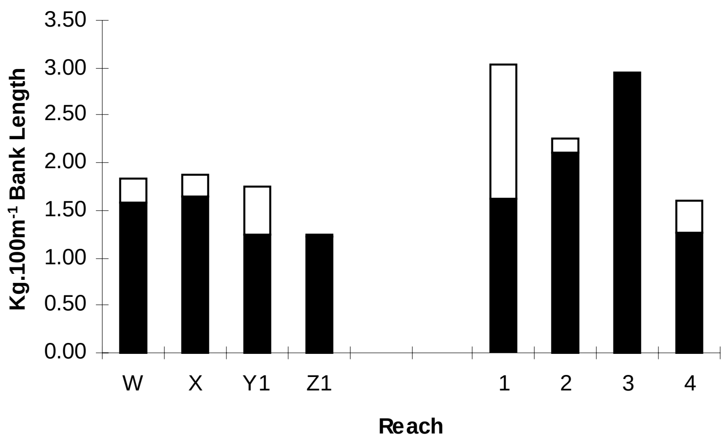

Figure 12. Biomass estimates by reach of coho and steelhead combined (black bars) and other salmonids (open bars) for the Keogh and Waukwaas Rivers, 1997.

Growth Data

Growth data was examined between the treated reaches of the Keogh River (W and X), the upper Keogh River untreated reaches (Y1 and Z1) and the untreated paired watershed (the Waukwaas River, Reach 1 and 2) and will eventually be analyzed in a "Before-After Control-Impact" experimental design (Stewart-Oaten et al. 1986).

Current growth information was calculated using the mean length and weight for steelhead parr and coho fry in each reach at date of initial sampling and the date of repeat sampling. The mean size in each reach was calculated by the method described by Hulbert (1984) and Stewart-Oaten (1986), as in both summer and autumn sampling each site represented a sub-sample of the reach population. Age-class breaks were again determined by length-frequency methods to be supported by subsequent scale analysis. Mean length and weight data in autumn was calculated for each reach along with growth rate as described by length gain (in mm) per day of sampling period (Table 12).

Table 12. Means of growth data for the Keogh River, 1997.

Reach	Steelhead Fry Autumn weight (g)	Length gain (mm•day)	Autumn length (mm)	Coho fry Autumn weight (g)	Length gain (mm•day)	Autumn length (mm)
	Keogh					
W (f)	4.48	0.22	67.2	4.4	0.14	67.2
X (f)	5.0	0.29	71.7	5.2	0.16	68.6
Y1	nd	nd	nd	4.4	0.12	63.0
Y2	nd	nd	nd	3.1	0.02	59.8
Z1	nd	nd	nd	4.3	0.12	60.7
Z2	nd	nd	nd	2.9	0.16	64.1
	Waukwaas					
1	2.3	0.22	58.8	nd	nd	nd
2	2.0	0.24	54.7	3.7	0.13	59.0
3	nd	nd	nd	nd	nd	nd
4	nd	nd	nd	nd	nd	nd

Note: f = fertilized, nd = no data.

Statistical analysis of mean length of coho fry in the autumn was undertaken using a simple analysis of variance (ANOVA). Three population groupings were used, Keogh unfertilized (Reach X and W), Waukwaas unfertilized (Reach 1 and 2) and Keogh fertilized (Reach Y1 and Z1). The null hypothesis was rejected with significant differences in the mean length of coho fry observed between these three groups (F=16.7** df=314). Coho fry from the fertilized areas showed greater summer and autumn lengths (Fig. 13) .

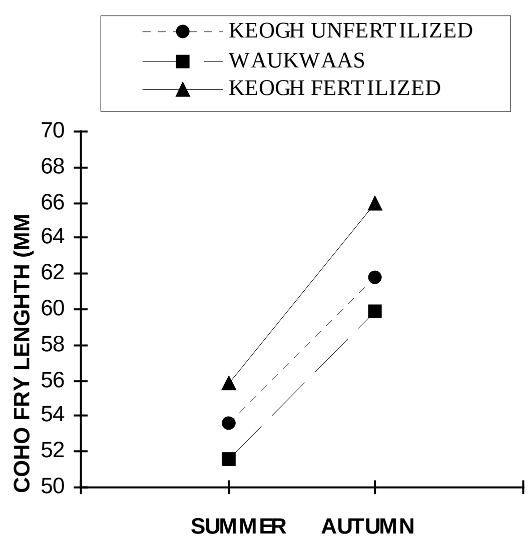

Figure 13. Coho fry growth, Keogh and Waukwaas Rivers, 1997.

As steelhead fry data were only available from the autumn sampling on the fertilized reaches of the Keogh and unfertilized reaches of the Waukwaas (there being no steelhead fry in the upper reaches of the Keogh) a one-tailed t-test was used to determine if mean length of fry in the fertilized group was greater than the control, unfertilized group. A significant result was obtained and the null hypothesis was rejected at the 1% level (t = 4.9, df=45). Thus steelhead fry, sampled in the autumn in the fertilized group from the Keogh River were significantly larger than their control counterparts from the Waukwaas River (Fig. 14).

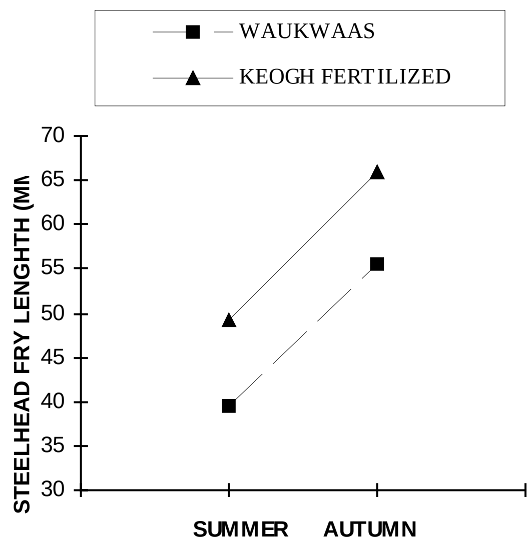

Figure 14. Steelhead fry growth, Keogh and Waukwaas River, 1997.

