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Coho Salmon Enhancement in British Columbia Using Improved Groundwater-Fed Side Channels

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COHO SALMON ENHANCEMENT IN BRITISH COLUMBIA USING IMPROVED GROUNDWATER-FED SIDE CHANNELS

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ABSTRACT

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Improved groundwater-fed side channels, which were originally built for increasing chum salmon (Oncorhynchus keta) production in British Columbia, show promise as a viable enhancement technique for coho salmon (O. kisutch). Preliminary results indicate that these channels can produce up to 3 coho smolts/m^2. Indirect evidence suggests that additional coho adults are produced from presmolt channel outmigrants that rear and overwinter beyond the confines of the channel. It is postulated that these outmigrants provide stability to the overall smolt and adult production in the parent river system.

Coho smolt abundance in groundwater-fed channels was found to be closely related to the availability of cover. Placing rip-rap armouring on channel banks, the crevices of which can provide sanctuary for up to 10 presmolts per linear meter, can increase smolt productivity over ten fold, as was demonstrated at Worth Creek Channel. At Deadman Channel, colonies of water cress (Nasturtium officinale) provided both escape cover and abundant food supply, and were associated with high densities of coho juveniles.

Other topics included in this paper are volitional spawner recruitment to a newly developed channel from the parent river system, surplus coho fry outmigrations, and seasonal patterns in distribution, diet and growth of juvenile coho.

RÉSUMÉ

Sheng, M.D., M. Foy and A.Y. Fedorenko. 1990. Coho salmon enhancement in British Columbia using improved groundwater-fed side channels. Can. MS Rep. Fish. Aquat. Sci. 2071 : 81 p.

De meilleurs chenaux latéraux alimentés par des eaux souterraines, conçus à l'origine pour augmenter la production de saumon kéta (Oncorhynchus keta) en Colombie-Britannique, sont prometteurs comme technique de mise en valeur rentable du saumon coho (O. kisutch). D'après des résultats préliminaires, ces chenaux peuvent produire jusqu'à 3 smolts de coho par mètre carré. Il semble, d'après des signes indirects, que d'autres cohos adultes sont produits à partir de saumons qui migrant en dehors des chenaux de présmoltification et qui se développent et passent l'hiver hors des limites du chenal. On suppose que ces migrants externes assurent une stabilité à la production générale de smolts et d'adultes dans le réseau hydrographique d'origine.

L'abondance des smolts de coho dans les chenaux alimentés par des eaux souterraines était étroitement liée à la disponibilité du couvert. L'enrochement des rives des chenaux, dont les crevasses peuvent servir de refuge jusqu'à 10 présmolts par mètre linésire, peut décupler la productivité, tel que montré au chenal du ruisseau Worth. Au chenal Deadman, des colonies de cresson de fontaine (Nasturtium officinale) offraient à la fois un couvert de fuite et une source abondante d'alimentation, et elles étaient associées à de fortes densités de juvéniles de saumon coho.

Les autres sujets traités dans le présent article sont le recrutement volontaire de géniteurs pour un nouveau chenal à partir du réseau hydrographique d'origine, un excédent de migrants externes d'alevins de coho, et des profils saisonniers au niveau de la distribution, du régime alimentaire et de la croissance des juvéniles de coho.

INTRODUCTION

The concept of developing inactive flood channels to create spawning habitat for chum salmon was pioneered in British Columbia in the late 1970s by Biologist D. Marshall and Engineer R. Finnigan of the Department of Fisheries and Oceans (DFO). Marshall observed that chum spawners in large rivers characteristically sought out areas of upwelling groundwater. He subsequently demonstrated that groundwater flow could be generated by excavating the gravel substrate of inactive flood channels down to a level below the ambient water table, and providing a drainage outlet to the parent stream. Groundwater upwelled through the exposed gravel substrate providing excellent conditions for spawning and incubation. These channels provided stable, silt-free flow year-round, and remained ice-free throughout the winter months.

Based on several early successes, the Department of Fisheries and Oceans invested in a program to enhance chum salmon production by developing groundwater-fed side channels. Several assessment studies of chum salmon spawner abundance, egg to fry survival and fry output verified high productivity in groundwater-fed side channels compared to natural streams (Lister et al. 1980; M. Foy, unpubl. data, 1982-1988; King and Young 1986 a,b; Bonnell 1990). From these assessment studies it became apparent that groundwater-fed channels could also produce coho salmon since colonization by this species has occurred in virtually all groundwater-fed channels constructed to date. Although the coho data gathered were often incidental and incomplete, some interesting trends were revealed regarding recruitment of spawners, fry and smolt production, and contribution from outmigrating channel presmolts to the returning escapement. We present these findings along with other study results showing the importance of rip-rap armouring on channel banks as escape cover for juvenile coho; the considerable winter-spring growth of coho presmolts during 1984/85 in Upper Paradise Channel, based on a diet mainly of chum adult carcasses, embryos and emergent fry; and the apparent direct relationship at Deadman Channel between juvenile coho densities and the presence of water cress beds.

DESCRIPTION OF GROUNDWATER-FED SIDE CHANNELS AND STUDY SITES

Most improved groundwater-fed channels in British Columbia have similar physical characteristics (Table 1). A typical channel is depicted in Figure 1. The following is a general description of the design and the steps followed during channel construction.

The first step in channel construction is to determine the depth of excavation. Current channel design calls for the water level at the top end of the completed channel to be 0.9-1.2 m below the lowest level of the water table recorded in the summer prior to excavation. This ensures year-round flow even during drought periods. Channels are generally excavated parallel to the parent river and have little or no gradient. There is no connection with the river at the upstream channel end. Unless the site is already protected by a dyke or a raised road, material excavated from the channel is placed on the side closest to the river to be used for constructing a dyke for flood protection. The exposed materials of the channel bed are the fluvial deposits of an old river

Table 1. Physical characteristics for reactiviated groundwater-fed channels in British Columbia.

Characteristic	Range
Length	300-1,000 m
Width	5-6 m
Depth	20-40 cm
Surface velocity	5-15 cm/s
Discharge	0.085-0.14 m3/s (2-5 cfs)
Summer water temperature	8-13°C
Winter water temperature	3-7°C

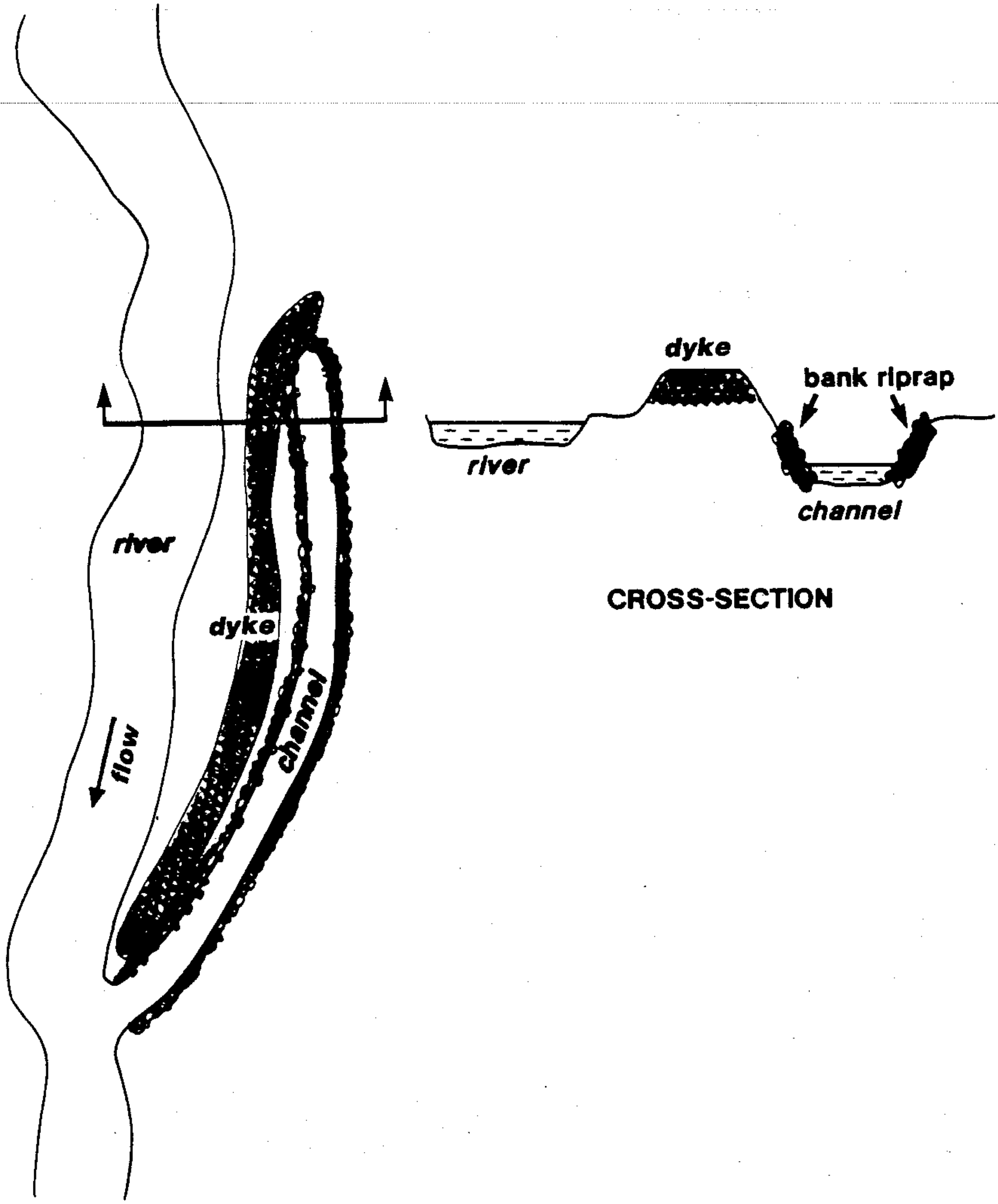

Figure 1. Typical layout for a groundwater-fed channel.

meander. This material becomes the spawning bed, although a 15-30 cm layer of screened gravel or native gravel from a nearby source has been introduced in some instances. Lastly, to protect the banks, rip-rap 30-46 cm in diameter, is placed along both channel banks, extending from the channel bed to a height of about 60 cm above the normal water level (Fig. 1). This armouring material prevents spawners from undermining the banks and provides hiding cover for juvenile coho.

Our study sites were limited primarily to four groundwater-fed channels: Worth Creek, Upper Paradise, Mamquam and Deadman. The first three are coastal channels, while the Deadman Channel is located in the interior of the province (Fig. 2). Worth Creek Channel flows into Norrish Creek, a tributary of the lower Fraser River. Upper Paradise and Mamquam channels flow into the Cheakamus and Mamquam rivers respectively, which are major tributaries of the Squamish River . Lastly, the Deadman Channel flows into Deadman River, a tributary of the Thompson River which enters the Fraser River. These four channels range from 150 m to 575 m in length, and from 850 m^2 to 2,625 m^2 in area (Table 2). Presently, only the Mamquam Channel has the original native substrate. Two other channels were considered briefly in this report. They are Judd Slough and B.C. Rail Channel, both located in the Squamish River system (Fig. 2).

