Stream Rehabilitation in British Columbia's Watershed Restoration Program: Juvenile Salmonid Response in the Keogh and Waukwaas Rivers 1998

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Watershed Restoration Project Report No. 12
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D.J.F. McCubbing[1] and B.R. Ward[2]

[1]Instream Fisheries Consultants, #2 – 1883 West 3rd Avenue, Vancouver, British Columbia V6J 1K9 e-mail don@instream.net

[2]Ministry of Fisheries, Fisheries Research and Development Section, 2204 Main Mall, University of British Columbia, Vancouver, BC V6T 1Z4

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ABSTRACT

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The effectiveness of stream habitat rehabilitation was evaluated in year two of a five-year program in the treated (logged and rehabilitated) watershed, the Keogh River, compared to the neighbouring and untreated (logged, no rehabilitation) watershed, the Waukwaas River. Anadromous salmonid density and growth were compared in untreated and treated reaches of the Keogh River, which contained a variety of stream habitat structures as well as fertilized and unfertilized sections. Treatments were added annually to previously untreated reaches, starting upstream and working downstream with various placements of structures, and starting downstream and working upstream with addition of slow-release fertilizer, incrementally from 1997 to 1999. Significant increases were found in steelhead parr and fry abundance and coho fry abundance overall at the watershed level and in reaches treated with rehabilitation structures, compared to untreated controls both within and between watersheds, despite low levels of adult escapement. Detailed analyses of structure usage by species indicated variation from year to year; climatic factors (stream discharge) may have influenced annual variations in species and age-class distributions. A diversity of structural types appears to provide an optimum strategy for habitat rehabilitation, rather than singular types. Analysis of salmonid growth in-stream, continued to indicate that significantly larger salmonids were found in fertilized sections. Results indicate that habitat rehabilitation for juvenile salmonids in streams may partly counteract recent dramatic and persistent declines in survival observed in freshwater and marine life stages.

ACKNOWLEDGEMENTS

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INTRODUCTION

This is the second report of a five-year study for British Columbia's Watershed Restoration Program (WRP) on the effectiveness of watershed rehabilitation techniques on salmonid density, growth, survival, and smolt yield at the Keogh River, B.C. The primary objective of this study is to determine the effects of habitat restoration including stream fertilization with inorganic nutrients on steelhead trout (*Oncorhynchus mykiss*) and coho salmon (*O. kisutch*) using a study design that assists by accounting for the impacts of natural environmental variations on fish populations during the study period. Further details of the project's aims and objectives, and results of the first year of investigation were reported in McCubbing and Ward (1997). Here we report the results of investigations in 1998.

The study will assess the effectiveness of WRP stream habitat rehabilitation techniques through in-stream sampling (electrofishing) in representative treated and untreated sections, and through comparison of results with population dynamics data gathered from 24 years of salmonid juvenile abundance in-stream, smolt enumeration, and adult steelhead run size estimates, recently summarized in Ward (2000) and Ward and McCubbing (1998). In-river treatments, i.e., stream habitat structures and slow-release fertilizer application, to the Keogh watershed will incrementally escalate over the five-year period, along with some hillslope stabilization, road deactivation and side channel construction. Juvenile salmonid density, growth, smolt yield and adult escapement data will be collated and analysed for change, in a staircase-type experiment (Walters et al. 1988). To strengthen the analysis, a neighbouring watershed will also be monitored, but will not undergo any WRP stream rehabilitation treatments during the course of the experiment. Data on the escapement enumeration of pink (*O. gorbuscha*) and coho salmon in the Keogh River (McCubbing and Ward 1998; McCubbing et al. 2000 in press) will be added to the adult steelhead data, to further assist the evaluation of the effectiveness of WRP techniques and to calibrate coho and steelhead smolt yield to adult escapement (i.e., smolts per spawner as a function of spawners pre- and post-treatment).

METHODS

Study Area

The Keogh and Waukwaas Rivers, two fourth-order streams, are situated at the northern end of Vancouver Island, B.C., in the coastal western hemlock biogeoclimatic zone. The logging histories of both watersheds are similar; the Keogh logging history has been described by Potyrala (1997), who reported that approx. 53% of the basin had been logged since 1940, including 55% of the floodplain and up to 70% of the sub-basins. Past forest practices harvested 23 km of the mainstem riparian zone, and 26 km along the riparian zones of its tributaries. Further description of location and reaches was reported in McCubbing and Ward (1997).

In 1997, 121 WRP structures (i.e., treated habitat sites) were placed in the Keogh River (Potyrala 1999a) over 5.4 km, and nutrient addition included the lowermost 19 km of the Keogh River mainstem and approximately 10 km of tributary stream length to compensate for depressed salmon escapements. In 1998, an additional 67 WRP structures were placed (Potyrala 1999b) for a total treated length of 6.8 km. Inorganic nutrients, as a once annual application of slow-release briquettes (application rates on file) were added over a total length of 27.5 km of the Keogh River mainstem, from the river mouth to Muir Lake (Fig. 1), as well as fertilizer addition to 11 km of key tributaries entering the mainstem from Muir Lake to the river mouth (Potyrala 1999b).

