New Zealand Freshwater Research Report No. 1

NIWAR

National Institute of Water & Atmospheric Research Ltd

Te Tari Taiharo Nukurangi

Effect of artificial freshes in experimental channels on benthic macroinvertebrate density and drift and on quinnat salmon growth

M.J. Rutledge
J P. Graybill
J.F. Kilpatrick
J.R.M. Kelso

ISSN 1171-9842

New Zealand Freshwater Research Report No. 1

Effect of artificial freshes in experimental channels on benthic macroinvertebrate density and drift and on quinnat salmon growth

by

M.J. Rutledge
J P. Graybill
J.F. Kilpatrick
J.R.M. Kelso

Report to: Electricorp

Freshwater Division
NIWAR
Christchurch

December
1992

NEW ZEALAND FRESHWATER RESEARCH REPORTS

This report is one of a series issued by the Freshwater Division of the National Institute of Water and Atmospheric Research Ltd. (NIWAR).

A current list of publications in the series with their prices is available from Freshwater Division. Organisations may apply to be put on the mailing list to receive all reports as they are published. An invoice will be sent for each new publication.

For all enquiries and orders, contact:

The Publications Officer
Freshwater Division
NIWAR
PO Box 8602
Riccarton, Christchurch
New Zealand

ISBN 0-478-08301-7

Edited by:
C.K. Holmes

The studies documented in this report have been funded by the Electricity Corporation of New Zealand Limited

NIWAR

National Institute of Water & Atmospheric Research Ltd
Te Tari Taiharo Nukurangi

The National Institute of Water and Atmospheric Research Ltd. specialises in meeting information needs for the sustainable development of water and atmospheric resources. It was established on 1 July 1992. Freshwater Division comprises scientific and technical personnel from the former Marine and Freshwater Division, Department of Scientific and Industrial Research (Hydrology Centre, Christchurch and Taupo Research Laboratory) and from the former Freshwater Fisheries Centre, MAF Fisheries, Christchurch.

The *New Zealand Freshwater Research Report* series continues the *New Zealand Freshwater Fisheries Report* series (formerly the *New Zealand Ministry of Agriculture and Fisheries, Fisheries Environmental Report* series), and *Publications of the Hydrology Centre, Christchurch.*

CONTENTS

TABLES

FIGURES

SUMMARY

The effects of different frequencies of artificial freshes on benthic macroinvertebrate density, macroinvertebrate drift and quinnat salmon growth was examined in five experimental channels. Experimental flow regimes were: channel 1, constant low flow (100 l/s); 2, constant high flow (370); 3, weekly freshes; 4, fortnightly freshes; and 5, four-weekly freshes. Flows were selected to maximise mean velocity differences, i.e., base flow 0.3 m/s, peak flow 0.9 m/s.

Highest macroinvertebrate densities found on tiles used as artificial substrates were in channel 4 followed by channels 3, 5, 2 and 1. The greatest number of taxa was found in channels 1 and 2 (30 taxa). The three channels receiving artificial freshes had 22-25 taxa. Highest macroinvertebrate drift density occurred in channel 1 followed by channels 5, 4, 3 and 2. Hydroptilid caddisflies dominated both the macroinvertebrate fauna on tiles and the drift fauna, followed by molluscs. The experimental channels with the highest densities of macroinvertebrates on tiles generally had the lowest drift densities. These differences could have resulted from differential colonisation by taxa on artificial and natural substrates and the effect of differing periphyton production among the stream channels.

Diet of juvenile quinnat salmon (*Oncorhynchus tshawytscha*) was similar among the stream channels and was dominated by hydroptilids. Daily growth rates of salmon were similar among the stream channels but apparently less than that expected for the Waitaki River. Reduced food supply in stream channels or repeated electric fishing may have contributed to reduced growth rates.

The fresh occurring at fortnightly intervals resulted in the highest macroinvertebrate density, high drift density and no reduction in the growth of juvenile quinnat salmon.