METHODS

COHO SPAWNER ABUNDANCE

Numbers of coho spawners were estimated primarily from visual counts made at intervals throughout the spawning period. In addition, incidental coho counts made by field workers during the chum salmon carcass recovery at Worth, Upper Paradise and Mamquam channels (Foy et al. MS 1990), were utilized where possible. In most instances, visual counts were made weekly or every second week. These estimates were considered to be conservative. In estimating the total number of spawners, some error may have entered because spawner turnover rates had to be taken into account. Two or three peak live counts were usually identifiable within the spawning season, and these were interpreted as total counts for individual spawning waves. It was felt that the sum of these peak counts provided a reasonable estimate of total coho escapement.

ADULT SEX RATIO AND FECUNDITY

Adult sex ratio and fecundity estimates were not determined. The sex ratio was assumed to be 1:1. Supporting evidence for this assumption was that coho trapping data for Tenderfoot Creek, a natural groundwater-fed system on the Cheakamus River (Fig. 2), showed an average of 53% males over the seven-year period from 1981 to 1987 (D. Celli, pers. comm.).

Coho fecundities at all the channels were assumed to average 2,500 eggs per female. This was based on samples taken at Upper Paradise Channel between 1984 and 1986 and at Inch Creek Hatchery between 1979 and 1987 (Inch Creek is a natural groundwater stream near Worth Creek Channel). The fecundity data are shown in Appendix 1.

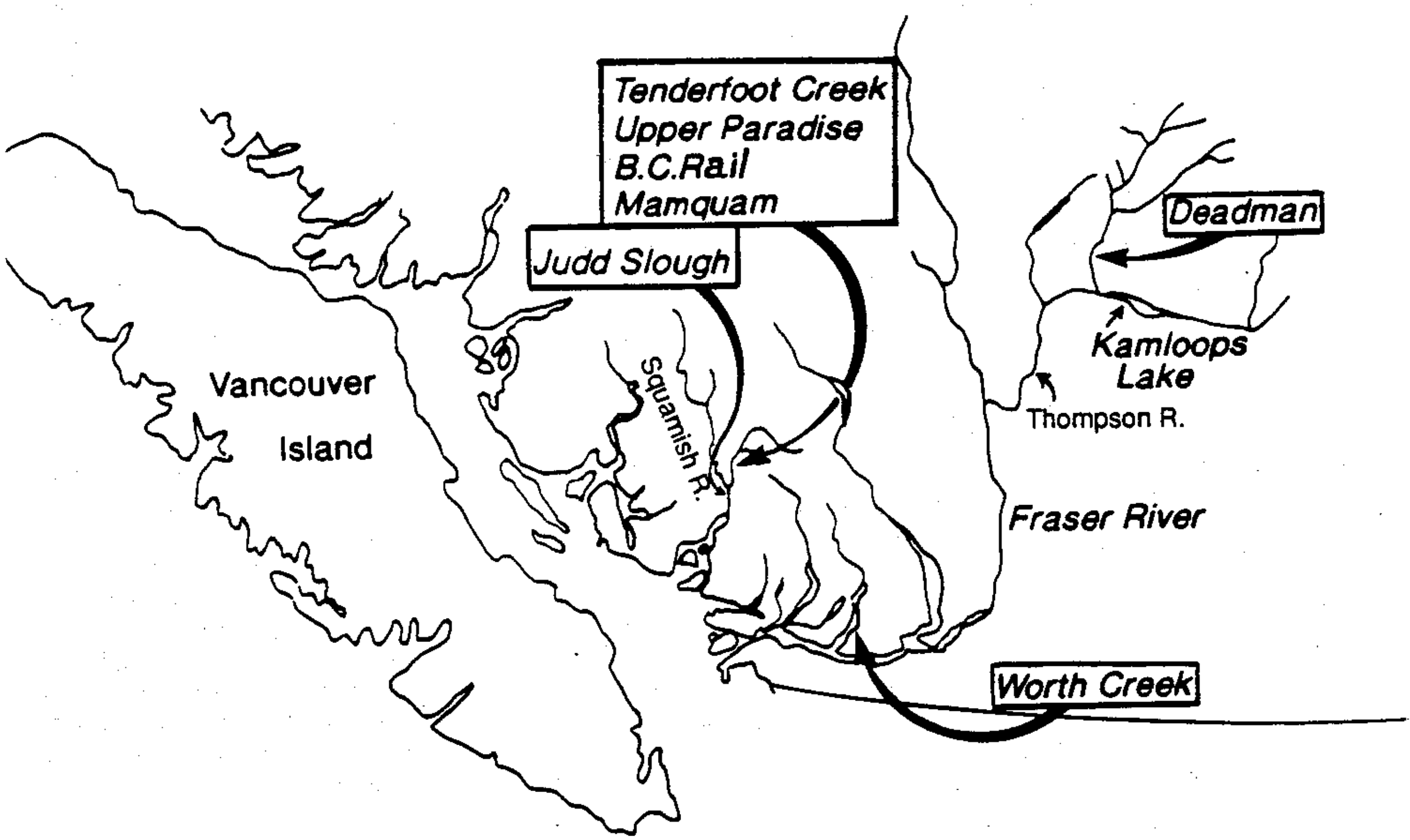

Figure 2. Locations of groundwater-fed channels with recorded coho escapements.

Table 2. Size dimensions of groundwater study channels and estimates of coho escapements to the channels and the parent rivers in the three years following channel construction.

Channel	Parent stream	Channel Length (m)	Channel Area (m^2)	Coho escapements[a] Brood year	Channel	River
Upper Paradise	Cheakamus River	420	2,625	1982	75	1,500
				1983	50	1,500
				1984	50	1,500
Mamquam	Mamquam River	300[b] (360)	1,700[b] (2,000)	1983[c]	200	300
				1984	100	400
				1985	100	300
Judd Slough	Squamish River	1,470	11,600	1984	50	10,000
				1985	75	10,000
				1986	250	1,000
B.C. Rail	Cheakamus River	390	2,340	1985	250	4,000
				1986	150	6,000
				1987	200	UNK
Worth Creek	Suicide Creek (Norrish Creek)	150	850	1979	50	UNK
				1980	50	UNK
				1981	50	UNK
Deadman	Deadman Creek	575	1,753	1985	50	500
				1986	125	265
				1987	50	2,176

[a] Visual estimates.

[b] The entire 2,000 m^2 area of Mamquam Channel (360 m long section) was considered suitable for juvenile rearing; however, only the lower 1,700 m^2 area (300 m long section) was considered suitable for spawning since the top 300 m^2 area (60 m long section) consists of large rocks installed for pink salmon egg planting.

[c] Mamquam Channel was excavated in summer of 1983, but rip-rap was added in 1984.

POPULATION ESTIMATES OF COHO JUVENILES

Downstream Migrant Populations

Downstream movement of coho fry and smolts was monitored each spring during the enumeration of chum fry. Live traps with V-type screen fence leads (Conlin and Tutty 1979) were operated at Worth Creek and Mamquam channels, and a horizontal screen type of weir was used at Upper Paradise Channel (Foy et al. MS 1990). To adjust for missing count days due to flooding, vandalism or other events, fry counts were estimated by inter-and extrapolation of data (Appendix 2). In some years, juvenile enumeration was interrupted for prolonged periods, or the trap was removed at the end of chum fry migration despite large numbers of coho fry still migrating. In such cases, no attempt was made to correct the large data omissions and fry counts were noted as incomplete (Appendix 2). In the case of coho smolt counts, no corrections were made for missed trapping days and only actual counts were used in calculations.

Rearing Populations

Rearing populations in the channels were estimated using a Petersen mark-recapture method (Ricker 1975) and a three-pass electroshocking removal technique (Zippen 1958). The latter method involved a 12 volt D.C. backpack electroshocker. Methods for each channel are discussed below.

Worth Creek Channel

On February 25, 1987, an electroshocking survey was conducted to estimate the resident coho population. During September 1-12, 1989, an extensive mark-recapture program was carried out in order to assess the juvenile population remaining in the channel after the completion of downstream trapping on August 28 of that year. Fry were captured by minnow trapping and seining during September 1-5, and held in several net pens until sufficient numbers had accumulated. Captured fry were marked with left-ventral fin clips and released for subsequent recapture on September 12. During this program, the downstream fence remained in position in order to prevent in- or out- movement of juveniles, thereby assuring that only channel-produced juveniles were enumerated.

Upper Paradise Channel

On July 5, 1984, an electroshocking survey was carried out to estimate the resident coho population. In August and September of that year, a Petersen mark-recapture survey was carried out to assess the resident population. In this latter procedure coho were minnow-trapped from the channel and their left ventral fin was removed. The juveniles were then returned to the channel sections from which they were removed. Minnow-trapping in the channel was repeated five days later, and the fish examined for marks. Trapping and examination for marks continued throughout the fall, winter and spring of 1984/85. All juveniles were returned to the channel after each sampling. Minnow traps were used in the second and third sampling, while an electroshocker was used in the subsequent sampling surveys. During this program, juveniles could move freely between the channel and the mainstem.

Mamquam Channel

No formal studies on juvenile abundance were conducted at Mamquam Channel. However, on November 20, 1985, the upper 300 m^2 section of the channel was electroshocked and captured coho juveniles moved downstream. This was a predator control measure aimed at reducing predation on the subsequently emerging pink fry in this section.

UPPER PARADISE CHANNEL STUDY

Seasonal changes in diet, distribution and growth of coho juveniles in the Upper Paradise Channel (Fig. 3) were studied from July 1984 to June 1985. Population estimates were determined from electroshocking and mark-recapture surveys (see section above). Samples of approximately 10 to 25 fish were obtained at intervals, and individual anaesthetized fish were weighed to the nearest 0.1 g. Stomach contents were flushed out through the mouth using a water-filled hypodermic syringe with a blunt needle (Meehan and Miller 1978), and examined under a microscope. The stomach contents, usually from 5 to 10 juveniles, were always taken in the morning from coho captured either in minnow traps set 12 hours earlier, or by electroshocking. All juveniles were returned to the channel once sampling was completed.

DEADMAN CHANNEL STUDY

The densities of juvenile coho and steelhead in relation to the abundance of water cress were observed at Deadman Channel for four consecutive brood years, 1984 to 1987. Juvenile abundance was estimated by electrofishing in 1986 and 1988 (combined with mark-recapture in 1986), downstream trapping in the spring of 1987 and winter/spring of 1987/88, as well as visual surveys throughout the study period. Estimated capture efficiency from single pass method of electroshocking, based on previous trials, was $p = 0.45$. Downstream trapping utilized a V-type fence which was installed just below the middle channel section (Fig. 7). Water cress abundance was expressed as percent of wetted area colonized by this plant. Table 10 summarizes sampling dates and methods used each year in the Deadman Channel study.

BIOLOGICAL SAMPLING

Juvenile coho were sampled for weights and stomach contents during the 1984/85 study at Upper Paradise Channel (see section above). Length and weight measurements of yearling coho were taken in some years during downstream trapping at Worth Creek, Upper Paradise and Mamquam channels, and during electroshocking at Worth Creek Channel. At Deadman Channel, captured coho and steelhead juveniles were sampled for individual weights during that study.