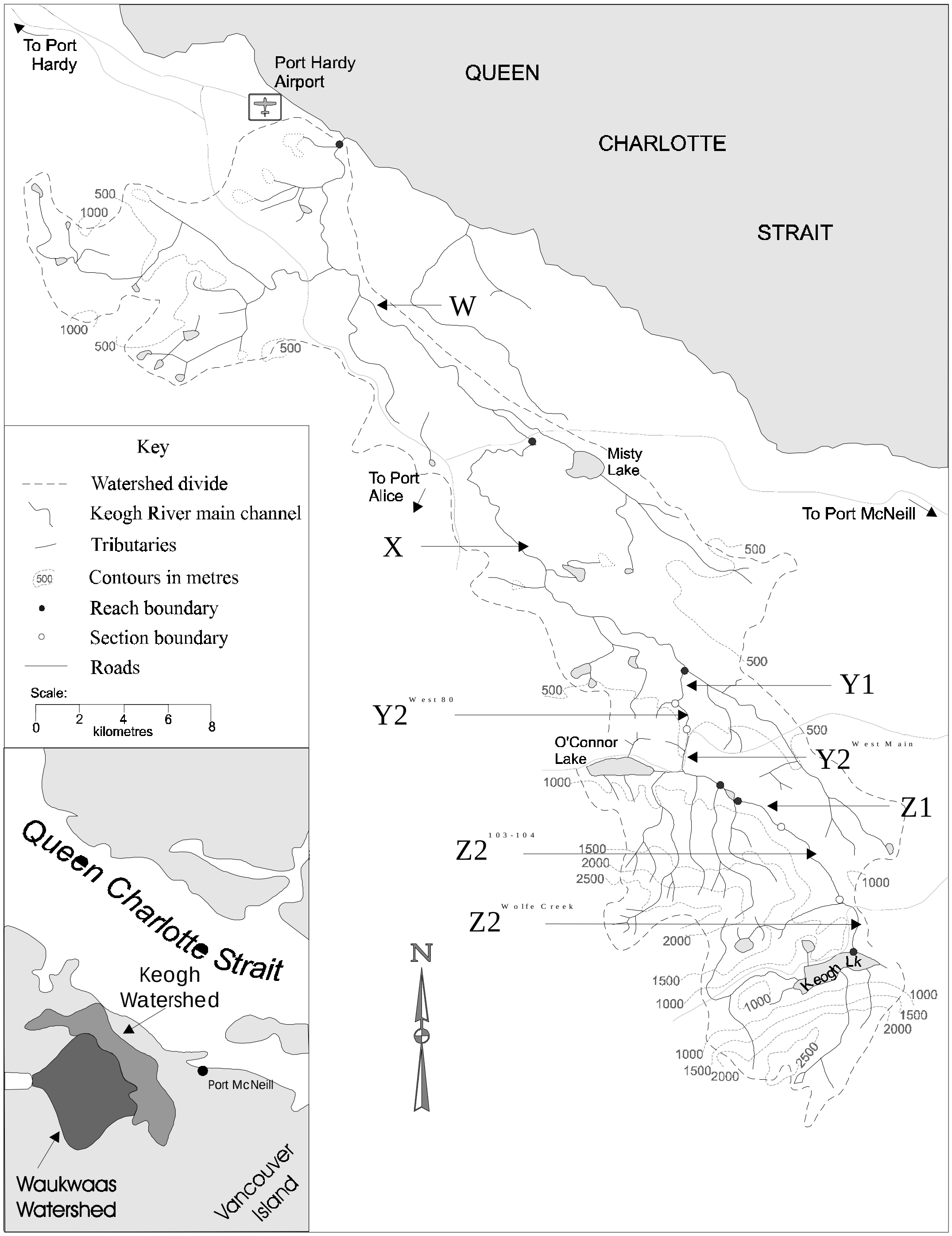

Figure 1. The Keogh River watershed, indicating reach boundaries and section boundaries used in this study, elevations, the watershed divide, and the location on the B.C. coast (inset), as well as the relative position of the neighbouring Waukwaas River, B.C.

Experimental Design

As described in McCubbing and Ward (1997) the experimental design considers two treatment types, habitat structures and slow-release fertilization. The p1an of restoration within the Keogh watershed has been adapted to the experimental design (Table 1). The timing of treatment within specific reaches has been altered slightly from the original experimental design, although the overall result and analyses will be as intended, where density of salmonid juveniles in the stream and growth will be analyzed by staircase ANOVA, while smolt yield comparisons will require trend analysis.

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. See Figure 1 for definition of reaches; t= treated, u=untreated, blank = no treatment, f = fertilized, s = structures, and fs = fertilized and structures.

Unit	1994-96	1997	1998	1999	2000	Reach
1		s	s	fs	fs	Z2
2		s	fs	fs	fs	Y2
3		f	f	fs	fs	X
4		f	f	f	fs	W
5			f	f	f	Y1
6				f	f	Z1
7						Waukwaas

Structure placement and habitat restoration was undertaken on significant areas of sections of reaches Y and Z by the summer of 1998 (Fig. 1). Reach X was partially treated in 1998, although treated areas were not sampled since construction of habitat structures was undertaken during the survey period.

Fertilizer was applied to reaches Y, X and W in 1998 by placing slow release briquettes in riffle areas during mid-May (IMC Vigoro, Winter Haven, Florida; described in Ashley and Slaney 1997). The target concentration was $5\mu g \bullet L^{-1}$ soluble reactive phosphate. Water samples were taken in fertilized reaches, but results of analysis were not available. Periphyton accrual was monitored as described in Ashley and Slaney (1997), and these samples have likewise been preserved for later analysis.

To evaluate the effectiveness of watershed rehabilitation techniques towards salmonid benefits, two primary methods are utilized. First, salmonid juvenile density in freshwater is assessed by mark-recapture electroshocking techniques (McCubbing and Ward 1997). In addition, representative structures are sampled (electroshocked and minnow trapped) for salmonid use in winter conditions.

Site Selection

Prior to site selection in 1997, every reach on both watersheds was surveyed visually for frequency distribution of habitat types. The same frequencies were apparent for development of the sampling scheme in 1998 with the exception that on the rehabilitated sub-reaches Zt and Yt of the Keogh River; habitat restoration had altered the frequency of habitat types, thus the sampling was changed to match. Representative sub-reaches (250 m) within main reaches of the river, one within each sub reach, were assessed for habitat frequency by the methods described in Potyrala (1997) and McCubbing and Ward (1998). The habitat sub-classes, pool, flat, riffle and run, were summed to give total lengths of each type for all treated sub-reaches. The relative frequency of habitat types was calculated from the total length of habitat in each sub-class and the total length of each reach (Table 2).

Table 2. Relative frequency (expressed as m of bank length per 100m) of habitat types within reaches of the Keogh and Waukwaas Rivers, 1998.

River Reach	Flat	Pool	Riffle	Run
Keogh				
W	25	41	13	21
X	25	10	49	16
Y1	23	22	31	23
Y2 West Main	14	16	38	32
Y2 West 80	28	27	21	23
Z1	24	11	50	15
Z2 West 103/104	44	16	20	20
Z2 Wolfe Creek	36	20	29	15
Waukwaas				
1	35	32	23	10
2	40	18	32	10
3	38	11	51	0
4	20	26	54	0

Sampling within each reach (totalling 100 meters) was undertaken in the proportion 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 was flat, thus as close to 35m of flat was sampled as practicable). This method of stratified sampling decreased variance in the population distribution of species within the sample reaches (Elliot 1972; Hankin and Reeves 1988). Where possible, replicates of habitat types were sampled (Table 3), and the mean of these replicates was used in calculating density estimates within reaches for each habitat type.