Steelhead Parr Tagging

Steelhead parr were limited in numbers through the Keogh river in 1997, following low adult escapement in the preceding spawning seasons. On average, slightly less than 200 parr were calculated to be present for every kilometre of river length (Table 5). Efforts to collect as many parr for tagging as possible were made, but low numbers were compounded by high water temperatures (when tagging was deemed to be too stressful) and an abundance of small parr (less than 90mm fork length), where tagging was avoided. A total of 145 parr of greater than 90mm fork length were tagged over the length of the river (Table 13).

Table 13. Summary of PIT-tagged steelhead parr, Keogh River, 1997.

Reach and Location	Nos. tagged
W	18
X	31
Y1	7
Y2	25
Z1	6
Z2	58
TOTAL	**145**

Two PIT-tagged steelhead parr, one from the W80 structure location (Y2) and one from the W103/104 structure location (Z2) were recaptured during collection of growth data in the autumn. Both fish had grown several millimetres, and showed healed incision wounds with no ill effects other than light scarring.

Winter Minnow Trapping Results

Sampling with minnow traps resulted in only low numbers of coho parr and steelhead parr (all fry of the 1997 year class were now classed as parr having been present in the river for nearly a year). Differences in fish abundance through the Keogh River were not evident other than for Wolfe Creek where, as expected, no steelhead parr were recorded. This will be a result of the absence of steelhead fry in this area in the preceding summer. The majority of fish sampled, in particular steelhead, were associated with pool habitat where natural or introduced LWD provided cover.

Table 14. Numbers of parr sampled in minnow trapping during winter flow conditions.

Date	Reach Code	Reach Name	Water Temp	Trapping Time (hours)	Flow Type	Habitat Structures	Coho Parr	Steelhead Parr
16-Mar	W	Pumphouse	6	4	Run	None	6	0
16-Mar	W	Pumphouse	6	4	Riffle	None	0	0
16-Mar	W	Pumphouse	6	4	Pool	Natural Debris Jam	10	3
05-Apr	X	Highway	8	12	Riffe	None	0	0
05-Apr	X	Highway	8	12	Run/Pool	Natural Debris Jam	8	3
05-Apr	X	Highway	8	12	Pool	None	4	0
05-Apr	Y	West Main	8	12	Riffle	Boulder Cluster	0	1
05-Apr	Y	West Main	8	12	Run/Pool	Debris Jam	5	3
16-Mar	Z	Wolfe Ck	5	4	Riffle	Riffle Reconstruction	0	0
16-Mar	Z	Wolfe Ck	5	4	Run	Single Deflector Log	0	0
05-Apr	Z	Wolfe Ck	7	12	Riffle	Riffle Reconstruction	0	0
05-Apr	Z	Wolfe Ck	7	12	Run	Single Deflector Log	0	0

DISCUSSION

The experimental data to date is restricted to three years pre-treatment smolt yield (1995,1996,1997) and one year's density and growth data (1997). It is therefore premature to determine the effects of treatments already undertaken on smolt yield. However, the data collected can be utilized to examine effects of the various treatments (habitat restoration and fertilization) methods on the abundance and growth of juvenile salmonids within the treated reaches and compare this data with baseline information from the Waukwaas River.

Reaches and Salmonid Production

Similarities in salmonid production in terms of species, age classes, densities and distribution were limited both between reaches within watersheds and between watersheds. These differences were the result of a combination of factors, including habitat availability, adult escapement, juvenile mortality and reach location within the watershed.

Steelhead parr and fry abundance at the Keogh river has been limited by low adult escapement in recent years, which in turn is related to recent poor smolt survival rates (i.e., 4%, Welch et al. 1997). As early run fish are known to spawn in the upper watershed it is possible that the low steelhead fry abundance observed in this area results from severely depressed returns of the early run component of wild steelhead. The Waukwaas River which currently has higher adult escapement shows a skew towards greater steelhead fry production in the middle and upper river reaches. Overall steelhead fry densities in the Keogh River in 1997 were low, 5 to 16 fry•100m^{-2} when compared to historical data (12 to 90 fry•100m^{-2}, Ward and Slaney 1993a). This may result in high fry-to-smolt survival rates (in excess of 40%, Ward et al. 1993) providing food and cover requirements are met, although recent data suggests this is not the case, Ward and McCubbing 1998. Steelhead parr in the Keogh control reaches were evenly spread through the entire watershed (Table 4) while in the Waukwaas River they were in greatest abundance in Reach 3, towards the upper end of the watershed. The lack of variation in abundance of steelhead parr in the Keogh River control reaches (W,X,Y1,and Z1) is difficult to explain, as preferred habitat types (riffle and run) were found in varying proportions through the four reaches. It is probable that the current observed steelhead parr population is significantly lower than the carrying capacity of the existing habitat, resulting in a simple spatial distribution where all fish may find suitable quantities of preferred habitat and food to create territories, in any reach, without the need for active selection through migration to reaches with increased availability of preferred habitat type. In the Waukwaas River steelhead parr dominated Reach 3, where riffles were abundant and offered good cover with boulders. Riffles were also abundant in Reach 4, but these were of a different nature, being largely composed of cobble with little boulder cover. These areas were possibly less attractive to parr due to the bed movement which occurs under high flow conditions.