1. INTRODUCTION

Because hydro-electric impoundments have substantially altered the flow regime of the lower Waitaki River, the potential for accumulation of silt (Jowett 1983; Kirk 1983) and changes in macroinvertebrate communities (Rutledge 1987) is increased. Further, periphyton growth is known to be encouraged downstream of dams by the reduction in peak flow and mean discharge (Graybill *et al.* 1988). These changes to river characteristics may also affect fish through their food supply. A potential tool to remedy the effects from any residual river such as that resulting from power development of the lower Waitaki River could, therefore, include manipulation of the flow regime to at least reduce periphyton accrual and silt deposition and enhance macroinvertebrate and fish production.

This study investigates the influence of differing flow regimes in the lower Waitaki replicate stream channels (Irvine 1984) on macroinvertebrate density, macroinvertebrate drift and growth of quinnat salmon. These studies extend the initial assessment of effects of successive flow perturbations on stream invertebrates by Irvine (1985).

2. STUDY AREA AND REPLICATE CHANNEL FACILITY

The research was carried out in the replicate channel facility (Irvine 1984) located on the south bank of the lower Waitaki River, near Black Point (Fig. 1). The facility consisted of five artificial stream channels, each approximately 100 m long, 3 m wide and with hydraulic gradients of 1:900. Each channel had four riffles (about 17 m long) alternating with three pools (approximately 8 m long and 1 m deep). The channels were lined to a depth of about 60 cm with cobble-gravel sized substrate, obtained from the bed of the Waitaki River.

The replicate channels received water from the Waitaki River via a 30 ha irrigation header pond and a 0.15 ha constant level header pond. Water entered each of the channels through 750 mm diameter intake pipes, regulated by hand wheel operated slide gates. Screens (5 mm mesh) at the upstream ends of the channels prevented fish leaving upstream. Inclined plane screen traps at the bottom of each channel allowed fish to leave downstream, but prevented others from entering.

3. METHODS

3.1 Experimental flow regimes

Flow volumes and mean velocities for each channel are summarised in Table 1 and Figure 2. Channels 1 and 2 operated at constant "low" and "high" flows, respectively, for the duration of the study. Channels 3, 4, and 5 received an artificial fresh at weekly, fortnightly and four-weekly intervals respectively, from base to peak flows. Fresh duration was two days.