Table 3. Numbers of replicate sample sites of stream habitat within reaches of the Keogh and Waukwaas Rivers, 1998.

River Reach	Flat	Pool	Riffle	Run
Keogh				
W	3	2	2	2
X	1	1	2	1
Y1	2	1	1	1
Y2 West Main	2	3	2	2
Y2 West 80	2	2	1	2
Z1	2	1	2	2
Z2 West 103/104	2	2	1	1
Z2 Wolfe	4	1	3	3
Waukwaas				
1	1	1	2	2
2	1	1	2	1
3	2	1	3	0
4	2	2	3	0

Thirty-four of the introduced habitat structures (18%) were sampled in 1998 (Table 4). These structures were sub-sampled according to structure type and location, and were selected for their visual representation of the treatment structures installed. They also represented the most commonly introduced structure type in that section, or were sampled again in 1998 for comparison with results in 1997. Structures installed in 1998, and those which had undergone significant alterations to design between sample years, were avoided.

Table 4. Number of habitat structures that were sampled in 1998 within experimental reaches of the Keogh River. Refer to Fig. 1 for locations. Numbers in brackets are composition of combination structures.

Structure Type	Code	W80 Y2	Reach West Main Y2	W103-104 Z2	Wolfe Creek Z2
Boulder cluster	BC	3		1	2
Debris jam	DJ		4	1	2
Double deflector log	DDL	1(+1)			(1)
Plunge pool log	PP			1	
Riffle reconstruction	RR				3
Single deflector log	SDL	2	2	1	
Root wad	RW	1(+1)			1 (+1)
A-logs	AL		1	1	2
Double floating log	DFL			1	

Data on fish distribution and density were also collected on a representative sample of the established (pre-1997) structures at four locations (covering two reaches). In particular, structures which were sampled in 1997, and which remained unaltered in 1998, were re-sampled in 1998. Where possible, structures were sampled individually but such that sufficient river area near the structure was included, to enumerate fish that may have been using the structure as a refuge, but were outside of the structure and actively foraging during the day.

Data collection

Data collection was as described in McCubbing and Ward (1997), with the exception of data for growth, which was collected in the autumn through the use of minnow traps compared to sample collection by electroshocking during both summer and fall in 1997. Flows during autumn 1998 precluded effective electrofishing, due to frequent and intense storm events (Environment Canada Port Hardy Weather Office, data on file, UBC).

Population estimates

Population estimates were calculated using the mark-recapture equation (Riley and Fausch 1995):

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

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

Coho and steelhead juveniles were split into age classes of fry (0+) and parr (>0+) based on length frequency distributions. For example, steelhead >80mm were estimated to be parr, based on the length-frequency histogram. Similarly, coho juveniles >70mm were classed as parr rather than fry, although more overlap of size classes was evident than with steelhead. Scale samples will be analysed to confirm these estimates of age designation.

Growth of juvenile steelhead and coho was examined among the treated reaches of the Keogh River (W, X and Y), the upper Keogh River untreated reach (Z1) and between the Keogh and the untreated watershed (Waukwaas River (reaches 1 to 4), in a “Before-After Control-Impact” analysis (Stewart-Oaten et al. 1986).

Growth 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. Steelhead fry capture was too low during the autumn period for analysis.. The reach mean was calculated by the method described by Hurlbert (1984) and Stewart-Oaten et al. (1986), as in both summer and autumn sampling each site represented a subsample of the reach population. Age class breaks were again determined by length frequency methods.

Statistical analysis of the length of coho fry by autumn used analysis of variance (ANOVA). Three population groupings were used, Keogh fertilized (reach X, W and Y), Waukwaas unfertilized (reach 1 and 4) and Keogh unfertilized (Z1).

No steelhead parr were tagged with passive integrated transponder (PIT) tags in 1998 due to continued concerns over steelhead stock status on the east coast of Vancouver Island. In addition, there were low recapture rates of tagged fish during the 1998 smolt-sampling season. PIT-tagging of steelhead has been deferred until tag recoveries are assessed from the 1999 smolt enumeration.

RESULTS

Fish abundance within stream reaches

Estimates of salmonid abundance from the Keogh and Waukwaas Rivers were collated in three ways, as in McCubbing and Ward (1998):

- as numbers•$100m^{-1}$ of representative bank length by reach (adjusted for replicate habitat sites and relative habitat frequency; Table 4),
- as population densities•$100m^{-2}$ of habitat type (adjusted for replicate habitat sites but ignoring reach,; Table 5), and
- as densities•$100m^{-2}$ of reach (adjusted for replicate habitat sites but not for relative habitat frequency).

Fish were not distributed equally between rivers. For example, steelhead fry per m were in greatest densities in the lower reaches of the Keogh, yet they numerically dominated the middle reaches of the Waukwaas River (Table 5.). Coho fry densities were greatest in the upper reaches of both the Waukwaas and the Keogh Rivers in 1998, and within structure-treated sections of the Keogh watershed.

Table 5. Density (no.•$100m^{-1}$) of steelhead and coho in the summer of 1998 (1997 in brackets) within reaches (adjusted for replicate site data and stratified habitat frequency) of the Keogh and Waukwaas Rivers.

River Reach	Steelhead fry	Steelhead parr	Coho fry	Coho parr
Keogh				
W	287 (180)	24 (15)	209 (255)	14 (10)
X	136 (93)	46 (21)	183 (436)	11 (5)
Y1	37 (37)	9 (21)	201 (291)	7 (22)
Y2 West Main	202	36	197	30
Y2 W80	102	64	312	18
Z1	6 (0)	10 (14)	127 (425)	9 (9)
Z2 W103/104	6	6	364	18
Z2 Wolfe Creek	21	40	901	27
Waukwaas				
1	7 (86)	60 (70)	25 (27)	8 (0)
2	442 (488)	27 (36)	103 (311)	6 (69)
3	339 (411)	41 (136)	171 (398)	9 (16)
4	109 (240)	41 (22)	187 (99)	21 (12)

Variation in steelhead fry abundance was apparent for comparable reaches in both watersheds from year to year (Fig. 2.). Positive increases in steelhead fry abundance were observed throughout the Keogh River. Reach W (fertlized only) and reach Yt (fertilized and habitat structures installed) displayed the greatest increases in fry abundance. In comparison, all reaches sampled in the Waukwaas River were lower in fry abundance than that observed in 1997, although actual densities remained comparable or higher than those in the Keogh River (Table 5).