Densities of coho fry were varied in distribution in the Keogh and Waukwaas Rivers. Obvious relationships between habitat distribution were evident on the Keogh River. Reach X and Z1 were dominated with flat the preferred habitat type selected by coho fry and showed high coho fry abundance despite an observed lack of LWD. Overall mean densities on the Keogh River remained similar to those found in previous surveys at around 0.4 fry•m^{-2} for all habitat types combined (P.Slaney, pers. comm). Similar results were found in the Waukwaas although occasional sites gave unexpectedly high density figures (e.g., Site 39, Reach 4, 0.9 fry•m^{-2}).

Habitat Structures and Juvenile Salmonid Densities

The analysis of salmonid enhancement through the re-creation of habitat diversity is well documented (Solazzi and Johnson 1994, Schuler et al. 1994 and Bonnell 1991). More specifically, the introduction of man-made structures has been undertaken on many watersheds and the resulting effect on salmonid production monitored (Keeley et al. 1996). Historical work has been undertaken on the Keogh River (Ward and Slaney 1979;1981) examining boulder placement to enhance steelhead parr production. Similar investigations have been undertaken elsewhere to examine the effect of LWD structure placement on both winter and summer coho juvenile densities (Keeley et al. 1996, Solazzi and Johnson 1994). In this study, these investigations will be enhanced by examining the effect over time of treating an entire watershed with structures. This preliminary data analysis simply compares the first years results with historical expectations.

Steelhead parr are known to associate with riffle and run habitats (Hartman 1965) probably in response to their propensity to feed effectively on drift organisms (Fausch 1984, Hughes 1992). Furthermore, studies have shown increased steelhead parr abundance in riffles where boulders are in greater evidence naturally (Facchin and Slaney 1977), or are experimentally introduced (Ward and Slaney 1979, 1981, 1993b). The results of this study show a strong relationship between steelhead parr and riffle/run habitat. Boulder clusters and riffle reconstructions showed elevated levels of steelhead parr abundance (3 to 10 parr•$100m^{-2}$ structure area, or one parr per boulder – similar to that documented by Ward and Slaney 1981, 1993b), although the 95% confidence interval associated with these densities overlaps with that found in structures thought to be less suited to steelhead parr production (for example, single log deflectors). An increase in sample size is therefore required in subsequent years. One key element in this high variability is probably related to whether any individual structure is associated with riffle and run habitat when sampled.

In addition to boulder clusters, and riffle-pool reconstructions, complex structures dominated by LWD (e.g., lateral jams) were also found to be used by higher than average densities of steelhead parr if they were associated with riffle or run habitat (4 to 9 parr•$100m^{-2}$ structure area).

These results are slightly lower (on average 65%) than historical data reported (Ward and Slaney 1979, 1981), where mean densities of 10 parr•$100m^{-2}$ were recorded. The difference is likely to be a result of the current low adult escapement to the system. It is, however, considerably higher than the data found in untreated reaches of the river in 1997, where mean densities were only around 1 to 2 parr•$100m^{-2}$.

As steelhead fry were found in very low densities in the upper treated and untreated reaches of the Keogh River, no effect on their survival and distribution could be determined in 1997.

Coho fry were abundant throughout the entire watershed and were used as a further indicator of structure performance. Coho fry, unlike steelhead parr, seek out slower water areas of flat and pool, where they partially feed on surface food items. This is particularly evident in flood or winter conditions (Peterson 1982a, b; Murphy et al. 1984, Keeley et al. 1996). This was expressed in the structure sites sampled, with greatest coho fry production found at sites dominated with flats. As with steelhead parr abundance, large variations in structure performance were evident within replicates of all structure types and between structure types, with no structure type significantly outperforming the others statistically, although complex debris jams producing greatest densities of coho fry (20 to 140 fry•$100m^{-2}$, mean 80 fry•$100m^{-2}$). Overall the densities of coho fry found in the areas treated with structures was not significantly higher than in untreated areas during the summer study period with a mean density of around 40 fry•$100m^{-2}$. This may, however, misrepresent the importance of LWD structures during the important over-wintering period. No detailed prescription for suitable structure types can be derived from the observed data. However clear indications exist that if target species prefer fast flowing riffle and run habitat (e.g., steelhead parr), a structure placed in or close to this type of stream flow will perform better in the short term. Equally, structures placed in slower flats or pools will perform better for species preferring this type of flow.

The lack of correlation of coho fry production to LWD area or volume is perhaps not unexpected given the variety of structure types, locations and positioning in summer flow conditions.

Salmonid Growth and Fertilization

A key element in the survival and growth of anadromous salmonids in freshwater is the input of marine derived nutrients and carbon, (Bilby 1996, Mathisen et al. 1988). Where the impacts of past logging and over-fishing have created a reduction in returning adults, the likely effect is a negative feedback loop, although experimental confirmation is required. Less returning adults, mean less nutrients, which in turn results in less fit juveniles migrating to sea (Larkin and Slaney 1996).

The effects of inorganic fertilization to enhance salmonid production have been previously examined both on the Keogh River (Johnston et al. 1990, Slaney and Ward 1993) and on other watersheds (Mouldey and Ashley 1996). The process involved affects the primary algal production of a stream when fertilization takes place. This primary production in turn increases both the number and size of invertebrate food items present within the system, which stimulates the growth of fish (Ashley and Slaney 1997).

Data from the Keogh River in 1997, showed coho fry in the fertilized areas (Reach X and W) had a mean length of 5 to 10mm greater than samples from unfertilized reaches ($p<0.01$). They also showed a greater than 30% increase in mean weight, over their unfertilized controls both in summer and autumn sampling as observed previously (Johnston et al. 1990). With as little as a 10mm increase in mean length accounting for a doubling in survival of coho pre-smolts through winter freshets to the smolt stage (Scriviner and Brown 1993), increases in coho smolt output from the lower Keogh fertilized reaches may be predicted for 1998. One exception to this improved growth, was the data collected on Reach Z2, where autumn length and weight was comparable to the fertilized reaches. The reasons for this exception are unclear but may relate to improved habitat, due to the recreation of LWD structures in predominantly flat/pool habitat, increased food production through the re-creation of riffle structures and warmer summer temperatures influenced by Keogh Lake, at the upper end of the reach.