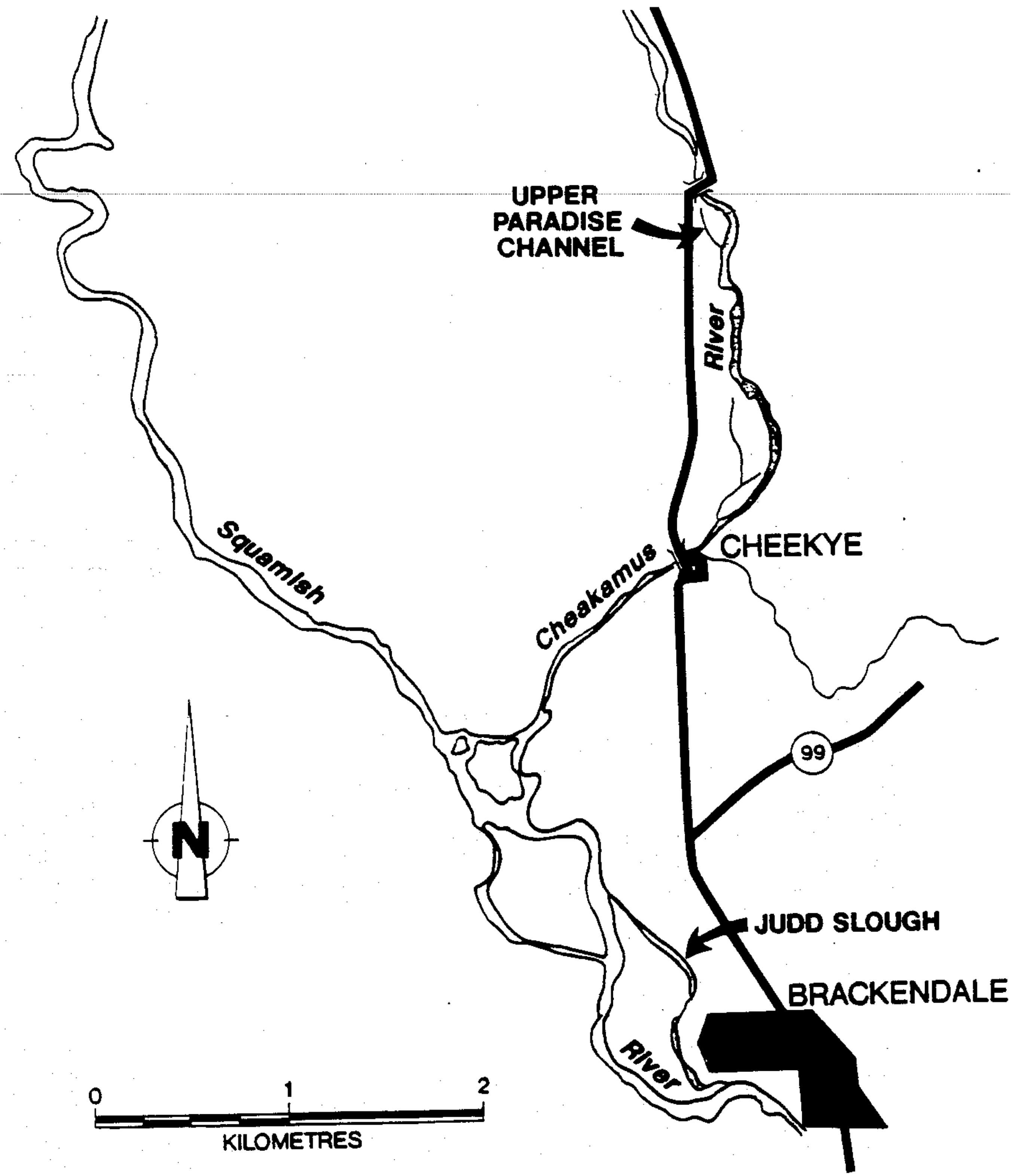

Figure 3. Map of the Squamish area showing location of Upper Paradise Channel.

RESULTS AND DISCUSSION

This section consists of three parts. Part one deals with coho production at the Worth Creek, Upper Paradise and Mamquam channels; part two gives details of the 1984-1985 juvenile study at the Upper Paradise Channel; and part three describes the 1985-1988 study at Deadman Channel.

I. COHO PRODUCTION AT WORTH CREEK, UPPER PARADISE AND MAMQUAM CHANNELS

Adult Production

Recruitment of spawners

Coho spawning populations in Worth Creek, Upper Paradise, Mamquam and Judd Slough channels were monitored each year after channel construction (Tables 2 and 3). In the first three years of channel operation, numbers of spawners were low, in the 50-250 range (Table 2). Coho returns to the newly developed Worth, Upper Paradise, Mamquam and Judd Slough channels were thought to be derived from strays originating from elsewhere in the parent river system and from local stocks that had previously spawned in the undeveloped groundwater-fed areas. Coho returns to the Deadman Channel were derived from strays from the Deadman system and from adults transported to the channel from the downstream adult fence.

Spawner contributions from channel-reared juveniles

In the fourth and subsequent years after channel construction when channel-produced adults (progeny of initial colonizers) began returning, escapements to all channels increased by about 2 to 8-fold (Table 3). At Worth Creek Channel which has the longest escapement record, the escapement appeared to stabilize at about 200 adults over the 1982-1987 period, but more than doubled that value in 1988 (Table 3).

Estimated Seeding and Spring Carrying Capacity of Fry

The study channels appeared to be fully seeded each year, as indicated by the considerable outmigration of surplus channel fry each spring (Table 5). The number of juveniles that could be supported in a channel at a given time was termed the carrying capacity.

Worth Creek Channel

Table 4 summarizes the results of the mark-recapture program conducted during September 1989. The resulting population estimate of 11,978 juveniles represented solely the channel-produced coho since no migration was possible in or out of the channel (see Methods section). Given the channel area of 850 m^2, the above estimate translates to a carrying capacity of 14 juveniles/m^2.

Table 3. Annual coho escapement estimates for Worth Creek, Upper Paradise, Mamquam and Judd Slough channels, 1979-1988 brood years (asterisk indicates first year of channel operation; boxed returns include channel produced adults).

Year	Coho escapements[a]			
	Worth Creek	Upper Paradise	Mamquam	Judd Slough
1979	50*			
1980	50			
1981	50			
1982	200	75*		
1983	300	50	200*[b]	
1984	200	50	100	50*
1985	250	400	100	75
1986	200	350	300	400
1987	150	300	300[c]	1,000
1988	500[d]	-[e]	-[e]	-[e]

a Escapements were based largely on visual estimates by fishery officers.

b Mamquam Channel was excavated in summer of 1983 allowing for adult spawning that year; rip-rap was added in 1984.

c An estimated additional 100 coho adults spawned below the developed Mamquam Channel section in 1987.

d Based on a count of 456 dead and 20 live coho in 1988.

e Accurate channel escapement estimates not available.

Table 4. Population estimate of coho juveniles in Worth Creek Channel using mark-recapture, September 1 - 12, 1989.

Date 1989	Method	No. coho fry captured	No. marks released	No. marks recaptured	Comments
Sep 1	Minnow trapping	1,759	-	-	Minnow traps were set for 24 hr intervals using salmon roe as bait. Larger juveniles were captured selectively in minnow traps. Therefore, several random seine sets of uniform length were also made along the channel to provide a less biased sample compared to minnow trapping.
2	Minnow trapping	725	-	-	
3	Minnow trapping	435	-	-	
4	Minnow trapping	209	-	-	
5	Beach seining	4,186	-	-	
	Total	7,314	-	-	
Sep 7,8	L-ventral fin clipping and release	-	7,290	-	
Sep 12	Beach seining	3,112	-	1,894	

Peterson population estimate = 11,978 juveniles or 14 fry/m^2

Upper Paradise Channel

The electroshocking survey conducted in July 1984 gave a calculated rearing population of 17,220 fry or about 7 juveniles/m^2 given the channel area of 2,625 m^2. This is a minimum estimate since unknown fry numbers left the channel before the survey.

The above carrying capacities are expected to show little year to year variation if the groundwater channel habitat is assumed to be characteristically stable from year to year. However, our approximations of spring carrying capacity for Worth Creek and Upper Paradise channels (no reliable data were available for Mamquam Channel) should be viewed with caution since data collection was limited to a single assessment per channel. A series of annual assessments are required to provide a more reliable estimate of the spring carrying capacity of coho fry in the channels.

Surplus Fry Output

Table 5 shows the annual estimates of downstream surplus fry migrants at each study channel. Appendices 3-5 show the daily counts. Only those years with relatively complete counts were considered.

The annual surplus fry output varied greatly at each channel, with Worth Creek showing the greatest range (5,816 - 259,178, Table 5). Apparent annual egg to fry survivals, based on the potential egg deposition and surplus fry output, were 9-41% at Worth Creek, 1-18% at Upper Paradise and 25-40% at Mamquam (Table 5). These survival estimates are considered minimal given the low spawning densities and apparently good incubation survivals (Foy et al. MS 1990). The estimates are further weakened by the uncertainties in estimating the potential egg deposition since the escapement, sex ratio and fecundity values were only semi-quantitative. Also, the total emergent channel fry population (ie. surplus fry migrants plus resident fry) was not determined in most years. An exception was the 1988 brood year data for Worth Creek Channel when the estimated total emergent fry population yielded an egg to fry survival of 43% (Table 5).

Smolt Production

Table 6 shows the annual smolt counts for each channel, smolt production per m^2 of rearing channel area, and per linear meter of channel bank. Appendices 3-5 show the daily smolt counts. Production at each channel is discussed below.

Worth Creek Channel

Constructed in 1979, Worth Creek Channel showed a smolt production range of 0.1 to 0.3 smolts/m^2 for the 1978 to 1984 brood years; these values were

Table 5. Estimated potential coho egg deposition and downstream counts of coho fry at Worth Creek, Upper Paradise and Mamquam channels.

Brood year	No. adult females[a]	Potential egg deposition[b]	Estimated downstream counts of coho fry[c]	% Coho egg to fry survival based on downstream fry counts
		WORTH CREEK (Screened Gravel Channel)		
1979	25	62,500	25,086[d]	40
1981	25	62,500	5,816	9
1983	150	375,000	32,052	9
1988	250	625,000	259,178	41 (43)[e]
		UPPER PARADISE (Screened Gravel Channel)		
1982	40	100,000	13,608	14
1983	25	62,500	9,819	16
1984	25	62,500	11,463	18
1985	200	500,000	20,902	4
1986	175	437,500	3,591	1
1987	150	375,000	3,127	1
		MAMQUAM (Native Gravel Channel)		
1986	150	375,000	151,652	40
1987	150	375,000	92,169	25

a Using escapement estimates (Table 3) and 1 : 1 sex ratio.
b Using estimated mean fecundity of 2,500 eggs per female (see text).
c Trap counts expanded to correct for missed trapping days (Appendix 2).
d From Lister et al. (1980); not corrected for trap efficiency.
e Based on total emergent channel fry population in 1989 which includes 11,978 estimated resident fry (Table 4).

Table 6. Coho smolt production at the study channels, 1978 - 1987 brood years[a].