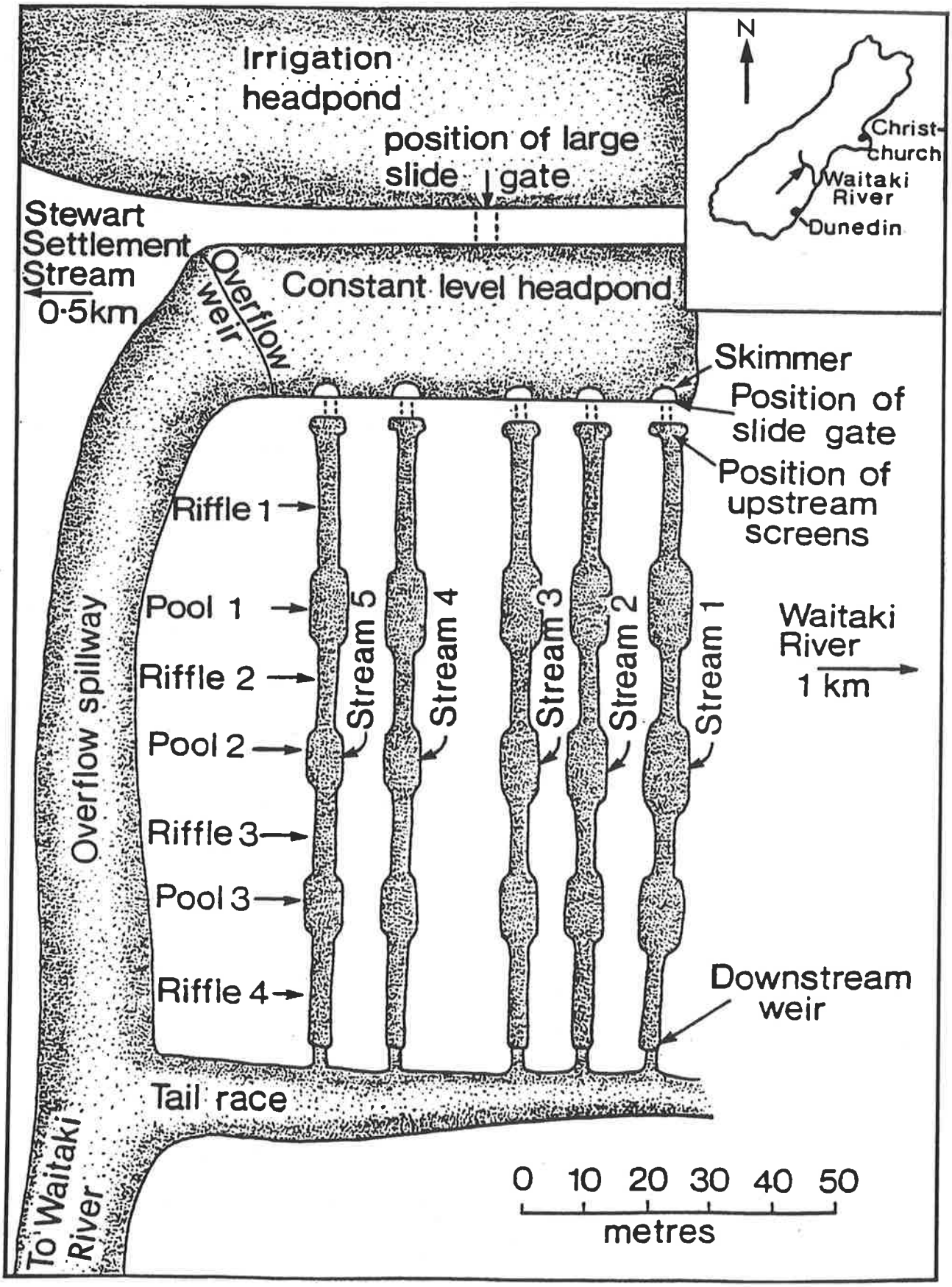

FIGURE 1. Replicate channel facility (semi-diagrammatic). Inset shows location of Waitaki River in South Island, New Zealand (reproduced from Irvine 1984).

TABLE 1. Flow volumes and mean velocities for experimental flow regimes in five experimental channels, lower Waitaki River.

Channel No.	Flow regime	Flow volume (l/s) base flow	Flow volume (l/s) 2-day high flow	Mean velocity (m/s) base flow	Mean velocity (m/s) high flow
1	constant low flow	110	NA	0.3	NA
2	constant high flow	370	NA	1.06	NA
3	weekly fluctuation	130	410	0.3	0.8
4	fortnightly fluctuation	110	460	0.3	0.9
5	4-weekly flucutation	130	390	0.3	0.9

While flows changed in channels 3, 4 and 5, mean base and peak velocities were maintained. Flows were selected *a priori* to maximise mean velocity differences. The changes from base flows to peak flows occurred virtually instantaneously. Timber weirs were installed at the tail ends of each riffle in channels 1, 3, 4, and 5 to enable equalisation of mean velocities at approximately 0.3 m/s during base flows. The weirs were removed before initiating freshes in each of the channels. The first fresh was initiated in channel 3 on 23.12.85 and the last fresh was on 28.05.86.

The upstream screens were cleaned at least twice weekly. During the freshes in channels 3, 4 and 5 it was sometimes necessary to clean screens every four hours. Maintaining clean screens in channel 2 became impossible after about six weeks because of high debris levels. The upstream screens in channel 2 were therefore removed on 24.02.86.