Only limited autumn data was collected on steelhead parr in the lower reaches of the Waukwaas or the Keogh Rivers, due to persistent high water conditions in the autumn period, restricting sampling areas to backwaters and areas of slow flow, with low parr productivity. However as previous studies (Ward and Slaney 1993a) describe significant increases in mean weight of steelhead parr being associated with observed increases in coho fry growth, following fertilization, such improved growth data although unobserved, is likely.

Steelhead fry data could only be compared between the fertilized reaches of the Keogh River and the unfertilized lower reaches of the paired Waukwaas watershed due to restricted distribution factors on the Keogh River, as already described. As with coho fry significant ($p<0.01$) differences, over 120%, between mean autumn weight were recorded in fertilized and unfertilized reaches when all data were combined. Results exceeded those previously observed in experimental studies (Johnston et al. 1990).

Growth rates were also elevated in the treated reaches. This should increase overwinter fry survival and eventually smolt survival (subject to marine conditions at smolt migration (Ward 1996).

Winter Habitat Usage.

Minnow trapping results indicate a strong relationship between pool habitat associated with LWD and winter habitat requirements of both coho and steelhead juveniles. This relationship has been documented as the main bottleneck in salmonid production in the Pacific Northwest (Cederholm et al. 1997), and may be responsible for improved overwinter survival of salmonid juveniles. This should be evident in the 1998 sampling season.

CONCLUSIONS

Initial results suggest significant variations in the distribution and production of juvenile salmonids, particularly coho and steelhead, in the paired watersheds. The Waukwaas River currently favours steelhead production, while the Keogh River favours coho production. Despite this pattern of juvenile production, overall biomass figures suggest the standing crop of salmonids during the summer months is currently greater on the Waukwaas River (ignoring reaches which have already been treated with structures on the Keogh River).

Steelhead and coho juvenile production shows no relationship to introduced structure type in sampled sites, with reach location and flows being more important in determining structure performance. Studies of summer microhabitat use by coho fry and steelhead parr would assist in determining the reasons for structure performance (Keeley and Slaney 1996), but are outside of the scope of the current study. Currently detailed prescriptions for structure design based on target species can not therefore be determined.

The impact of fertilization increased growth rates, overall autumn size of juvenile coho and steelhead, and elevated fish biomass figures by over 30% on the Keogh River. The implications of this increased length should be increased overwinter and possibly smolt survival. Smolt yield estimates in 1998 are essential in monitoring these results through to the effects on adult escapement.

The need for continued data collection to determine the outcome of WRP rehabilitation is compelling. It is the key recommendation of this report that the experimental design proposed is followed to completion so that the benefits of watershed restoration can be fully assessed.

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Appendix 1. Site details - reaches