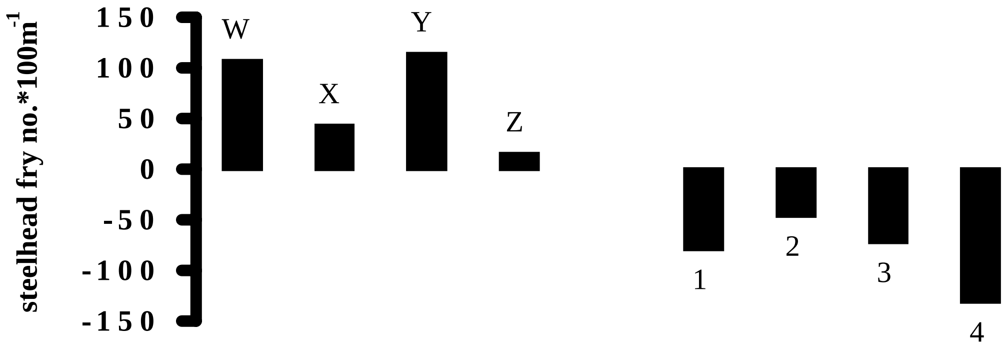

Figure 2. Relative change (Δ) in steelhead fry number (no.•100m^{-1}) from 1997 to 1998 on the Keogh (reaches W to Z) and Waukwaas (reaches 1 to 4) Rivers.

Relative steelhead parr abundance (no.•100m^{-1}) was also higher in 1998 than in 1997 by an average increase of 20 parr per 100m within reaches of the Keogh River (Fig. 3), a mean increase of 110%. In contrast, three of the four sample reaches on the Waukwaas River showed reductions in parr abundance (a mean of 30% reduction for all reaches), to levels which were not significantly different than those in the Keogh River; densities in reach 4 increased, but only to levels that were similar to Keogh River densities in treated areas.

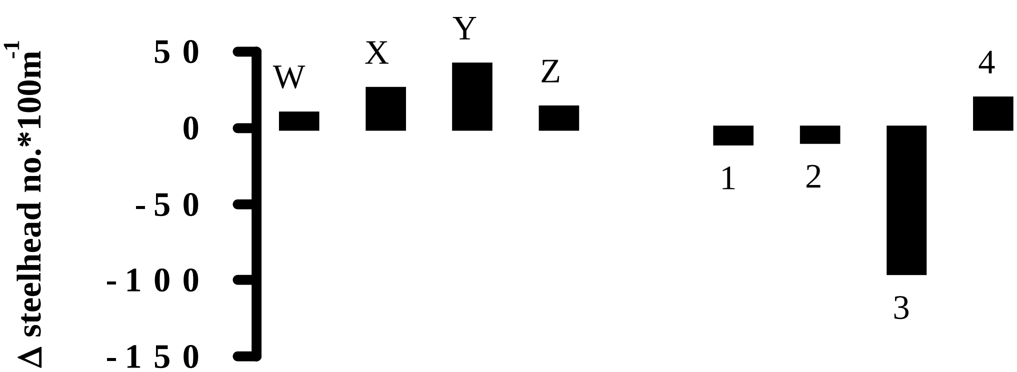

Figure 3. Relative change (Δ) in steelhead parr abundance (no.•100 m^{-1}) from 1997 to 1998 on the Keogh (reaches W to Z) and Waukwaas (reaches 1 to 4) Rivers.

Coho fry densities were lower in both watersheds compared to 1997 data, except in the upper-most reaches of both watersheds (Fig. 4).

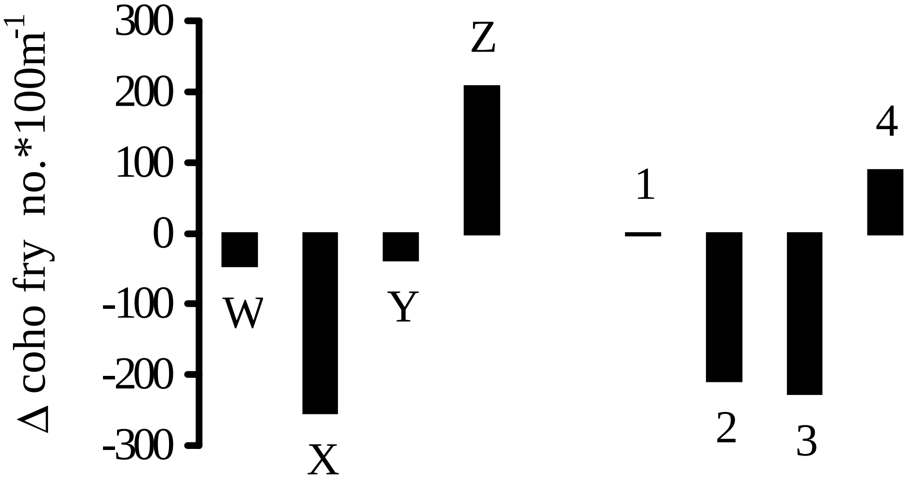

Figure 4. Relative change (Δ) in coho fry abundance (no.•100 m^{-1}) from 1997 to 1998 on the Keogh (reaches W to Z) and Waukwaas (reaches 1 to 4) Rivers.

No statistical differences were found between treated and untreated reaches or between the Keogh River and Waukwaas Rivers in numbers of steelhead parr or coho fry in 1998. Significant differences were found in coho fry abundance (no.•100m^{-1}) between the two sample years (1998 lower than 1997) in the Keogh River ($p<0.05$), but not on the Waukwaas River. No other significant differences were found in analysis of data between years.

Fish utilization of habitat structures

Favoured habitat types for each species and age class were examined (Table 6). Variation in the preferred habitat of steelhead parr was observed in both watersheds and in both years. In 1998, steelhead parr were found in greatest densities in pool habitat in both watersheds; in 1997, greatest densities were in riffles on the Waukwaas River, and riffle and run habitat of the Keogh River (Fig. 5). Coho fry distribution within habitat types was similar for both years on the Waukwaas River, but were more abundant in pool habitat on the Keogh River in 1998, whereas they were more abundant in flat habitat in 1997.