3.2 Introduction of macroinvertebrates and quinnat salmon

After construction of the replicate channels in 1981, the channels were "seeded" with macroinvertebrates from nearby streams (Irvine 1984). Inspection of the channels in October 1985 showed that the density and diversity of macroinvertebrates was low. From 25.12.85 - 14.02.86, the channels were seeded four times with macroinvertebrates collected from the Hakataramea, Maerewhenua, lower Waitaki Rivers, and Stewart Settlement Stream. The introduced fauna was typical of New Zealand streams and included large numbers of mayflies, caddisflies and stoneflies. Introduced taxa are listed in Appendix I. Care was taken to ensure roughly equal quantities of macroinvertebrates were introduced into the upstream end of each channel.

Each of the five channels was electric fished on 21.01.86 to remove all fish. Large numbers of large long-finned eels and 1+ brown trout, as well as a few quinnat salmon fry and fingerlings, were captured and released downstream of the replicate channel facility. Each channel was then stocked with 120 juvenile quinnat salmon captured by seining side braids of the lower Waitaki River. Because of difficulties in obtaining enough fish, simultaneous stocking of the channels was not possible. Instead, fish were introduced over a period of six days from 24.01.86 - 31.01.86. One subsample of 75 fish was measured (fork length to nearest mm) and weighed (to nearest 0.01 of a gram) after anaesthesis in benzocaine. Fish were released into the top pool of each channel.

3.3 Benthic macroinvertebrate density

To obtain directly comparable estimates of the density of benthic macroinvertebrates in each channel, we used hexagonal paving tiles (150 mm diameter x 30 mm deep) as sampling substrates. Tiles were placed in groups of 20 (four rows of five) at the downstream end of riffles 1 and 4 in each channel. Tiles were embedded in the substrate with their surface flush with that of the surrounding substrate. Four tiles were selected from each of the two arrays over five sampling periods, giving a total of 40 samples per channel over the duration of the experiment.

The tiles were easy to remove and processing of samples was rapid. They were recovered by slowly and carefully lifting the tile into a standard (0.125 mm mesh) surber sampler placed immediately downstream. The tile was then scrubbed and animals and periphyton were retained in the surber sampler. The surber sampler was inverted over a white plastic tray (400 x 275 mm) half filled with water; animals and material adhering to the sampler were rinsed off using squirt