ID	Reach	River	Date	Water Temp	Riparian Species	Canopy Closure	Bankfull Width	Bankfull Depth	D (m)	Channel Morphology	Disturbance Level	Stream Habitat	Wetted Width (x)	Site Length (x)	Area (m2)	Wetted Width (max)	Velocity	Mean Depth Wetted
2	Wa	KEOGH	21-Jul-97	16	MIXED	10	22.9	0.6	0.1	RPg-w	MOD. DEGRADED	FLAT	14.5	20.2	293	18.2	0.3	0.25
3	Wa	KEOGH	18-Jul-97	16	MIXED	10	19.4	1.1	0.1	RPc-w	MOD. DEGRADED	RIFFLE	18.4	35.4	651	23	1.03	0.15
4	Wa	KEOGH	18-Jul-97	16	MIXED	20	21.7	0.9	0.2	RPg-w	MOD. DEGRADED	RUN	10.8	21.7	234	10.8	0.5	0.35
5	Wb	KEOGH	16-Jul-97	14	MIXED YF	30	8.6	0.8	0.1	RPg-w	STABLE	FLAT	8.6	18	155	8.6	18	0.5
6	Wb	KEOGH	16-Jul-97	14	MIXED YF	10	26.1	1.75	0.1	RPg-w	STABLE	POOL	6.2	19.4	120	17.35	0	0.89
7	Wb	KEOGH	17-Jul-97	14	MIXED	30	18.6	0.65	0.1	RPg-w	STABLE	POOL	10	14	140	10.6	0.29	0.28
8	Wb	KEOGH	17-Jul-97	15	MIXED	10	20.8	0.35	0.35	RPc-w	STABLE	RIFFLE	15.9	14.2	226	16	0.76	0.19
9	Wc	KEOGH	21-Jul-97	18	DECIDUOUS	40	18.9	1	0.2	RPg-w	STABLE	FLAT	15	22.3	335	16.3	0.7	0.6
10	Wc	KEOGH	21-Jul-97	18	MIXED	20	23	1	0.4	RPc-	MOD. DEGRADED	RIFFLE	19.7	11.8	232	20.9	0.5	0.23
11	Xa	KEOGH	22-Jul-97	15	MIXED	70	18.2	0.87	0.25	RPc-w	MOD. DEGRADED	RIFFLE	14.4	20.2	291	15.6	0.62	0.16
12	Xa	KEOGH	22-Jul-97	15	MIXED	75	16.5	1.4	0.2	RPc-w	STABLE	POOL	13.2	26.3	347	14	0.25	0.69
13	Xa	KEOGH	22-Jul-97	15	MIXED	40	19.4	0.85	0.23	RPc-w	STABLE	RUN	17.3	18.3	317	18.3	0.43	0.18
14	Xb	KEOGH	23-Jul-97	15	MIXED	0	16.2	1.9	0.37	RPc-w	MOD. DEGRADED	FLAT	10.7	23.5	251	12.1	0.51	0.42
15	Xb	KEOGH	23-Jul-97	15	CONIFERS	30	11.7	1.46	0.38	RPc-w	MOD. DEGRADED	RIFFLE	8.5	30.3	258	9.2	0.54	0.23
17	YU	KEOGH	30-Jul-97	14	MIXED MF	30	15.6	1.14	0.25	RPG	STABLE AGRADING	FLAT	9.3	13.1	122	10.5	0.1	0.2
18	YU	KEOGH	30-Jul-97	14	MIXED MF	20	20.4	1.1	0.19	RPg-w	STABLE AGRADING	RIFFLE	11.53	21.1	243	15.8	0.65	0.1
19	YU	KEOGH	29-Jul-97	14	MIXED MF	30	18.1	1.37	0.19	RPg-w	STABLE AGRADING	RUN	7.53	16.3	123	9	0.23	0.55
20	YU	KEOGH	31-Jul-97	14	MIXED MF	20	30.5	0.6	0.13	RPg-w	STABLE AGRADING	FLAT	5.76	24.6	142	8.2	0.08	0.26
53	YU	KEOGH	31-Jul-97	14	MIXED MF	50	20.7	0.74	0.13	RPg-w	STABLE AGRADING	RIFFLE	6.1	8.7	53	7.4		0.14
21	YU	KEOGH	31-Jul-97	14	MIXED MF	5	18.6	0.8	0.1	RPg-w	STABLE AGRADING	POOL	6.3	21.7	137	7.2	0.5	0.48
46	ZU	KEOGH	01-Aug-97	14	MIXED YF	3	12.1	0.7	0.18	RPg	MOD. AGGRADED	FLAT	6.6	14	92	6.6	0.28	0.2
47	ZU	KEOGH	01-Aug-97	14	MIXED	45	14.1	1.3	0.15	RPg	MOD. AGGRADED	POOL	8.1	10.5	85	10.4	0.14	0.8
48	ZU	KEOGH	01-Aug-97	15	MIXED YF	20	12.3	0.3	0.2	RPg	MOD. DEGRADED	FLAT	8.7	16.6	144	9.7	0.09	0.16
49	ZU	KEOGH	01-Aug-97	15	MIXED YF	25	13.9	0.59	0.15	RPg	MOD. DEGRADED	RIFFLE	6.9	8.7	60	8.7	0.4	0.29
50	ZU	KEOGH	02-Aug-97	16	DECID. YF	40	9	0.7	0.2	RPg	MOD. DEGRADED	RIFFLE	5.6	22.4	125	6.5	0.6	0.2
51	ZU	KEOGH	02-Aug-97	16	DECID. YF	30	10.3	0.48	0.26	RPg	MOD. DEGRADED	RUN	6.7	35	235	7.3	0.2	0.23
52	ZU	KEOGH	02-Aug-97	16	DECID. YF	30	11.3	0.68	0.25	RPg	MOD. DEGRADED	RIFFLE	5.4	10.5	57	6	0.4	0.18
46	1	WAUKWAAS	28-Jul-97	16	DECIDUOUS	90	22.8	1.61	0.15	RPg	MOD. AGGRADED	POOL	6.4	32.2	206	7.8	0	0.33
47	1	WAUKWAAS	28-Jul-97	16	MIXED MF	0	60.4	1.43	0.18	RPg	MOD. AGGRADED	RIFFLE	13.1	16.2	212	15.2	0.87	0.2
48	1	WAUKWAAS	29-Jul-97	15	MIXED MF	10	27.3	1.7	0.18	RPg	MOD. AGGRADED	RUN	9.85	21.3	210	0	0.23	0.3
49	1	WAUKWAAS	29-Jul-97	15	MIXED MF	10	28.3	1.7	0.18	RPg	MOD. AGGRADED	FLAT	10.1	14.7	148	0	0.56	0.18
50	1	WAUKWAAS	29-Jul-97	14.5	MIXED MF	5	26.5	1.51	0.12	RPg	MOD. AGGRADED	RUN	8.5	16	136	8.5	0.43	0.28
51	1	WAUKWAAS	29-Jul-97	14.5	MIXED MF	0	28.2	1.84	0.21	RPg	MOD. AGGRADED	RIFFLE	10.7	9.2	98	16	0.7	0.14
52	2	WAUKWAAS	24-Jul-97	12	MIXED YF	10	17.3	0.6	0.15	RPg	MOD. AGGRADED	RIFFLE	10.4	24.4	254	12.5	0.5	0.19
29	2	WAUKWAAS	24-Jul-97	12	MIXED YF	10	28.6	0.99	0.1	RPg	MOD. AGGRADED	FLAT	6.9	24.8	171	12	0.22	0.49
30	2	WAUKWAAS	24-Jul-97	12	MIXED YF	30	28.2	1.52	0.4	RPg	MOD. AGGRADED	POOL	7.83	17.3	135	10.4	0.2	0.52
31	2	WAUKWAAS	24-Jul-97	12	MIXED YF	0	39.3	1.24	0.25	RPg	MOD. AGGRADED	RUN	7	26.8	188	8.4	0.5	0.24
32	2	WAUKWAAS	25-Jul-97	12	MIXED YF	50	15	1.6	0.4	RPg	MOD. AGGRADED	RIFFLE	14.1	21.2	299	16.2	0.6	0.2
33	3	WAUKWAAS	13-Jul-97	12.5	DECIDUOUS	30	18	1.3	0.27	RPc	MOD. DEGRADED	RIFFLE	10.9	13.8	150	11.3	0.75	0.27
34	3	WAUKWAAS	14-Jul-97	12	MIXED YF	20	20.4	0.4	0.2	RPc	MOD. DEGRADED	RIFFLE	17	26	442	17.4	0.3	0.18
35	3	WAUKWAAS	14-Jul-97	12	DECIDUOUS	30	18.02	0.5	0.25	RPc	MOD. DEGRADED	FLAT	15.95	32.2	514	16.8	0.46	0.25
36	3	WAUKWAAS	15-Jul-97	12	MIXED YF	20	19.2	1.8	0.25	RPg	MOD. DEGRADED	POOL	11.7	13.7	160	16.7	0.47	0.8
37	3	WAUKWAAS	15-Jul-97	12	MIXED YF	20	18.5	1	0.15	RPg	MOD. DEGRADED	FLAT	14.6	9.5	139	14.6	0.31	0.27
38	3	WAUKWAAS	15-Jul-97	12	MIXED YF	35	18.3	0.75	0.32	RPc	MOD. DEGRADED	RIFFLE	14.9	12.9	192	15.5	0.83	0.17
39	4	WAUKWAAS	12-Jul-97	10	DECIDUOUS	30	11.2	0.8	0.16	RPc	MOD. DEGRADED	FLAT	6.02	17.6	106	8.2	0.3	0.35
40	4	WAUKWAAS	12-Jul-97	10	DECIDUOUS	40	15.5	0.65	0.25	RPc	MOD. DEGRADED	RIFFLE	5.6	7.8	44	6	2	0.2
41	4	WAUKWAAS	12-Jul-97	10	CONIFEROUS	95	11.9	1.2	0.13	RPc	MOD. DEGRADED	POOL	4.3	8.8	38	5.5	0	0.7
42	4	WAUKWAAS	12-Jul-97	10	MIXED YF	90	13.8	1.35	0.45	RPc	MOD. DEGRADED	RIFFLE	6.5	27	176	8.4	0	0.25
43	4	WAUKWAAS	12-Jul-97	10	MIXED YF	95	14.1	0.85	0.3	RPc	MOD. DEGRADED	FLAT	6	17.7	106	6.2	0.49	0.3
44	4	WAUKWAAS	13-Jul-97	11	MIXED YF	60	17.5	1	0.26	RPc	MOD. DEGRADED	POOL	9.1	15	137	14.5	0.27	0.3
45	4	WAUKWAAS	13-Jul-97	11	MIXED YF	70	15.6	0.85	0.3	RPc	MOD. DEGRADED	RIFFLE	6.8	17.7	120	8.2	0.5	0.2