Brood Year	Smolt Production		
	No. smolts[b]	No./m²	No./m of bank[c]
	WORTH CREEK (150 m, 850 m²)		
1978	81[d,e]	0.1	0.3
1979	N/A[f]	-	-
1980	87	0.1	0.3
1981	120	0.1	0.4
1982	120	0.1	0.4
1983	4[g]	-	-
1984	285+[h]	0.3+	1.0+
1985	1,712[i]	2.0	5.7[j]
1986	N/A[f]	-	-
1987	877	1.0	2.9
	UPPER PARADISE (420 m, 2,625 m²)		
1981	1,580[e]	0.6	1.9
1982	8,240+[h]	3.1+	9.8+
1983	6,228	2.4	7.4
1984	4,453+[h]	1.7+	5.3+
1985	5,483+[h]	2.1+	6.2+
1986	4,923	1.9	5.9
1987	2,355+[h,k]	0.9+	2.8+
Mean[l]	5,280	2.0	6.2
	MAMQUAM (360 m, 2,000 m²)		
1982	N/A[e,f]	-	-
1983	157[e]	0.1	0.2
1984[n]	5,813[n]	3.4[m]	9.7[m]
1985	1,126+[h]	0.6+[o]	1.6+[o]
1986	29	0.01[p]	0.04[p]
1987[n]	6,265[n]	3.1	8.7

(Cont'd)

Footnotes for Table 6.

a Channel length and developed area are shown for each channel in parenthesis.

b Used unadjusted trap counts of coho smolts (Appendices 3 - 5) except for Worth Creek Channel, 1985 brood year, when an electroshocking survey was conducted.

c Calculations based on coho smolt counts at the downstream trap and double the length of channel banks.

d Actual unadjusted trap count from Lister et al. (1980).

e Production from this brood year originated from mainstem fry that colonized the newly constructed channel: in 1979 for Worth Creek, in 1982 for Upper Paradise and in 1983 for Mamquam. Note that although the undeveloped groundwater-fed areas at Upper Paradise and Mamquam sites were accessible to spawners prior to channel construction and were used by rearing juveniles, those rearing populations were severely disrupted during the channel construction phase.

f No downstream trapping conducted.

g Trap counts were very incomplete and no production estimate was possible.

h Underestimated due to incomplete smolt trap counts (see Appendices 3 - 5).

i Using Worth Creek electroshocking survey data from February 1987.

j The 1985 brood year was the first year of smolt production at Worth Creek, following rip-rap placement in 1986.

k Some of the rearing mortality of 1987 brood coho at Upper Paradise Channel was attributed to mechanical damage during substrate reworking in August 1988.

l Mean excludes the 1981 brood year when fry from the parent system colonized the newly constructed channel.

m Smolt production of 3.4 fish/m^2 or 9.7 fish/m bank for the 1984 brood year was based on a reduced rearing area of 1,700 m^2 and channel length of 300 m between November 1985 and spring 1986. This is because in November 1985 coho juveniles were electroshocked in the top 300 m^2 (60 m long channel segment) where pink eggs were planted, and moved to lower channel section below vexar screens, to eliminate coho predation on emergent pink fry in the top section.

n The 1984 and 1987 broods were the only ones for which Mamquam Channel remained flowing for the entire summer rearing period (ie., summers of 1985 and 1988).

o More than half the Mamquam Channel dried in summer of 1986 due to drought conditions.

p The entire Mamquam Channel dried in summer of 1987.

considerably lower compared to the other study channels (Table 6). Smolt production at Worth Creek Channel was probably limited during that period by the lack of cover for rearing juveniles. Unlike the Upper Paradise and Mamquam channels which had rip-rap armouring, bank armouring at Worth Creek consisted initially of compactly arranged, rounded cobbles which provided few crevices for hiding or escape. The addition of large-sized angular rocks in the summer of 1986 apparently served to increase considerably smolt production in 1987 to $2.0/m^2$ or 5.7/m bank length (Table 6).

Upper Paradise Channel

Constructed in September 1982, this channel showed some of the highest smolt production values among the study channels, with an average density of 2.0 $smolts/m^2$ reported for the 1982 to 1987 brood years and a maximum of 3.1 $smolts/m^2$ reported for the 1982 brood year (Table 6). This maximum density translates to 9.8 smolts per linear meter of channel bank. The lowest smolt output of $0.6/m^2$, observed for the 1981 brood, originated solely from fall-winter migrants from the mainstem, following completion of channel construction in the fall of 1982. In contrast, the considerably higher smolt outputs for subsequent broods originated primarily from progeny of channel spawners and secondarily from potential juvenile immigrants from the mainstem.

Mamquam Channel

Assessment of the Mamquam Channel, excavated in the summer of 1983, commenced with the 1983 brood coho smolt counts. The low smolt output for that brood year ($0.1 /m^2$, Table 6) originated mainly from fall-winter immigrants from the mainstem following final channel construction activities in 1984 which included rip-rap placement. The highest production density of 3.4 $smolts/m^2$ observed for the 1984 brood year, was similar to the highest density of 3.1 $smolts/m^2$ observed at Upper Paradise Channel. However, production at Mamquam Channel declined markedly to only 0.6 $smolts/m^2$ for the 1985 brood year and 0.01 $smolts/m^2$ for the 1986 brood year. This decline was the result of drought conditions in the summer of 1986 and 1987, when more than half the channel and the entire channel, respectively, had dried. Rearing conditions improved for the 1987 brood year when smolt production of 3.1 $fish/m^2$ was reported. It is noteworthy that the trap count of only 29 smolts originating from the drought-affected 1986 brood year indicates that fall-winter recruitment of juveniles from the parent system was negligible.

It should be cautioned that the above coho smolt production estimates for the three channels are minimal for most years since the downstream trap counts were often incomplete. Nevertheless, it is clear from the data that the Upper Paradise Channel was consistently the most successful smolt producer of the study channels. Smolt production at Worth Creek Channel was low until rip-rap armouring was added in 1986, while smolt production at Mamquam Channel failed repeatedly as a result of recurrent summer drought conditions.

The available smolt production estimates for the study channels, excluding production years with no rip-rap armouring (Worth Creek), drought conditions (Mamquam) or habitat disruption due to channel construction (all channels), ranged from about 1 to 3 $smolts/m^2$ (Table 6). This narrow range suggests that habitat carrying capacity for smolt production in improved groundwater-fed channels is relatively stable between years and channels. A stable channel habitat should produce similar numbers of smolts each year, regardless of the numbers of juveniles moving in or out of the system, assuming that egg deposition always exceeds initial fry carrying capacity.

Factors Affecting Coho Smolt Production

Major factors affecting coho smolt production in groundwater-fed channels include:

1. Initial fry seeding,
2. Food supply and
3. Escape cover.

Each of these factors is discussed below.

Initial fry seeding

One of the key requirements to sustaining a high smolt yield in groundwater-fed channels is an adequate seeding of fry. Without this initial input, smolt production will be significantly lower than the potential for the channel. This was exemplified by the low coho smolt outputs from the Worth Creek, Upper Paradise and Mamquam channels for the 1978, 1981 and 1983 brood years respectively (Table 6). Only the fall-winter recruitment of juveniles from the mainstem contributed to those outputs due to construction activities in 1979, 1982 and 1983/84 at the respective channels. [At Worth Creek channel, however, the absence of suitable bank armouring also contributed to the low smolt output until the 1985 brood year (Table 6)]. In addition to low smolt production due to underseeding of fry, smolt production may be highly variable when based on natural fry recruitment alone. This was noted by Peterson (1985) and Everest et al. (1985) for off-channel rearing ponds.

Food supply

Groundwater-fed channels have the inherent characteristics of stable flows, moderate temperatures (3-13 °C) and clean gravel substrate. These features promote high invertebrate production and hence a rich foraging environment for rearing juveniles throughout the year.

At Upper Paradise Channel, stomach samples of coho juveniles taken in July and September 1984, indicated that coho were feeding primarily on aquatic insects at this time (Table 8). A 90% canopy cover from bankside alders and cottonwoods no doubt contributed to the insect component of the coho diet at this channel. However, the major factor leading to the high production of coho smolts from Upper Paradise Channel may be the presence of chum salmon . The 1984-1985 study at this channel showed that chum carcass remains formed the bulk of the coho diet from at least January, and perhaps as early as October, while emergent chum fry became the dominant food source in the spring (see section below on Seasonal Patterns in Distribution, Diet and Growth of Juvenile Coho in Upper Paradise Channel).

At Deadman Channel, dense colonies of water cress (Nasturtium officinale) provided an abundant supply of aquatic insects, particularly mayflies and stoneflies, to the rearing coho. Densities of coho juveniles were directly related to the water cress abundance in this channel (see section below on Interrelationship of Coho Juveniles with Aquatic Vegetation in Deadman Channel, 1984-1987 Broods).

Escape cover

In the absence of suitable escape cover, smolt densities will remain low. The Worth Creek Channel study clearly illustrates the significant positive effects of rip-rap armouring on coho smolt abundance. Prior to rip-rap placement in 1986, smolt densities never exceeded 0.3 fish/m^2 (Table 6). In the summer of 1986, the original round cobble bank cover was replaced with rip-rap armouring in the form of large 30-46 cm diameter angular rocks placed loosely on both sides of the channel. In February 1987, a 3-pass electrofishing survey gave a total estimate of 1,712 presmolts or 2.0 fish/m^2 (Table 6), with the juveniles found only in the rock crevices. Assuming the above presmolt estimate in February was representative of the smolt output that spring, the increase in density following rock placement was 14 times the previous five-year average (Table 6).

The 1984-1985 study at the Upper Paradise Channel also showed that the presence of rip-rap bank armouring is a major factor affecting coho abundance in that channel. While graded gravel spaces were used primarily by small fry (<1.0 g) for cover, larger juveniles made extensive use of the rip-rap bank armouring during both summer and winter (see section below on Seasonal Patterns in Distribution, Diet and Growth of Juvenile Coho in Upper Paradise Channel, July 1984 - June 1985).

At Deadman Channel, coho densities were considerably higher in areas with dense colonies of water cress. This growth provided both an escape cover and a rich food supply for the rearing juveniles. In particular, data from the 1986 and 1988 electrofishing surveys at Deadman Channel showed a strong positive relationship between densities of coho juveniles and water cress abundance (see section below on Water Cress Growth Related to Juvenile Abundance).

Review of the available data on groundwater channels in British Columbia shows that all channels which feature both intrinsically high food production and some form of rip-rap cover, produce in excess of 1.5 smolts/m^2. In our study, smolt densities expressed as numbers per linear meter of armoured channel bank reached 5.7 coho/m for Worth Creek Channel, 9.8/m for Upper Paradise Channel and 9.7/m for Mamquam Channel (Table 6).

Use of Groundwater-Fed Channels as Overwintering Refuges

It is generally assumed that groundwater-fed channels provide overwintering refuges for juvenile coho that originated in the mainstem. The fall-winter movement of juvenile coho into tributary or side channel habitats has been well documented (Skeesick 1970). Peterson (1982) observed that juvenile coho in the Clearwater River in Washington State migrated as much as

33 km in the fall to overwinter in downstream groundwater ponds. Fedorenko and Cook (1982) reported similar migrations to groundwater overwintering sites in southern B.C. streams.

Unlike typical coastal streams, groundwater-fed channels experience no freshets, thereby reducing overwinter mortalities. Peterson (1982) found that overwinter survivals in the studied groundwater ponds ranged from 28% to 78%, significantly higher than expected in more exposed mainstem refuges. Bustard and Narver (1975) calculated overwinter survivals of 73% in a series of old beaver ponds on Carnation Creek. This value is significantly higher than the estimate of 35% overwinter survival for the Carnation system as a whole.

As was mentioned previously, smolt production in our study channels may be attributed to two sources: channel-produced juveniles (ie., the progeny of channel spawners which may include adult strays from the parent system), and mainstem-produced juveniles (ie., potential juvenile immigrants from the parent system). These two contributing components were not distinguished in this study.