Table 6. Density (no.•100m^{-2}) of steelhead and coho juveniles in 1998 within habitat types of the Keogh and Waukwaas Rivers. Values are the means of replicate sites, where available.

River Habitat Types	Steelhead fry	Steelhead parr	Coho fry	Coho parr
Keogh				
Flat	7.1	3.2	34.3	2.9
Pool	7.8	6.7	39.3	2.6
Riffle	20.5	2.2	16.5	1.7
Run	12.0	2.2	37.9	2.5
Waukwaas				
Flat	21.0	3.6	19.6	2.1
Pool	31.7	6.8	9.4	1.6
Riffle	18.6	4.4	16.0	1.4
Run	20.5	3.5	4.6	0.3

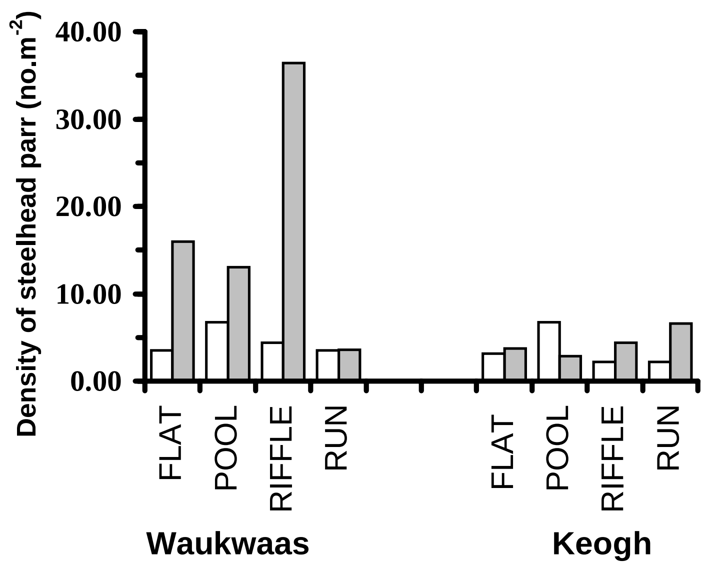

Figure 5. Density (no.•m^{-2}) of steelhead parr in the Keogh and Waukwaas Rivers during 1997 (grey bars) and 1998 (open bars) within stream habitat types.

Overall, steelhead parr and coho fry densities (no.•m^{-2}) were not significantly different between 1997 and 1998 in the Keogh River. However, steelhead fry densities were statistically higher in 1997 (Fig. 6; $p<0.05$).

Figure 6. Mean densities (no.•100m^{-2}) of steelhead fry (SHF), steelhead parr (SHP) and coho fry (COF) in representative structure sites on the Keogh River in 1997 (grey bars) and 1998 (open bars).

Mean density of fish (no.•100m^{-2}) for all sites sampled and for each structure type were compared, including coho fry (Fig. 7), steelhead parr (Fig. 8), and both in comparison to 1997. Range in mean density was broad within structure types (coho fry, 16 to 122 fry•100m^{-2}; steelhead parr, 1 to 14 parr•100m^{-2}). This was in agreement with the overall range in values observed in 1997, although fish response within structure type was markedly different. For example, the greatest steelhead parr density in 1998 was recorded in Root Wad complexes (RW), versus A-Log structures (AL) in 1997.

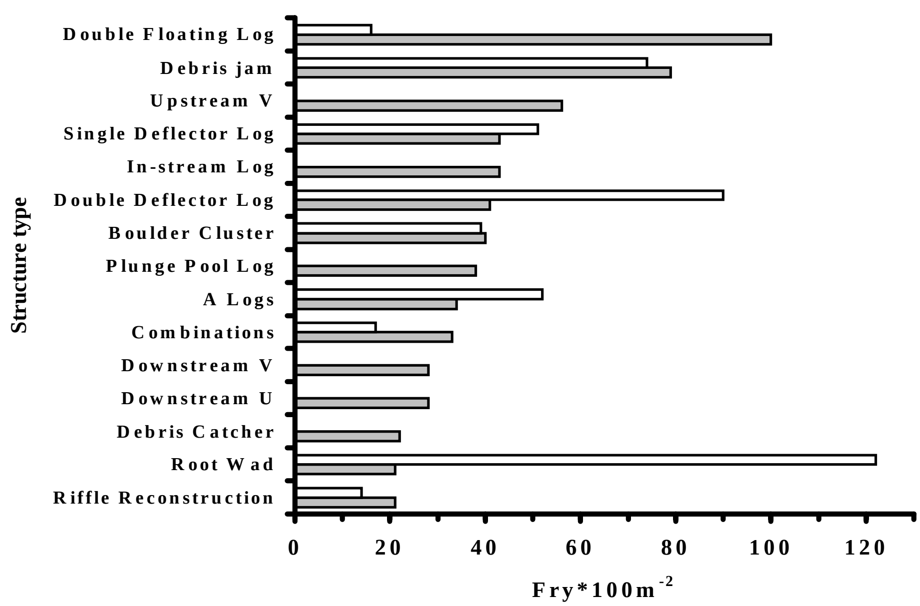

Figure 7. Mean densities of coho fry (no.•100m^{-2}) in habitat structures in the Keogh River during 1997 (grey bars) and 1998 (open bars).