Site data - structures

ID	Site Nos.	Reach	Date	Water Temp	Riparian Species	Canopy Closure	Bankfull Width	Bankfull Depth	D (m)	Channel Morphology	Disturbance Level	Stream Habitat	Wetted Width (x)	Site Length	Area (m2)	Wetted Width	Velocity	Depth Wetted (x)
53	21	W80	8/6/97	15	MIXED YF	75	17.8	0.4	0.3	RPg-w	LOW AGGRADED	FLAT	10.7		22.47	10.7		0.4
54	19	W80	8/6/97	15	MIXED YF	25	26	1.2	0.18	RPc-w	MOD AGGRADED	RIFFLE	6.3	5.5	34.66	7.2		0.28
55	15	W80	8/6/97	15	MIXED YF	20	14.7	1.35	0.35	RPc-w	MOD AGGRADED	FLAT	7.5	21.8	163.5	9.5	0.3	0.24
56	14	W80	8/6/97	15	MIXED YF	10	14.5	1.88	0.24	RPc-w	MOD AGGRADED	FLAT			35.89	7.5		0.6
57	13	W80	8/6/97	15	MIXED YF	100	15.5	0.6	0.17	RPc-w	MOD AGGRADED	FLAT	2.2	8	17.6	2.4		0.17
58	10.11	W80	8/6/97	15	MIXED YF	20	14.9	0.71	0.29	RPg-w	MOD AGGRADED	RIFFLE	8.7	10.8	93.96	10.5	0.42	0.21
59	8	W80	8/6/97	15	MIXED MF	10	16.6	0.95	0.2	RPc-w	MOD AGGRADED	FLAT	9	15.1	135.9	10.6	0.27	0.5
60	6.7	W80	8/6/97	15	MIXED YF	20	15.3	0.74	0.2	RPg-w	MOD AGGRADED	FLAT	6	12	72	7.7	0.18	0.35
61	5	W80	8/7/97	16	DECIDUOUS YF	5	18.4	1.65	0.2	RPg-w	MOD AGGRADED	RUN	6.4	6.7	42.88	6.4		0.35
62	4	W80	8/7/97	16	DECIDUOUS YF	5	17.8	1.9	0.15	RPg-w	MOD AGGRADED	FLAT	8.3	5.8	43.99	8.3		0
63	3	W80	8/7/97	14	DECIDUOUS YF	70	12.5	1.13	0.2	RPc-w	MOD AGGRADED	FLAT	4.37	8.2	35.8	5.5		0.33
64	3	WEST MAIN	8/18/97	17	MIXED YF	25	11.8	1.1	0.3	RPc-w	STABLE	RIFFLE	8.15	5.9	48.08	8.2		0.21
65	2	WEST MAIN	8/18/97	17	MIXED YF	20	13.4	0.8	0.48	RPc-w	STABLE	RIFFLE	9.45	6.7	63.3	10.1		0.24
66	8	WEST MAIN	8/8/97	17	DECIDUOUS YF	50	17.7	1.6	0.35	RPc-w	STABLE	FLAT	8.6	7.6	65.36	9	0.11	0.5
67	9	WEST MAIN	8/8/97	17	MIXED YF	95	18.3	1.2	0.15	RPc-w	STABLE	FLAT	5.6	5.8	32.48	6.1	0.3	0.23
68	11	WEST MAIN	8/8/97	17	MIXED YF	70	15.4	1.34	0.4	RPc-w	STABLE	MIXED YF	10.5	11.1	116.55	11	0.3	0.34
69	12	WEST MAIN	8/8/97	17	MIXED YF	90	14.6	1.4	0.35	RPc-w	STABLE	RUN			34.3	12		0.3
70	19	WEST MAIN	8/11/97	17	MIXED MF	85	15.8	0.74	0.18	RPc-w	STABLE	RIFFLE AND FLAT			44.8	10.3		0.29
71	20	WEST MAIN	8/11/97	17	DECIDUOUS YF	80	16.2	0.7	0.4	RPc-w	STABLE	FLAT	9.4	7.9	74.26	9.4	0.5	0.2
72	23	WEST MAIN	8/11/97	18	MIXED MF	95	15.1	1.2	0.35	RPc-w	STABLE	RUN AND POOL	12	13.4	160.8	14.1	0.7	0.25
73	22	WEST MAIN	8/11/97	18	DECIDUOUS MF	75	15.1	1.25	0.25	RPc-w	STABLE	RUN AND RIFFLE	12	9.3	111.6	14.6	0.12	0.45
74	24	WEST MAIN	8/12/97	17	DECIDUOUS MF	80	14	0.95	0.35	RPc-w	STABLE	FLAT			20.9			0.15
75	25	WEST MAIN	8/12/97	17	MIXED YF	60	15.7	1.5	0.25	RPc-w	STABLE	RUN	10.3	7.8	80.34	12	1.2	0.2
76	28	WEST MAIN	8/11/97	17	MIXED YF	85	17.3	1.1	0.3	RPc-w	STABLE	RIFFLE			35.6	8.6	0.49	0.26
77	30	WEST MAIN	8/12/97	17	MIXED MF	100	17.3	0.95	0.25	RPc-w	STABLE	RIFFLE AND RUN			24.57			0.3
78	32.33	WEST MAIN	8/13/97	18	MIXED MF	70	15.4	1.24	0.35	RPc-w	STABLE	RIFFLE AND RUN	8.7	9.6	83.52	10.4	0.31	0.53
79	34	WEST MAIN	8/13/97	18	MIXED MF	80	15.2	0.8	0.4	RPc-w	STABLE	RUN			27.8			0.5