However, in Upper Paradise Channel, a constant seasonal movement in and out of the channel of channel-produced and mainstem-produced juveniles was suggested by a mark-recapture study conducted in 1984 to 1985 (Table 7). In late August 1984, an estimated 13.5% of the Upper Paradise coho residents were marked with a ventral fin clip. Subsequent recaptures showed that the percentage of marks declined through the winter and following spring to only 3.5%. It is possible that mainstem juveniles migrated into the channel during fall and winter, displacing a portion of channel residents. This could arise if the mainstem intruders held a size advantage over the channel residents because of faster summer growth in the warmer surface-fed mainstem. Admittedly, this explanation is conjecture. Ventral fin clip regeneration, differential mark mortality, differential movement of marked juveniles out of the channel, or a combination of these factors could also result in the decline of marked proportion of juveniles in the channel. The fact remains that little is known about the population dynamics of resident coho juveniles in the study channels. A comprehensive marking program is required to assess both the in and out movement of juveniles in a channel, and clarify the contribution of channel-produced and mainstem-produced juveniles to smolt and adult production in a channel.

Table 7. Population estimates and mean weights for 1983 brood coho juveniles, and the occurrence of marked (ventral fin clipped) coho juveniles between July 1984 to June 1985 in Upper Paradise Channel.

Sampling date	Method	Population estimate	No. coho/m² (Area 2,625 m²)	Mean Wt.[a]	MARK - RECAPTURE: No. marks applied	No. marks recaptured	Total sample[b]	% Marks in sample
Jul 5/84	Electro-shocking removal method.	17,220	6.6	1.0g	0	0	950	-
Aug 30/84	Minnow-trapping and fin-clipping.	-	-	2.0g	2,213	0	0	-
Sep 5/84	Mark-recapture.	16,357	6.2	1.6g	0	212	1,567	13.5
Oct 30/84	Recapture.	-	-	2.5g	0	(data lost)		8.0
Jan 4/85	Recapture.	-	-	2.9g	0	6	102	5.9
Mar 6/85	Recapture.	-	-	3.9g	0	22	546	4.0
Mar 19/85	Recapture.	-	-	-	0	2	88	2.3
May 9/85	Recapture.	-	-	7.1g	0	-	-	-
Mar 8 - Jun 24/85	Downstream trap.	6,228	2.4	12.0g[c]	0	223	6,335	3.5

a See also Table 9.
b All sampled fish were returned to the channel.
c Size samples were for the period April 14 to June 6, 1985 (Table 9), when 94% of total smolt migrants were trapped (Appendix 4.)

II. SEASONAL PATTERNS IN DISTRIBUTION, DIET AND GROWTH OF JUVENILE COHO IN UPPER PARADISE CHANNEL, JULY 1984 - JUNE 1985

The most striking characteristic of Upper Paradise Channel is the magnitude of its smolt migration, with an equivalent of 20,000 smolts/km channel length produced in 1984 (Table 6). A number of physical and biological aspects of the channel no doubt contribute to this level of production, among them abundant food supply and adequate escape cover. Seasonal changes in distribution, diet and growth of coho juveniles in Upper Paradise Channel were examined between the summer of 1984 and the spring of 1985. The study findings are presented in a chronological order below.

Seasonal Changes in Distribution and Diet of Juvenile Coho

July - August 1984: During the early stages of channel residence, coho fry were well distributed both across and along the channel. Fry utilized for cover both the interstices in the graded gravel and the coarse rip-rap armouring on channel banks. However, electroshocking revealed that larger fry (>1.0 g) used the coarse rip-rap banks, rather than the graded gravel for escape cover. At this stage, coho fry were seen feeding throughout the summer daylight hours, with stomach contents consisting primarily of mayflies, stoneflies and gastropods (Table 8, July data).

September - October 1984: After an October freshet in the mainstem which resulted in backwatering of the channel for several days, no fry were visible in open water during the day. Electroshocking revealed that all juveniles were associated with the coarse rip-rap banks during the daylight hours. Juveniles moved out only at night during feeding, and insects continued to be their primary food source (Table 8, September data).

December 1984 - January 1985: During December, juveniles remained closely associated with rip-rap cover along the channel banks. Highest juvenile densities were found in loosely packed heaps of rip-rap which provided maximum interstitial spaces for cover. In contrast, rip-rap that was sparsely placed or tightly packed provided minimal fish cover and had low juvenile densities. Inspection of the rip-rap armouring showed that maximum utilizable fish habitat was apparently provided by rip-rap ranging in size from 30 cm to 45 cm in diameter.

In January of the following year, juvenile coho still remained in the rip-rap shelter during the day. During night capture of coho broodstock using lights, juveniles were observed well distributed throughout the channel and appeared to be actively feeding. They were often congregated around adult chum carcasses, and analysis of stomach contents of juveniles confirmed they were feeding primarily on carcass remains (Table 8, January data).

March - May 1985: In the spring, yearling juveniles still remained in the rip-rap armouring during the day. In March, approximately 60% of coho stomach contents by volume consisted of chum alevins and fry, 20% of adult chum carcass remains, and 20% of aquatic insects (Table 8, March data).

Table 8. Summary of juvenile coho stomach sampling in Upper Paradise Channel, 1984 - 1985[a].

Date	Primary food item	Gut contents from sampled coho juveniles
July 5/84	Insects.	- 50% unidentified insect remains, 17 mayfly nymphs, 9 stonefly nymphs, 2 chironomid larvae, 1 unidentified dipteran larva, 18 gastropods, 1 collumbra, 32 plant seeds.
Sep 5/84	Insects.	- 2 mayfly nymphs, 16 stonefly nymphs, 8 chironomid larvae, 7 adult insects, 1 chironomid pupa.
Jan 4/85	Adult chum carcass remains.	- over 95% of sample by volume consisted of adult chum carcass remains; the other 5% were insect remains with two fish egg shells.
Mar 6/85	Chum alevins, chum carcass remains and insects.	- approximately 40% of the sample by volume consisted of chum alevins, 20% chum fry, 20% adult chum carcass remains, 20% insect remains.
May 9/85	Chum fry and insects.	- 95% of the sample consisted of newly emerged chum fry; the remaining 5% were made up equally of insect parts and adult chum carcass remains.

[a] Approximately 25 coho stomachs were analyzed on each sampling date.

In May, during chum fry migration, noticeable concentrations of coho smolts were observed immediately upstream and downstream of low head weirs. These weirs likely provided good feeding stations for juvenile coho since emergent chum fry that would drop over these structures may become disoriented in the turbulence and hence be more vulnerable to predation. Analysis of coho stomach contents showed that 95% of the intake by volume consisted of chum fry (Table 8, May data). The average number of fry per coho stomach increased with smolt size, with the largest smolts (11-12 g) containing up to 3 chum fry (Fig. 4). Downstream trapping results in the spring of 1985 also suggested that coho smolts fed heavily on chum fry. That year, coho smolts did not start migrating until the start of peak chum fry migration around mid-April, and many smolts remained in the channel until chum fry migration was completed (Fig. 5, Appendix 4c). Foy et al. (MS 1990) estimated that in Upper Paradise Channel, approximately 250,000 chum fry were consumed by coho smolts in the spring of 1985.

Seasonal Changes in Weight of Juvenile Coho

Figure 6 and Table 7 show seasonal changes in the mean weight of 1983 brood juvenile coho in the Upper Paradise Channel during the 1984-1985 study period. Between January and June 1985, mean weight of sampled fish increased from 2.9 g to 12.0 g, giving an instantaneous growth rate of 0.95%. This rate exceeds the growth rates normally found at British Columbia hatcheries. For example, growth rates of 0.07% to 0.52% were observed for comparable rearing periods for juvenile coho from Inch Creek, Capilano and Chehalis hatcheries (1983-1986 broods, DFO-SEP Brood Summaries). We suggest that the high growth rates of juvenile coho in Upper Paradise Channel are related to scavenging on adult chum carcasses and intensive feeding on chum alevins and fry in preparation for smolting.

Table 9 shows that coho smolts migrated from Upper Paradise Channel at a mean weight of 9 - 14 g. Mean weight of migrating coho appeared to change during the course of spring migration in 1985. However, these differences were not significant ($p < 0.05$) due to small sample sizes. Table 9 includes comparative size data for coho smolts from other study channels.

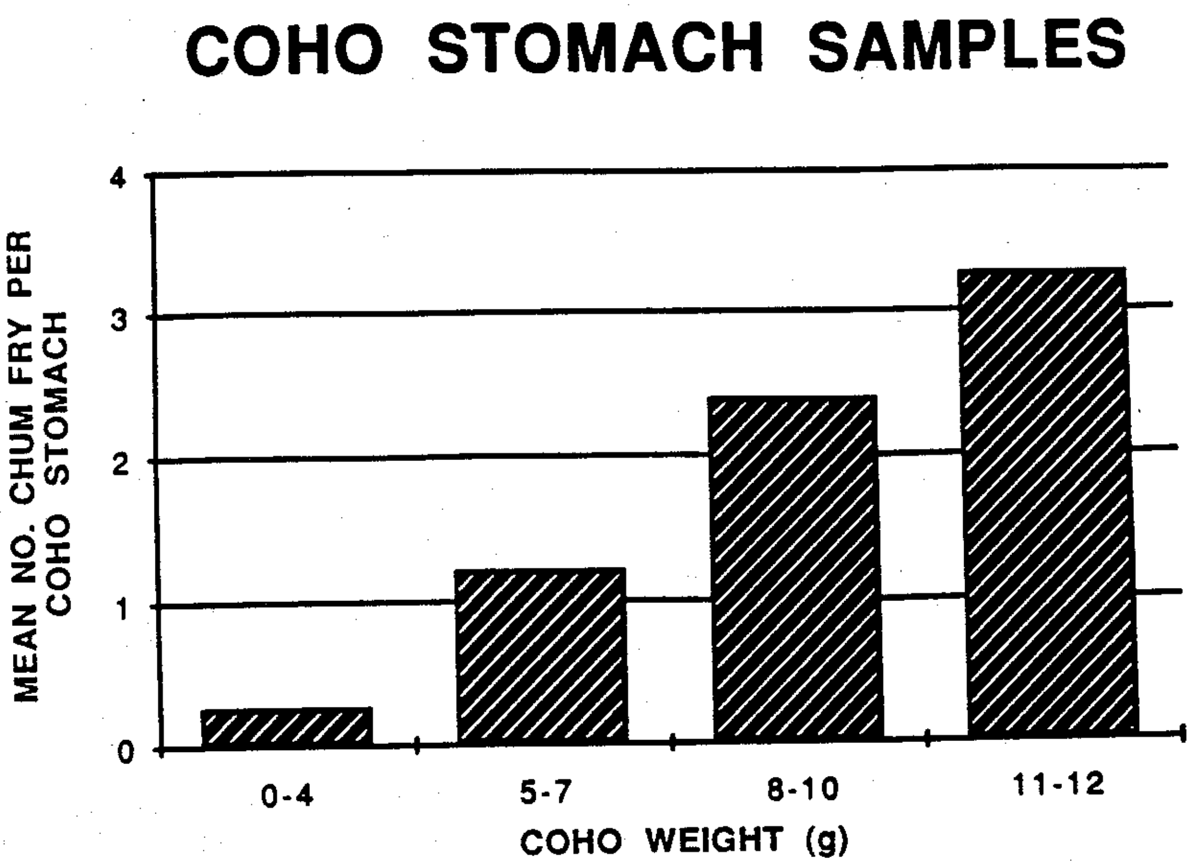

Figure 4. Relationship between juvenile coho weights and the average number of chum fry in their stomach contents, Upper Paradise Channel, May 9, 1985.