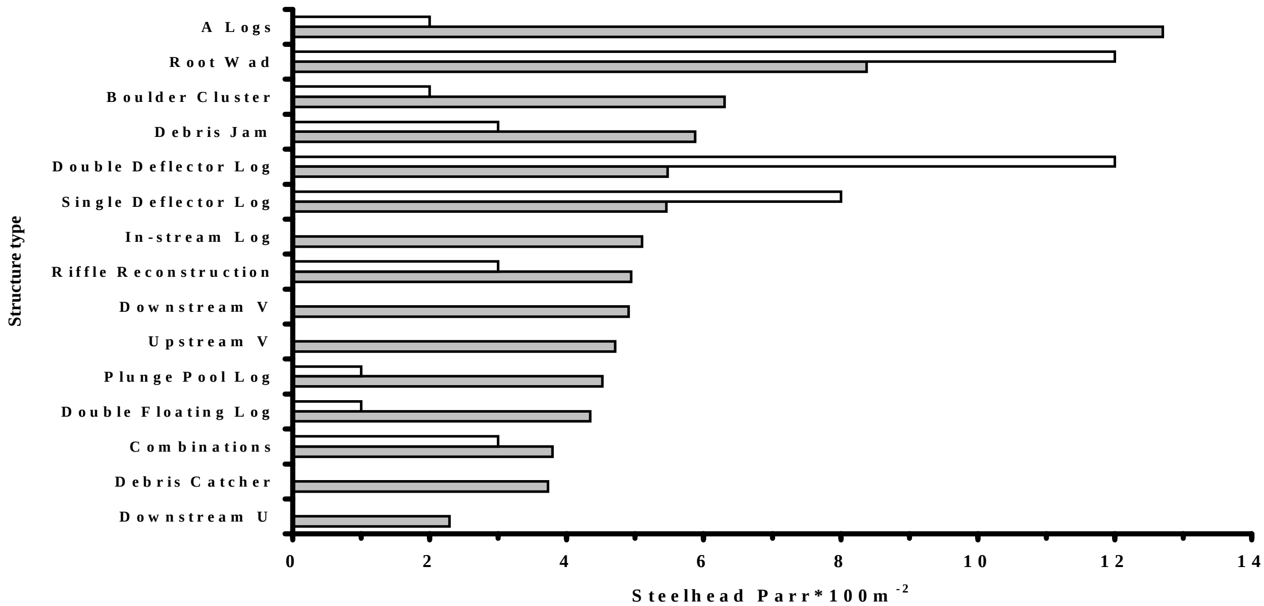

Figure 8. Mean densities of steelhead parr (no.•100m^{-2}) in habitat structures in the Keogh River during 1997 (grey bars) and 1998 (open bars).

Debris jams (DJ, n=6), boulder clusters (BC, n=6), single log deflectors (SDL, n =5), riffle reconstructions (RR, n=3), and A-logs (n=4) were not significantly different (ANOVA) in abundance of either species in these five structure types, possibly due to high variance and low sample size (e.g., Fig. 9).

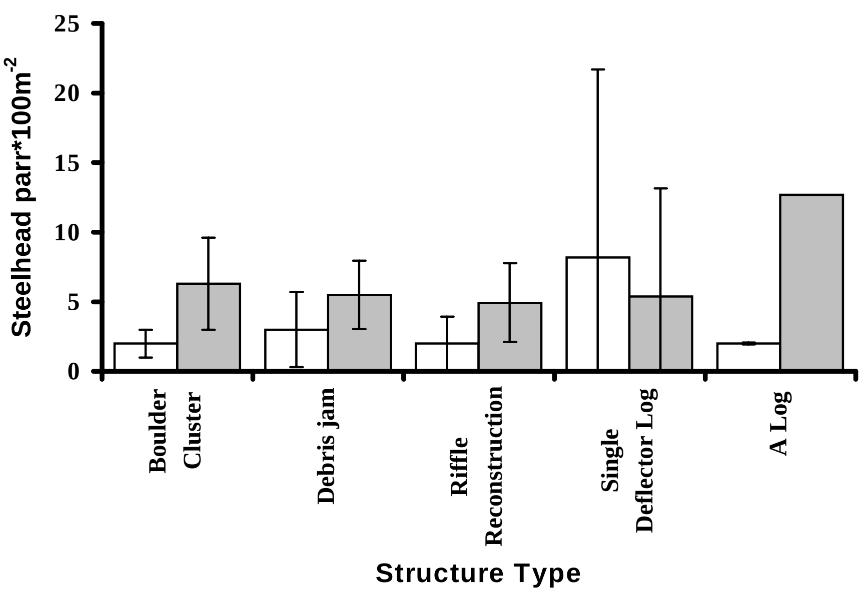

Figure 9. Mean density of steelhead parr (no.•100m^{-2}) within five of the most common stream habitat structures in the Keogh River during 1997 (grey bars) and 1998 (open bars).

The relation between the amount of large woody debris in a structure, expressed as a percentage of surface area, (both as instream, overstream, and combined amount) and salmonid abundance was examined by least squares regression. No significant relationship was found for either steelhead parr or coho fry.

Smolt yield

As reported in Ward and McCubbing (1998), smolt yield from the two watersheds has been assessed for four years, including two years pre-treatment and two years partial post-treatment of the Keogh River. Coho smolt numbers rose steadily for both watersheds through the first three years of investigation, but fell sharply in the Keogh River in 1998. In the Waukwaas River, a dramatic increase in coho smolt yield occurred in 1998. Steelhead smolt numbers have remained low over the four-year study period at the Keogh River and were significantly lower than previous years (Ward 1999), yet have increased steadily in the Waukwaas River in 1997 and 1998 (Fig.10).

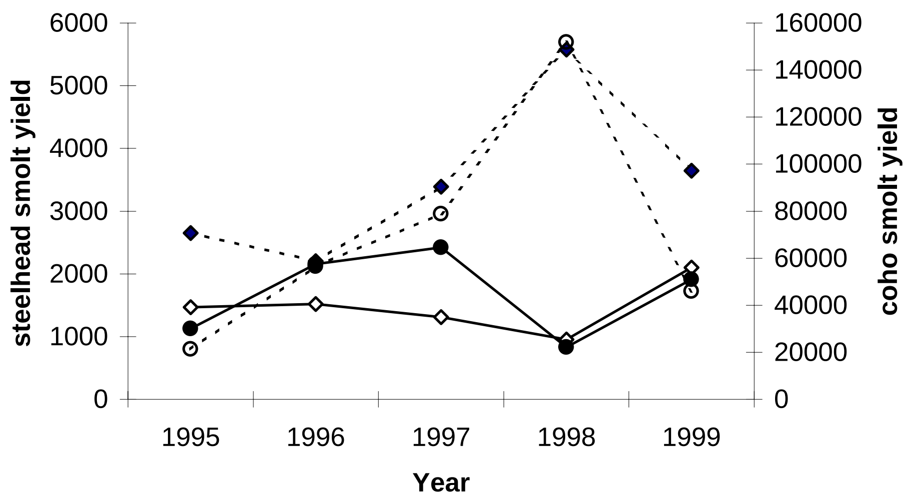

Figure 10. Steelhead (open markers) and coho (black markers) smolt yield from the Keogh (solid line) and Waukwaas (dashed line) watersheds from 1995 to 1998.