80	35	WEST MAIN	8/13/97	18	MIXED MF	95	12	1	0.3	RPc-w	STABLE	FLAT			23.8			0.25
81	36.37	WEST MAIN	8/13/97	18	MIXED MF	80	14.2	1	0.35	RPc-w	STABLE	FLAT	11.5	9.7	111.5		0.58	0.2
82	38	WEST MAIN	8/14/97	18	MIXED MF	50	15	1.4	0.35	RPc-w	STABLE	FLAT			73.8		0.28	0.2
83	39	WEST MAIN	8/14/97	18	MIXED MF	60	17	0.95	0.37	RPg-w	STABLE	FLAT	12.5	13.6	170.6	15	0.19	0.25
84	40	WEST MAIN	8/15/97	18	DECIDUOUS YF	65	15.2	0.91	0.36	RPg-w	STABLE	FLAT			73.8		0.19	0.27
85	41	WEST MAIN	8/15/97	18	DECIDUOUS YF	100	16	0.98	0.33	RPc-w	STABLE	RIFFLE	4.6	7.2	33.3	6.7		0.18
86	20	W103-104	8/19/97	17	DECIDUOUS YF	0	8.6	0.76	0.15	RPc-w	STABLE	RIFFLE	4.7	8.1	38.1	4.8	0.4	0.16
87	3	W103-104	8/19/97	17	DECIDUOUS YF	0	8.8	0.87	0.3	RPc-w	STABLE	RUN	5.8	9.4	54.52	6.9		0.12
88	5	W103-104	8/19/97	17	DECIDUOUS YF	2	7.4	0.74	0.15	RPc-w	STABLE	FLAT			19.8	6.5		0.29
89	8	W103-104	8/20/97	19.5	DECIDUOUS YF	5	13	1.25	0.25	RPc-w	STABLE	RUN	6.6	15.5	102.3	7.7	0.2	0.95
90	9	W103-104	8/19/97	19.5	MIXED YF	0	12.5	0.74	0.3	RPc-w	STABLE	RIFFLE	7	8.3	58.1	7.9	0.41	0.24
91	10	W103-104	8/20/97	19.5	DECIDUOUS YF	8	8	0.64	0.42	RPc-w	STABLE	FLAT	9	11.7	106	11	0.11	0.34
92	11.12	W103-104	8/20/97	19	DECIDUOUS YF	20	15.7	1.25	0.15	RPc-w	STABLE	FLAT	10.7	13.4	143.38	11.9	0.17	0.85
93	16	W103-104	8/21/97	19.5	DECIDUOUS YF	20	8.8	0.95	0.28	RPc-w	STABLE	RUN	6.3	6.2	39			0.33
94	18	W103-104	8/21/97	19.5	DECIDUOUS YF	3	10.7	0.5	0.2	RPc-w	STABLE	RIFFLE			25.4	8.2	0.31	0.2
95	20	W103-104	8/21/97	19.5	MIXED YF	70	9.3	0.71	0.1	RPc-w	STABLE	RUN			33.7	7.1		0.31
96	22	W103-104	8/21/97	20	DECIDUOUS YF	0	13.9	1	0.2	RPc-w	STABLE	FLAT			37.3	8.2	0.26	0.2
97	26	W103-104	8/25/97	16	MIXED YF	5	11	1.11	0.33	RPg-w	STABLE	FLAT			22.7	6.6	0.06	0.41
98	28	W103-104	8/25/97	16	MIXED YF	40	10.1	0.72	0.25	RPg-w	STABLE	FLAT			23.4	6	0.1	0.27
99	43	W103-104	8/25/97	16	MIXED YF	15	15.9	1.07	0.32	RPc-w	STABLE	POOL	6.2	10.7	66.34	8.4		
100	51	W103-104	8/26/97	16	DECIDUOUS YF	15	7.5	0.85	0.26	RPc-w	STABLE	RIFFLE	7.3	12.5	91.25	8.5	1.28	0.35
101	53	W103-104	8/26/97	16	DECIDUOUS YF	10	11	0.9	0.4	RPg-w	STABLE	RUN	7.5	10.5	79.3	7.8		0.5
102	5	WOLFE CREEK	8/27/97	17.5	DECIDUOUS YF	10	11.3	0.5	0.32	RPc-w	STABLE	RIFFLE	7.5	12	90	7.8	0.6	0.2
103	6	WOLFE CREEK	8/27/97	17.5	MIXED YF	1	10	0.55	0.4	RPc-w	STABLE	RUN	8.5	9.2	78.66	9.3	0.31	0.35
104	9	WOLFE CREEK	8/27/97	17.5	MIXED YF	10	11	0.58	0.44	RPc-w	STABLE	RUN	9.9	7.6	75.62	10.2	0.43	0.4
105	10	WOLFE CREEK	8/28/97	18	MIXED YF	10	20.8	1	0.4	RPc-w	STABLE	FLAT	8.7	7.5	65.25	8.7	0.18	0.6
106	11	WOLFE CREEK	8/28/97	17.5	MIXED YF	5	11.1	0.6	0.38	RPc-w	STABLE	RIFFLE	8.6	9.9	85.6	9.9	0.55	0.35
107	12	WOLFE CREEK	8/28/97	17.5	MIXED YF	5	12.4	0.7	0.38	RPc-w	STABLE	FLAT AND RUN	8.6	9.4	81.5	10.7		0.5
108	31.31	WOLFE CREEK	8/29/97	17.5	MIXED MF	50	15.8	0.85	0.4	RPc-w	STABLE	FLAT AND POOL	10.4	13.8	143	11.9	0.2	0.55
109	32.33	WOLFE CREEK	8/29/97	17.5	MIXED YF	70	12.4	1.05	0.35	RPc-w	STABLE	RIFFLE AND POOL	8	12.5	100.6	9.1		0.45