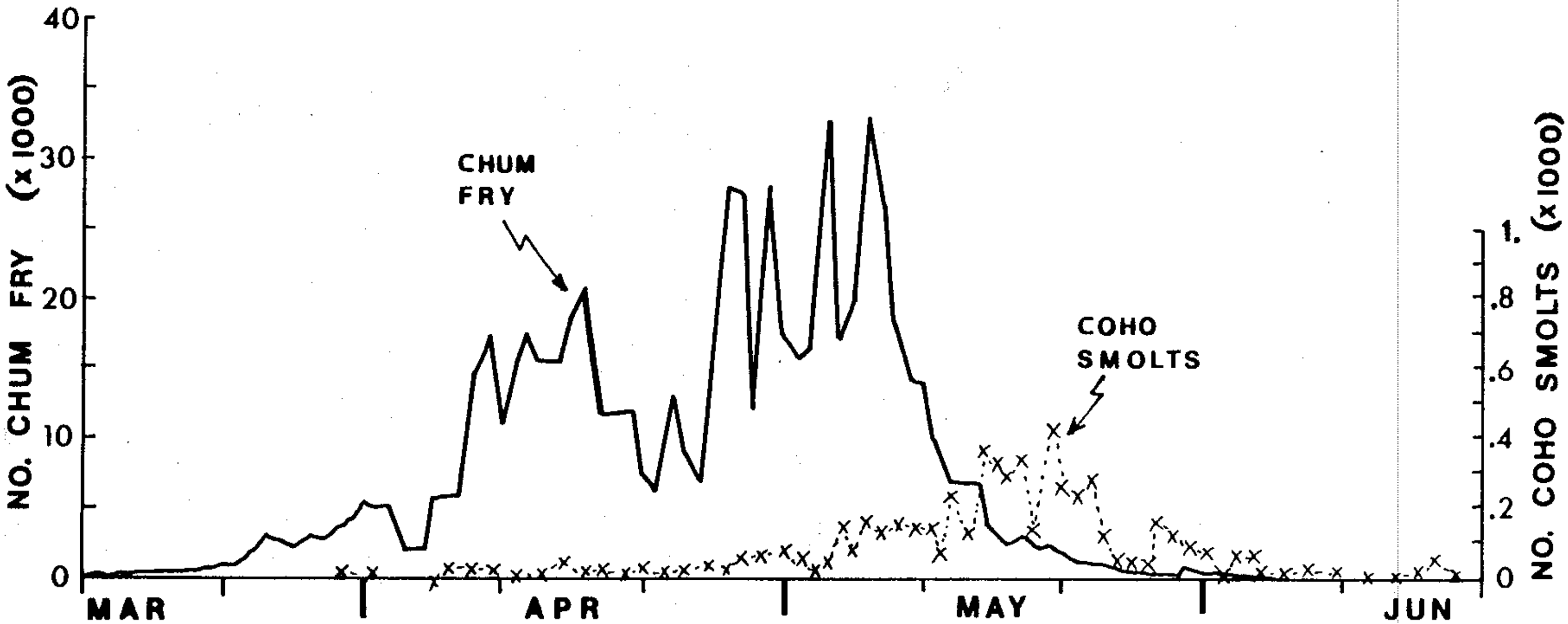

Figure 5. Daily downstream migration of chum fry and coho smolts from Upper Paradise Channel, March - June, 1985.

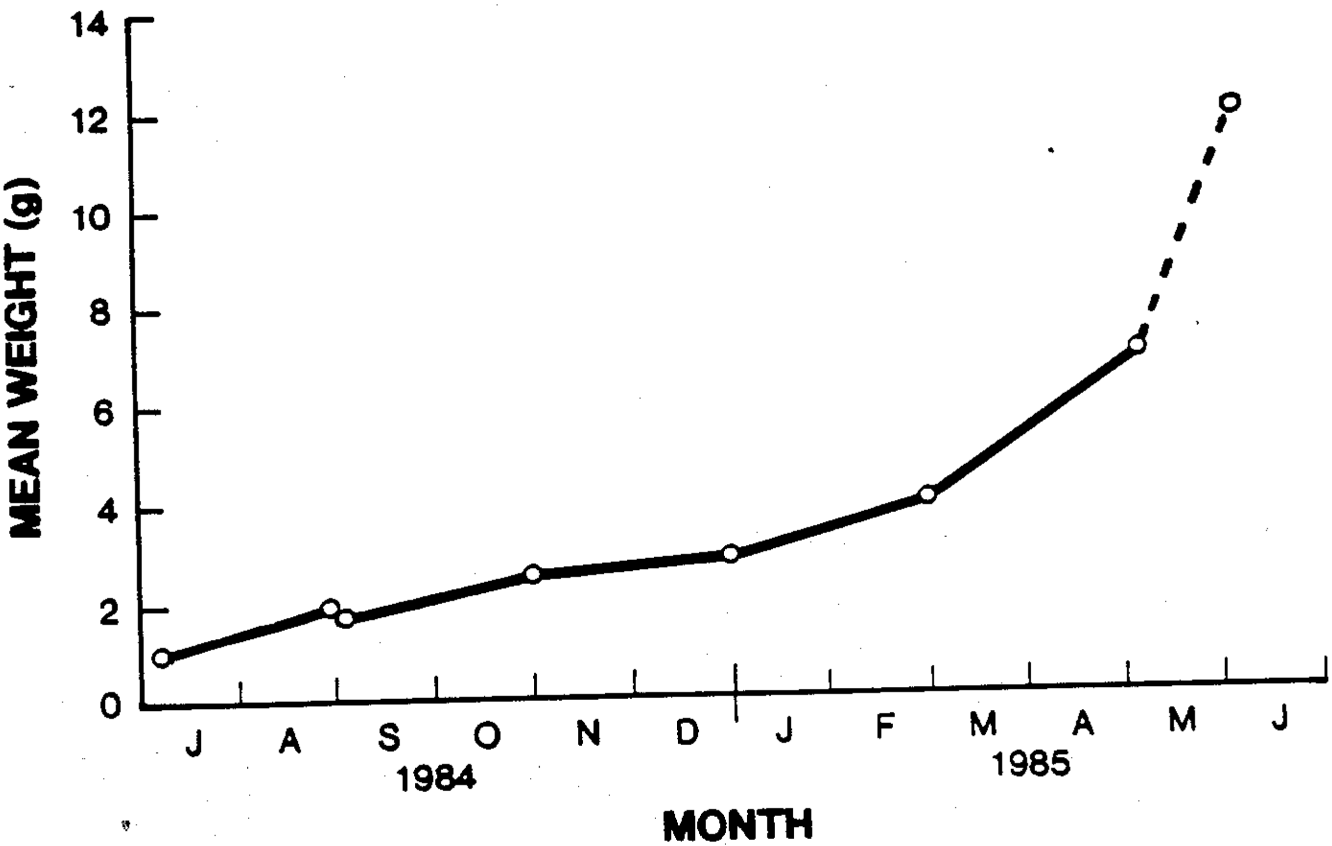

Figure 6. Mean weights of coho juveniles in Upper Paradise Channel, 1984-1985.

Table 9. Mean fork lengths and weights of coho juveniles captured by minnow trapping o electrofishing (both denoted with an asterisk), and in downstream traps at th study channels; n gives sample size.[a]

Sampling date	n	Length (mm) Mean	Length (mm) Range	Length (mm) SD	Weight (g) Mean	Weight (g) Range	Weight (g) SD
1985 Brood			WORTH CREEK				
*Feb 25/87	68[b]	83	60-114	12.5	-	-	-
*Feb 25/87	33[c]	67	51-85	10.9	-	-	-
Mean[d]		78					
1987 Brood							
May 13/89	10	111	84-132	16.7	15.5	6.6-24.7	6.
21/89	10	109	88-123	11.7	14.4	8.1-19.8	4.
26/89	10	120	110-150	11.3	19.4	14.4-34.0	5.
30/89	25	114	96-149	12.2	16.2	10.1-33.6	5.
Jun 5/89	25	118	95-210	23.8	19.4	10.5-87.6	15.
14/89	25	115	98-136	10.2	16.2	11.1-24.5	3.
20/89	20	113	96-132	9.3	15.3	11.7-23.4	2.
27/89	10	114	97-126	9.2	16.3	12.7-20.2	2.
Mean		114			16.6		
1988 Brood							
Apr 12-Jun 28/89	800[e]	-	-	-	0.34	0.32-0.37	-
1982 Brood			UPPER PARADISE				
May 9/84	24	97	75-115	11.9	10.0	4.4-16.5	3.
14/84	26	99	83-114	9.2	10.3	6.0-16.3	2.
Mean		98			10.2		
1983 Brood							
*Aug 30/84	25	53	32-83	11.0	2.0	0.8-6.5	1.
*Oct 30/84	25	59	43-80	10.1	2.5	0.9-5.4	1.
*Mar 6/85	25	71	62-83	4.9	3.9	2.7-6.9	0.
*May 9/85	25	82	70-94	8.0	7.1	4.2-11.2	2.
Apr 14/85	10	95	81-107	8.1	10.3	6.9-14.3	2.
23/85	10	96	80-114	14.0	10.7	4.3-16.8	5.
30/85	10	97	87-102	4.4	10.7	7.6-12.4	1.
May 9/85	10	106	89-125	12.5	13.6	7.0-24.5	5.
16/85	10	105	93-120	8.0	13.3	10.3-18.2	2.
29/85	10	109	80-123	13.8	14.2	5.7-20.3	5.
Jun 6/85	10	100	81-118	11.1	10.9	5.4-17.8	4.
17/85	10	95	77-118	13.0	8.8	4.8-14.5	3.
Mean		100[f]			11.6[f]		
1984 Brood							
May 15/86	10	106	83-123	12.3	12.9	5.0-19.5	4.
1987 Brood							
May 12/89	25	100	84-112	7.7	10.2	6.3-14.2	2.

(cont

Table 9 (cont'd).

Sampling date	n	Length (mm) Mean	Range	SD	Weight (g) Mean	Range	SD
			MAMQUAM				
1984 Brood							
May 7/86	25	91	79-107	5.2	7.9	5.0-13.6	1.6
Jun 8/86	15	84	65-95	8.7	6.5	2.9-9.0	1.8
Mean		88			7.2		
1985 Brood							
N/A /87	50	92	70-110	9.6	-	-	-
N/A /87	50	106	90-128	8.7	-	-	-
Mean		99					
1987 Brood							
May 13/89	25	69	55-89	10.9	3.8	1.6-8.2	2.1

[a] Overall seasonal mean is mean of means unless otherwise indicated.
[b] Top channel half.
[c] Bottom channel half.
[d] Weighted mean.
[e] Fry bulk-weighed approximately weekly in lots of 100.
[f] Mean size of migrating smolts (April 14 - June 17/85 data).