Effect of fertilizer addition on fish growth

Coho fry were not significantly different in length or weight ($p>0.05$) in reaches of the Keogh and Waukwaas Rivers in the summer sampling period. Differences were apparent in reaches, which were sampled later in the summer than others (reach 1 and Z2, Table 7). By late autumn, this pattern had changed; coho fry in the lower reaches of the Keogh (fertilized) exhibited weights nearly 100% greater and lengths 20% greater than the unfertilized upper reaches of the Keogh River (Z2; $p<0.05$, ANOVA). Growth differences in the middle reaches (reach Y2) of the Keogh river were less pronounced (i.e., ns), and less than in the unfertilized Waukwaas River.

Table 7. Mean length and weight of coho salmon fry in treated and untreated sections of the Keogh River and within the untreated Waukwaas River during 1998. f=fertilizer added, ND = No data.

River Reach	Coho fry Summer weight (g)	Coho fry Summer length (mm)	Coho fry Autumn weight (g)	Coho fry Autumn length (mm)
Keogh				
W (f)	3.62	62.00	8.81	90.63
X (f)	3.10	58.90		
Y1(f)	3.00	57.70		
Y2 (f)	3.58	63.64	4.89	75.25
Z1	3.17	61.70		
Z2	3.89	62.83	4.47	71.11
Waukwaas				
1	4.26	63.70	8.30	88.52
2	3.67	64.30		
3	3.00	60.50		
4	ND	70.50	6.44	80.45

Utilization of habitat structures during late autumn

Habitat use by salmonids during the autumn (Nov.) was investigated. Fish were trapped in representative habitat types of the Keogh River, with and without habitat structures. Coho fry were most abundant in pool and complex large woody debris (LWD) habitat whilst steelhead fry were associated with run and flat habitat, regardless of LWD presence. Steelhead and coho parr were found in low numbers in pool habitat and some flats, particularly when LWD was present (Table 8).

Table 8. Catch of steelhead and coho juveniles in minnow traps during fall within treated and untreated stream habitats of the Keogh River during 1998. SHF=steelhead fry, SHP=steelhead parr, COF=coho fry. CPUE = catch per unit effort. nat = natural structure.

Date	No. of Traps	Reach	Habitat	Structure	CPUE SHF	CPUE SHP	CPUE COF
9th Nov	2	Z2	Pool	DJ	0	0	0.5
	2	Z2	Flat	SDL	0	0	1
11th Nov	2	Y2	Riffle	None	1.5	0	0
	3	Y2	Pool	DJ	3.5	>1	8
	2	Y2	Run	BC	0.5	0	0
	3	Y2	Flat	SDL	3	>1	>1
10th Nov	4	W	Flat	None	2	0	0.5
	6	W	Pool	DJ (nat)	1.5	0.5	1.2

DISCUSSION

Statistically significant differences in salmonid densities and distribution were limited both among reaches within a watershed and between watersheds. Differences, where apparent, may have been the result of a combination of factors, including: habitat availability, adult escapement, juvenile mortality, and reach location within the watershed, along with environmental conditions in the year of sampling (e.g., drought, low flows, winter floods, etc.).

Steelhead fry abundance in the Keogh River has been limited by low adult escapement in recent years, which in turn is related to recent poor rates of survival from smolt to adult (<4%; Ward 2000). A statistically significant increase in steelhead fry was apparent between 1997 and 1998 (10-fold), within all structure sites sampled, despite the lowest adult escapement estimate on record (Ward and McCubbing 1998). Increased fry densities may have been a response to treatment in treated sub-reaches Y2 (West Main) and Y2 (W80). Reaches treated with structures (and fertilization, reach Y2 only) were different in their numeric response by fish to untreated controls in these locations (e.g., 152 steelhead fry per•$100m^{-1}$ in the treated areas (Y2) of Reach Y versus 37 fry per•$100m^{-1}$ in the control section (Y1). Similar, although less pronounced, differences were found in reach Z, where treated areas (Z2) had a mean of 13.5 fry per•$100m^{-1}$ versus 6 fry per•$100m^{-1}$ in untreated areas (Z1). The effect of treatment on steelhead fry in reach Z may have been less pronounced because of the lack of river fertilization in this area or as a result of poor spawning in this reach. In the Waukwaas River, steelhead fry abundance was greatest in the middle reaches. Steelhead fry in this river were caught at lower levels on all reaches in 1998, but densities were similar to or higher than those in the treated sections of the Keogh watershed.

Densities of steelhead parr were slightly higher in 1998 on the Keogh River (mean of 22.5 parr•$100m^{-1}$), compared to 1997 data (mean of 17 parr•$100m^{-1}$). In 1998, steelhead parr were in greatest abundance on the Keogh River in the reaches treated with structures, or structures plus fertilization (Z2 Wolfe Creek, Y2 West Main, and Y2 W80; 40 to 64 parr•$100m^{-1}$) when compared to control (fertilized-only) reaches in the same river locations, (Z1 and Y1, 9 to10 parr•$100m^{-1}$). These densities from treated reaches in the Keogh River were similar to steelhead parr densities throughout the untreated Waukwaas River (27 to 60 parr•$100m^{-1}$), and in the lower Keogh River (reach X and W; 24 to 46 parr•$100m^{-1}$), where steelhead fry and parr production in 1997 was much greater (McCubbing and Ward 1997). The improvements may be due to increased over-winter survival of fry and yearling parr in treated reaches rather than relocation of fish to improved habitat, because densities in untreated areas remained similar to those sampled in 1997.

Coho fry abundance was numerically lower than in 1997, although not statistically significant. None of the 8 reaches had increased coho fry abundance in 1998, with densities within reaches reduced by 14% to 76% from 1997 levels. Such reductions may reflect poor adult escapement to both rivers and/or unfavourable winter survival of eggs to fry on both watersheds. Reaches treated with structures on the Keogh River produced significantly more coho fry than untreated reaches in the Keogh or Waukwaas Rivers. This result is probably due to improved overwinter survival of ova or early fry in areas treated with structures, and indicates potential benefits of habitat rehabilitation techniques even at reduced spawning escapements; i.e., greater stock productivity. Poor survival during oceanic life stages of coho has reduced adult escapement and subsequent fry production in British Columbia throughout the 1990s (Beamish et al. 2000 in press) though recent re-structuring of the commercial fishery reversed this trend for adult escapement in the Keogh River in 1998, (McCubbing et al. 2000 in press).