Appendix 2.

Methods of Calculating Population Densities by Reach.

The methods used were taken from Elliot 1972, and are based on a stratified sampling methodology with replicates.

1) Initial population estimates were calculated using the mark-recapture methodology for each species and age class at each site.
2) Population estimates were expressed as nos. of fish of each age class and species at each site.
3) Three methods were then used to express population densities.

   i) Population densities by reach described as nos.•100meters^{-2} were calculated by dividing each site population estimate by the area sampled and multiplying by 100. Replicate sites (based on habitat type) were averaged and a simple mean of the resulting four habitat types was calculated to give a reach density.

   ii) Population densities by habitat type, across all reaches described as nos.•100meters^{-2} were calculated by dividing each site population estimate by the area sampled and multiplying by 100. Replicate sites (based on habitat) within reaches were averaged and then a mean of the population across the four sample reaches was calculated for each river.

   and

   iii) Population densities expressed as numbers of each species by age class per 100m bank length were calculated by dividing each site's population estimate by the corresponding site length. Replicate habitat types were then averaged. Each of the four habitat estimates was multiplied by the relative frequency of this habitat and type and the four results were added to give a total for each species and age class in each reach.

Methods of Calculating Biomass

The mean weight of each age class and species was multiplied by the numerical production estimates of fish for each reach based on a 100m bank length.

Mean weight (by reach) for coho, steelhead and Dolly Varden fry was calculated as a mean of the average weight of a sub-sample of fish taken at each site in that reach.

Mean weight (by reach) of steelhead and coho parr was calculated from a regression of the length and weight of parr across both rivers. The mean length for each reach was calculated from all sample data and a weight was determined from this regression equation.

Steelhead parr	Length = 1.87*weight+78.9	$r^2 = 0.78$
Coho parr	Length = 3.32*weight+58.5	$r^2 = 0.66$

Mean weight (by reach) of cutthroat parr and adults and Dolly Varden parr was calculated from a simple mean of all weights of all fish sampled from that reach.

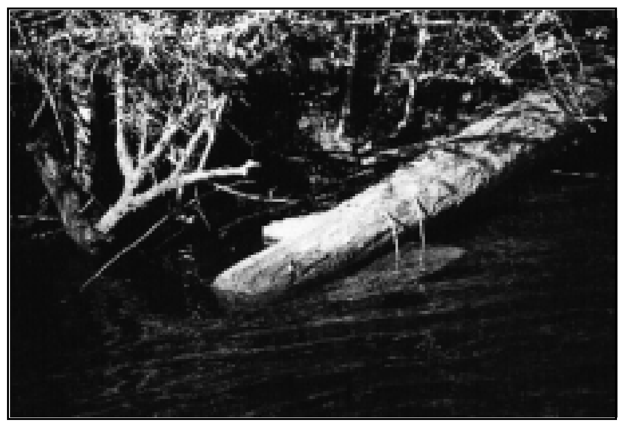
Appendix 3. Examples of structure types.

Example 1. A-Log structure.

Example 2. Boulder cluster.

Example 3. Lateral debris jam.

Example 4. Riffle reconstruction.



Example 5. Single deflector log.

Example 6. Root wad.