III. INTERRELATIONSHIP OF COHO JUVENILES WITH AQUATIC VEGETATION IN DEADMAN CHANNEL, 1984-1987 BROODS

Background

A groundwater channel was completed on Deadman Creek (Fig. 2) in August 1985. Figure 7 shows a diagrammatic sketch of the Deadman Channel. The uppermost 125 m long section was built with a zero gradient and an average width of 5 m, providing 625 m^2 of developed channel area. Native gravel in this section was replaced with a 15 cm deep layer of screened gravel (90% in the range 1.3-3.2 cm diameter) and rip-rap was placed along the banks. The remaining 450 m long lower section of the channel was only 2-3 meters wide and was built on a gradient ranging from 0.1% to 0.5%. This section had no bank armouring and hence no cover for juveniles, and its underlying gravel was covered with 15-30 cm of silt. The lower channel section could be best described as an "open ditch", intended only to provide access to the upper section, and having apparently little spawning or rearing potential. No juveniles were present initially in this lower section.

In less than two years, the lower section evolved into a productive spawning and rearing habitat. The change was credited to colonization by water cress, (Nasturtium officinale), an aquatic plant which quickly establishes roots in silt beds associated with slow moving water. Dense growth of water cress formed along the channel banks and attracted colonizing coho juveniles. The dense plant growth slowed the flow of water along the channel edge but caused increased velocity in mid-channel. This in turn increased water depth and established a thalweg (a path of maximum depth in a river or stream). The thalweg eventually prevented the water cress from growing completely across the channel. Silt in the path of this newly formed thalweg was washed away, exposing the gravel. This aided the formation of meandering pool-riffle sequences. In November/December 1986, approximately a year after channel construction, about 125 coho adults entered the channel and spawned in this lower section, primarily in the open water of the thalweg. Digging by spawners further modified the channel, extending the range of water depth from 5 cm to 90 cm.

Water cress beds in Deadman Channel provided suitable microhabitat for aquatic insects. Approximately 90% of the insects found in water cress beds were mayfields and stoneflies numbering some 50 insects per plant and averaging 3-4 mm in length. Highest insect densities were found on plants located in water velocities ranging from 15 to 40 cm/s. At velocities below 3 cm/s, few invertebrates were found on plants. This apparent preference of organisms for higher water velocities agrees with findings of Needham and Usinger (1956), Kennedy (1967) and Kimble and Wescle (1975). In addition, both Chapman (1966) and Mundie (1969) observed that the quantity of drift increases with water velocity. At Deadman Channel, the majority of salmonid juveniles appeared to be foraging in these higher velocity zones of 15-40 cm/s along the fringes of water cress that demarked the thalweg. Presumably, the thalweg/water cress interface provided an ideal place to forage, supplying juveniles with abundant drift food organisms adjacent to escape cover.

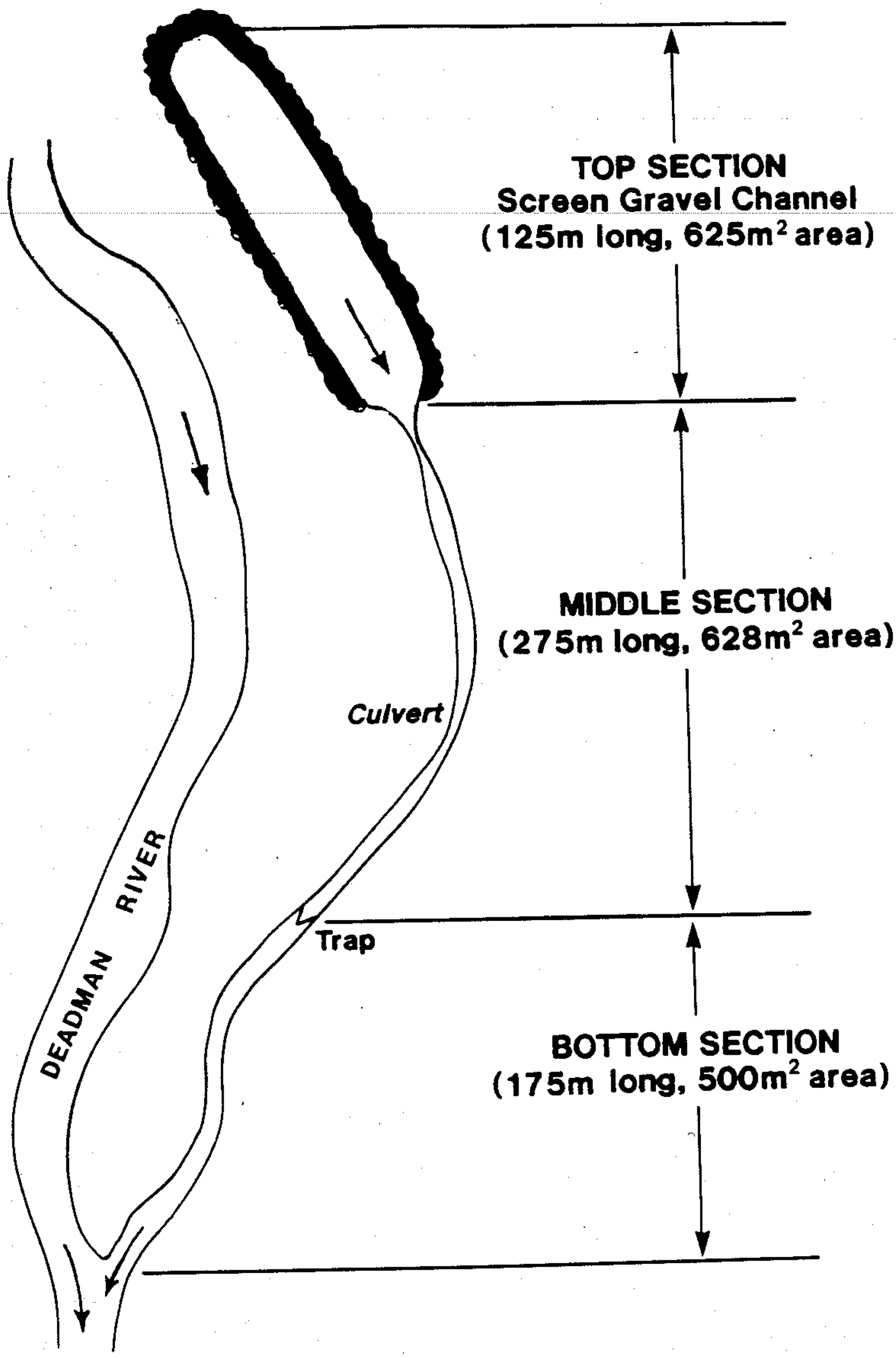

Figure 7. A diagrammatic sketch of Deadman Channel showing the top, middle and bottom sections.

Studies at Deadman Channel

Table 10 summarizes the changes in abundance of coho and steelhead juveniles in Deadman Channel for the 1984 to 1987 coho brood years. Individual coho broods are discussed below.

1984 Coho brood

Coho juveniles of the 1984 brood immigrated into the channel from the mainstem following channel completion in August 1985. By late winter of 1985/86, approximately 10% of the wetted channel area in the lower section was colonized by water cress. This provided the only source of cover for juveniles in that section. On April 10, 1986 approximately 500 juvenile coho were observed in the top channel section where only rocks provided cover, while an estimated 1,000 coho juveniles utilized the narrow lower channel section where water cress provided cover. In addition to coho, at least 700 rainbow juveniles, assumed to be steelhead, were present in the channel on April 10, 1986 (Table 10). On that date, several schools of juveniles were seen in the open channel water, and two of the schools were electroshocked. The resulting sample of 133 fish consisted of 60% coho and 40% steelhead juveniles, averaging 5.6 g and 2.8 g respectively. Schooling behaviour was probably related to downstream migration since the outmigration had ceased by late April as indicated by the absence at that time of juveniles in the channel and in a downstream fyke net trap which was operated for a brief period in the channel.

1985 Coho brood

Coho juveniles of the 1985 brood originated from spawners utilizing the channel and possibly included juveniles entering from the mainstem. Steelhead juveniles were apparently immigrants from the mainstem (see section below on Steelhead Fry Colonization). Figure 8 and Table 10 show that in 1986, juvenile coho densities declined from summer to winter, particularly in the middle section, while steelhead densities increased considerably during that period in both the top and middle sections (the bottom section was not surveyed in the summer). By December 9, 1986, the total calculated population of steelhead juveniles (8,059 or $4.6/m^2$) was about twice that of coho juveniles (3,868 or $2.2/m^2$).

Coho and steelhead juveniles from the 1985 brood apparently migrated out of Deadman Channel mainly between February 10, 1987 when several hundred fish were observed schooling, and February 16, 1987 when juveniles were no longer seen. Downstream trapping between March 3 and May 29, 1987 yielded only 78 coho and 1,227 steelhead juveniles (Table 10).

1986 Coho brood

The third year of channel assessment involving the 1986 brood, consisted of several visual surveys and the operation of a downstream trap between November 23, 1987 and May 29, 1988 (Table 10). Approximately 20,000-30,000 coho fry were estimated in the channel based on the May 15, 1987 visual survey. Deadman Channel was expected to produce a surplus of emergent fry that year given that approximately 125 adults spawned in the lower section the previous

Table 10. Abundance and mean weights of coho and steelhead juveniles in Deadman Channel, 1984-1987 coho brood years.

Date	Sampling method	Section sampled[a]	Coho[b] Total	Coho[b] No./m²	Coho[b] Age	Coho[b] Wt.	Steelhead[b] Total	Steelhead[b] No./m²	Steelhead[b] Age	Steelhead[b] Wt.	Comments
					1984 COHO BROOD YEAR						
Aug/85	-	-	-	-	-	-	-	-	-	-	Channel construction completed.
Winter 85/86	Visual survey.	All sections	-	-	-	-	-	-	-	-	By late winter 1985/86, approx. 10% of lower section was colonized by water cress.
Jan 14/86	Electro-shocking[c].	Top.	452	0.7	1+	8.0g	83	0.1	-	17.3g	
Mar 7/86	Mark re-capture/ electro-shocking.	Top.	480[d]	0.8	1+	8.7g	36	0.1	-	20.2g	The captured juvenile coho (1984 brood) represent immigrants from the mainstem.
Apr 10/86	Mark re-capture/ electro-shocking.	Top.	479[e]	0.8	1+	9.3g	84	0.1	-	-	
	Visual survey.	Mid + Bottom April total	~1,000 ~1,479	0.9 0.9	1+ 1+	5.6g 6.8g	- 700+	- 0.5+	- 0+	- 2.8g	Juvenile coho apparently migrated from the channel in Apr/86 after 2 winters in freshwater.

(Cont'd)

Table 10 (cont'd).