Results from investigations in 1998 of structure use on the Keogh River differed from those in 1997 and previous studies (Ward and Slaney 1979, 1981; Ward 1996). Habitats containing boulder clusters and riffle re-constructions, generally preferred by steelhead parr, were surpassed in steelhead abundance by single deflector logs and root wad complexes in 1998. The reason for this shift in preferred habitat may have been a transient one, perhaps as a result of low flow conditions during summer 1998. Steelhead parr and, to a lesser extent, coho fry were found to have been more abundant in pool habitat in 1998, probably as a reaction to the severe low flows that prevailed for most of the summer. Boulder clusters were constructed in run and riffle areas and riffle reconstructions were comprised of shallow and fast water, therefore, fish may have avoided these structure types during the summer drought flows of 1998, and sought refuge in deeper water where cooler temperatures from groundwater inflow and increased protection from predators were possibly available. Thus, fish moved from one preferred habitat under one set of flow conditions to a different habitat type under a second set of flow conditions. The increased availability of pool habitat that is evident in reaches Z2 and Y2, compared to Z1 and Y1, may have enhanced parr survival. Such observations suggest the need for placement of a diversity of habitat structures, and the usefulness of both natural and introduced structures in creating a diversity of river habitat. It also highlights the risks of assessing structure performance over the short term without investigating the effects of flow, adult escapement, habitat change, and overwinter survival, over the longer term.

Smolt yield in the two watersheds was similar for coho and steelhead in the first two years of study, but has shown differences in subsequent years. Coho smolt numbers increased in both watersheds in 1997, but fell abruptly in the Keogh River in 1998, whilst increasing in the Waukwaas River three-fold. Subsequent data shows a recovery in coho smolt production in the Keogh River in 1999, whilst coho smolt output from the Waukwaas River in 1999 fell to more typical levels.

Reasons for these yields are unclear, as juvenile coho fry densities in the Keogh River in the summer of 1997 (McCubbing and Ward 1998), exceeded those in the Waukwaas River. Predictions might have expected the Keogh River to have produced the larger yield of smolts. However low water conditions throughout the normal smolt migration period occurred in the Keogh River in 1998, (data on file) which may have resulted in increased residualization and predation pressures (Sawada 1993). In contrast, snow melt water on the Waukwaas River produced daily freshets during the smolt migration (data on file), giving excellent conditions for smolt migration. In addition because coho adults spawn in the upper river and tributaries of both river systems, full benefits of restoration works on smolt yield will not be realized until upper sections are fully treated, and will be less obvious for coho than steelhead, particularly for fertilization effects, which will not be fully applied in the upper Keogh watershed until 1999. Juvenile coho densities in the two rivers were lower in the summer of 1998. This resulted in a dramatic decline in smolt yield in the Waukwaas in the spring of 1999 as expected (despite good flow conditions), whilst the reduced fry densities in the Keogh River produced a dramatically increased smolt yield in the spring of 1999 under more normal flow regimes. This further indicates a bottleneck occurred in the smolt migration on the Keogh River in 1998.

Steelhead smolt yield fell slightly in the Keogh River in 1997 and 1998, before recovering to higher levels in 1999. This coincides with further reductions in adult escapement (Ward 2000). The full effects of restoration efforts on steelhead will not be realized until 2001, due to the age of smolts and amount of restoration through the watershed. Steelhead smolt yield in the Waukwass River rose in 1997 and 1998 before falling significantly in 1999. Reasons for these variations in smolt yield are complex and cannot be readily determined, but may have been related to varied brood-year strength, lower in-stream losses due to improved environmental conditions (unlikely, as climate should equally affect the Keogh watershed), or sampling error in smolt yield (low efficiency of recapture in Rotary screw traps used for smolt estimation was observed in 1998, resulting in unknown confidence limits on the yield estimate; Ward and McCubbing 1999).

Growth rates and overall sizes attained by the fall season, appeared, as in 1997, to be enhanced in the lower mainstem of the Keogh River by the addition of fertilization. Notably, the lower reaches of the Waukwaas River also show improved growth rates and sizes of coho fry were similar to those seen in the upper Keogh and Waukwaas in both 1998 and 1997. The lack of growth response for the middle reaches of the Keogh River could be an indication that too little fertilizer was applied, or was applied too late in the spring. In addition, relatively higher water temperatures in the Keogh River were a result of the influence of Muir Lake, Keogh Lake and O'Conner Lake (>22^{o}C in July and August) in the areas upstream, which may have caused thermal stress to juvenile salmonids and reduced food conversion rates.

CONCLUSIONS

Positive effects of treatments with fertilization and structure introduction as part of watershed restoration were apparent from studies of juvenile salmonids in the Keogh River, despite low escapement of steelhead and coho adults to the watershed. Increased steelhead fry densities in the treated reaches of the Keogh River in 1997 resulted in increased parr densities in 1998. Significant increases in smolt production were expected and observed in the spring of 1999. Coho fry densities were also higher in treated than non-treated reaches of the Keogh River, in a year when overall densities in untreated areas fell. Future smolt yield will be the key response variable to monitor for overall affect in years to come, as restoration continues on the lower portion of the river and effects of existing restoration impact all year classes of juvenile fish equally.

Enhanced growth of coho juveniles was again apparent, although not as striking as in 1997, possibly because of late application of the fertilizer. Future applications will encompass the whole watershed and should be undertaken to take advantage of the spring algal bloom in mid- to late April or early May.

The variations observed within structures both between and within years highlighted the need for longer-term studies of such restoration works. No particular structure type or location will always be suitable for even one species and age class of fish, because of differing environmental conditions. Juvenile salmonid densities were likely dependent on a variety of factors related to habitat and food availability, but also on adult seeding rates and environmental conditions. Information on juvenile densities delineated key features of habitat utilization under the range of in-stream circumstances presented in this coastal setting, but further work is required because sample sizes were generally too low to statistically detect differences which may exist.

Current increases in steelhead fry and parr densities on the Keogh River, and the exceptional escapement of adult coho (>8200 adults, McCubbing et al. 2000 in press) in 1998 strengthen the case for continued investigations of juvenile and smolt responses to habitat restoration techniques. Significant funding has been committed to habitat improvement works over the next five years by the Department of Fisheries and Oceans under the auspices of the coho recovery plan and Forest Renewal BC has committed to completing restoration of 20% of high priority watersheds over the next five years. Results from the Keogh and Waukwaas river assessments should prove beneficial for these and other large-scale habitat restoration programs.

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