Date	Sampling method	Section sampled[a]	Coho[b] Total	Coho[b] No./m²	Coho[b] Age	Coho[b] Wt.	Steelhead[b] Total	Steelhead[b] No./m²	Steelhead[b] Age	Steelhead[b] Wt.	Comments
				1985 COHO BROOD YEAR							
July 15/86	Electro-shocking.	Top	476	0.8	0+	1.6g	0	0	-	-	
		Mid	7,473	11.9	0+	-	0	0	-	-	
		Bottom	N/A[f]	-	-	-	N/A	-	-	-	
		Total	7,949	6.3							
Aug 19/86	Electro-shocking.	Top	433	0.7	0+	3.0g	130	0.2	0+	1.7g	Influx of steelhead juveniles into channel in late fall 1986 coincided with decline in coho densities.
		Mid	3,705	5.9	0+	-	1,695	2.7	0+	-	
		Bottom	N/A[f]	-	-	-	N/A	-	-	-	
		Total	4,138	-			1,825+	1.5			
Dec 9/86	Electro-shocking.	Top	370	0.6	0+	3.3g	2,741	4.4	0+	2.8g	
		Mid	2,198	3.5	0+	3.6g	3,768	6.0	0+	2.8g	
		Bottom	1,300	2.6	0+	3.3g	1,550	3.1	0+	-	
		Total	3,868	2.2		3.5g	8,059	4.6			
Feb 10 & 16/87	Visual survey.	All sections.	-	-	-	-	-	-	-	-	Schooling juveniles disappeared from the channel by mid-Feb/1987. Therefore, majority of coho juveniles probably migrated from the channel at this time, after two winters in freshwater.
Mar 3 - May 29/87	Downstream trap below mid-section.	Top + Mid[g]	78[h]	-	1+	3.0g	1,227[h]	-	-	4.6g	

(Cont'd)

Table 10 (cont'd).

Date	Sampling method	Section sampled[a]	Coho[b] Total	Coho[b] No./m^2	Coho[b] Age	Coho[b] Wt.	Steelhead[b] Total	Steelhead[b] No./m^2	Steelhead[b] Age	Steelhead[b] Wt.	Comments
				1986 COHO BROOD YEAR							
Nov - Dec/86	Visual survey.	All sections.	-	-	-	-	-	-	-	-	In Nov/Dec 1986, approx. 125 coho adults spawned in the lower channel section with water cress.
May 15/87	Visual survey.	All sections.	20,000-30,000	11.4+	0+	-	-	-	-	-	Very high juvenile denisities observed in Oct/87.
Oct 2/87	Visual survey.	All sections.	-	-	-	-	-	-	-	-	During Oct/Nov 1987, major livestock damage occurred to the channel water cress flora.
Nov 17/87	Visual survey.	All sections.	-	-	-	-	-	-	-	-	Schooling juveniles observed in mid-November 1987.
Nov 23/87 - May 29/88	Downstream trap below mid-section.	Top + Mid.	1,448[h]	-	1+	4.0g	5,167[h]	-	-	-	Juvenile coho apparently migrated from the channel in November 1987, after one winter.

(Cont'd)

Table 10 (cont'd).

Date	Sampling method	Section sampled[a]	Coho[b]				Steelhead[b]				Comments
			Total	No./m^2	Age	Wt.	Total	No./m^2	Age	Wt.	
			1987 COHO BROOD YEAR								
July 27/88	Electro-shocking.	Top	306	0.5	0+	2.7g	166	0.3	1+[k]		Abundant water cress growth in mid-section (about 80% cover).
		Mid	9,985	15.9	0+	3.6g	0	0.0	-		
		Bottom[i]	190	1.1	0+	-	20	0.1	1+		
		Bottom[j]	3,221	9.8	0+	2.8g	0	0.0	-		
		Total	13,702	7.8			186	0.1			

Channel sections were defined as follows: top section with screened gravel (625 m^2 area), mid-section with water cress (628 m^2 area) and bottom section with water cress (500 m^2 area) (Fig. 7).

Fish densities per m^2 were based on channel area per section (see footnote "a" above).

Estimated capture efficiency from single pass method of electroshocking, based on previous trials, was: p = 0.45.

March 7, 1986 population estimate was based on 94 marks (all released on January 14, 1986), as well as 39 mark recaptures and 199 total captures made on March 7, 1986.

April 10, 1986 population estimate was based on 221 marks (94 marks released on January 14, 1986 and 127 marks released on March 7, 1986), as well as 95 mark recaptures and 206 total captures made on April 10, 1986.

Bottom section was not surveyed in July and August 1986.

Due to trap location (Fig. 7), bottom section was not trapped.

Incomplete migration counts since many juveniles apparently migrated before trap installation on November 23, 1987.

170 m^2 channel area.

330 m^2 channel area.

Population estimates for 0+ steelhead juveniles were zero in all channel sections on this date.

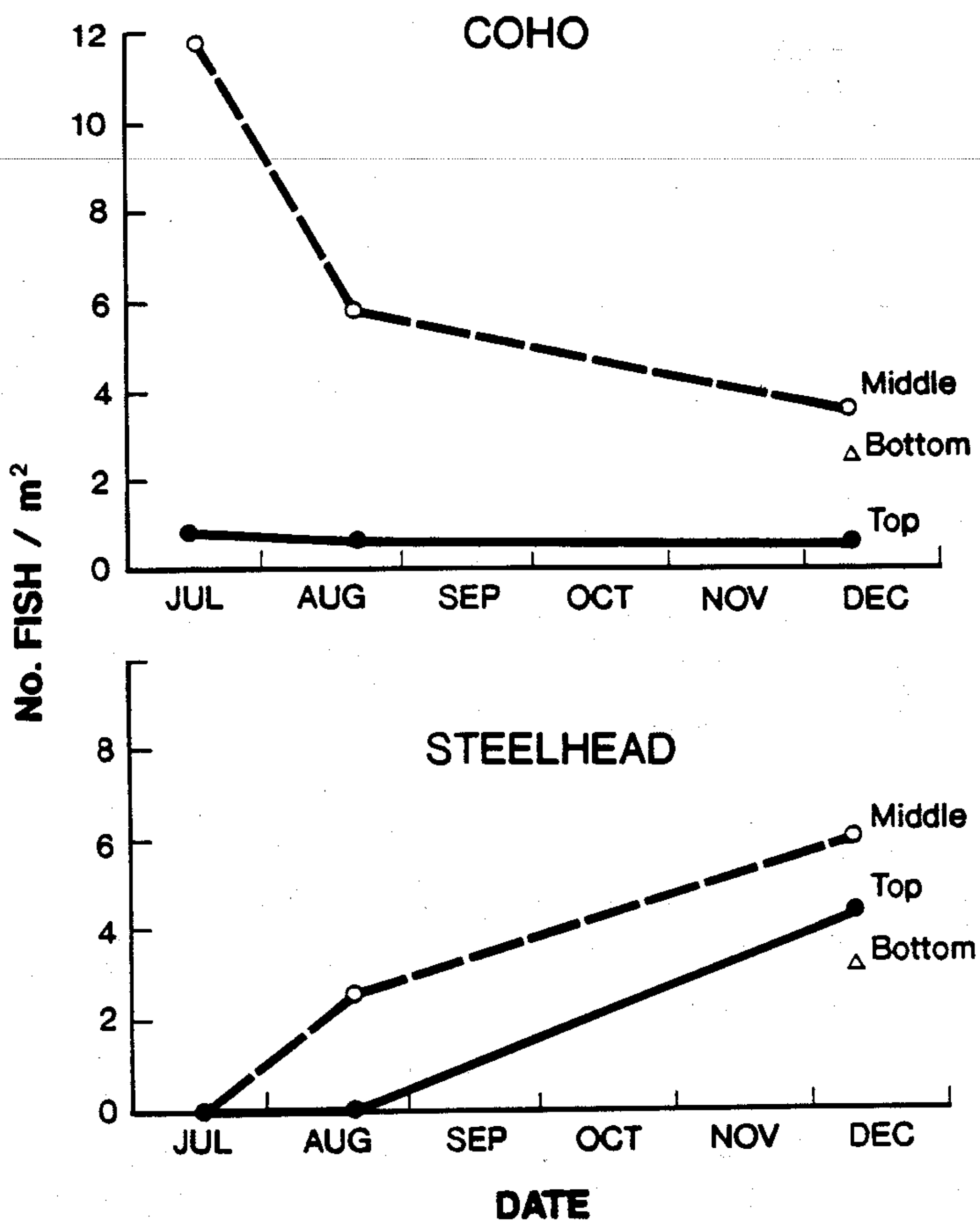

Figure 8. Estimated densities of coho and steelhead juveniles in the top, middle and bottom sections of the Deadman Channel on July 15, August 19 and December 9, 1986.

winter, and that hydraulic sampling indicated a mean survival to hatch of 95%. An inspection made on October 2, 1987 indicated that rearing densities were the highest observed in the channel for that time of year; however, no visual population estimates were made. On November 17, juveniles were seen schooling, and from past experience this behaviour indicated that downstream migration had already begun. By the time the fence was installed on November 23, many juveniles had left. A total of 1,448 coho juveniles and 5,167 steelhead juveniles were enumerated through the fence between November 23, 1987 and May 29, 1988 (Appendix 6). Mean size of coho migrants was 4 g.

The early migration of the 1986 brood coho (in November 1987 without overwintering in the channel, compared to April and February after overwintering in the channel for the 1984 and 1985 broods respectively) was attributed to disappearance of much of the water cress sometime between early October and mid-November 1987. Over half the area of the water cress beds was uprooted during that period by foraging cattle, as indicated by hoof prints found along the channel banks and extensive bank damage.

1987 Coho brood

The most notable change observed during the July 1988 survey compared to previous years, was the abundant growth of water cress in the middle channel section where approximately 80% of the wetted area was covered with this plant. Calculated abundance of coho juveniles, based on electrofishing results, was also very high (13,702 fish), with the highest density of 15.9 fish/m^2 observed in the mid-section (Table 11). At that time, steelhead densities were less than 0.5/m^2 throughout the channel (Table 11). Subsequent data on smolt yields and downstream migration timing were not available for this report.

Water Cress Growth Related to Juvenile Abundance

Table 11 shows the calculated densities for coho and steelhead juveniles, and the corresponding estimated water cress abundance in Deadman Channel in 1986 and 1988. In 1986, each of the July, August and December surveys showed a persistent positive relationship between juvenile coho densities and water cress abundance. In particular, the December survey indicated a significantly higher coho density in the middle and bottom channel sections containing water cress (3.1 coho/m^2) compared to the top unvegetated section (0.6 coho/m^2). A similar trend was observed in July 1988 when a heavy growth of water cress in the middle channel section was recorded along with high coho densities of 15.9/m^2, compared to only 0.5/m^2 in the top unvegetated section. Figure 9 shows the strong positive relationship between coho juvenile densities and water cress abundance in July 1988.

Unlike coho juveniles, densities of steelhead juveniles did not reflect water cress abundance (Table 11).

Steelhead Fry Colonization

Steelhead juveniles in Deadman Channel evidently originated in the mainstem since no spawners were ever observed in the channel. Juvenile steelhead densities increased significantly in the channel from late summer

Table 11. Density estimates for coho and steelhead juveniles and corresponding water cress abundance in Deadman Channel, 1985 and 1987 coho broods.[a]

Date	Channel section	Coho (Age 0+) No./m^2	Steelhead (Age 0+) No./m^2	% of Wetted area colonized by water cress
1985 BROOD				
Jul 15/86	Top	0.8	0	0
	Mid	11.9	0	20
Aug 19/86	Top	0.7	0.2	0
	Mid	5.9	2.7	20
Dec 9/86	Top	0.6	4.4	0
	Mid	3.5	6.0	20
	Bottom	2.6	3.1	10
	Mid + Bottom	3.1	4.7	-
1987 BROOD				
Jul 27/88	Top	0.5	0.3 (Age 1+)	0
	Mid	15.9	0	80
	Bottom[b]	1.1	0.1 (Age 1+)	10
	Bottom[c]	9.8	0	50

[a] Density estimates from Table 10.
[b] 170 m^2 channel area.
[c] 330 m^2 channel area.