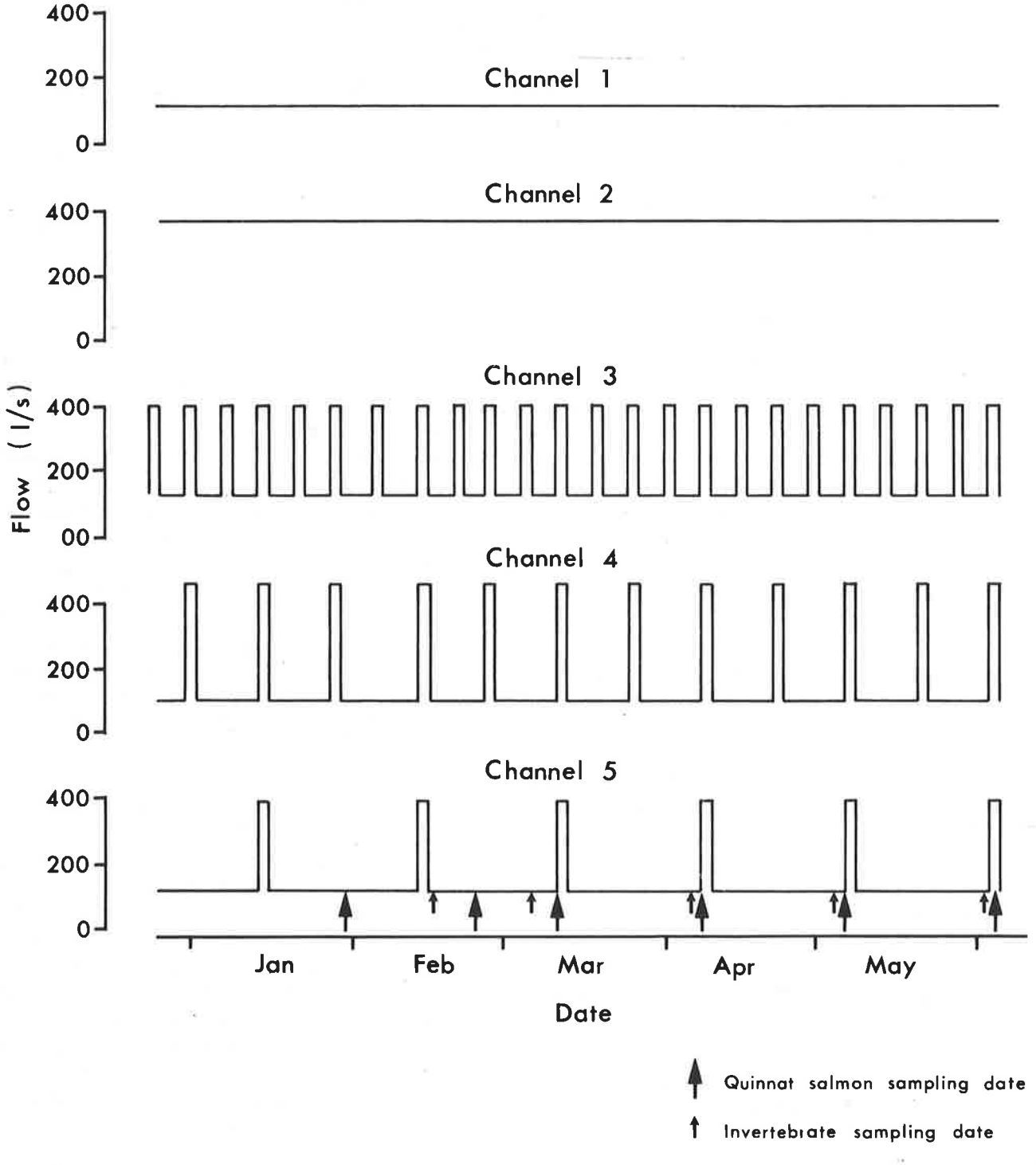

FIGURE 2. Schematic representation of flow regimes, channels 1-5 inclusive, with sampling dates for invertebrates and quinnat salmon.

bottles. The contents of the plastic tray were then filtered through a 0.125 mm sieve and material retained was transferred to either 10 or 500 ml plastic containers (depending on sample size) and preserved in 95% ethanol. Macroinvertebrates were identified and counted in the laboratory. Results are expressed as mean numbers/tile for the 8 tiles collected per channel during each sampling period and mean percentage composition by major taxonomic groups.

3.4 Macroinvertebrate drift

Macroinvertebrate drift was estimated using samplers similar to those described by Field-Dodgson (1983). Samplers consisted of three plastic rainwater adaptors attached between two lengths of flat aluminium. The upstream aperture of each sampler was 60 x 60 mm. A 0.25 mm mesh drift net was attached to the circular posterior end of each sampler. Samplers were set at the top of riffle 1 and bottom of riffle 5 in each channel during each of the five sampling periods. On each occasion, samplers were set one hour before sunset and retrieved one hour after sunrise the following day. Samplers were set about 5 mm below the water surface. Water velocities at sampler apertures were measured before and after sampling, using an Ott current meter, and the water volume filtered was calculated using the mean velocity value. All drift samples were collected during base flows (Fig. 2).

Following retrieval of drift nets, their contents were emptied into 500 ml plastic jars and preserved in 95% ethanol. The procedure for sample processing varied depending on the quantity of material collected. It was not practical to process the entire volume of large samples; therefore, three subsamples, collectively at least 20% by weight of the entire sample, were examined. This procedure was used for about half of the samples collected. Macroinvertebrates were identified and counted, and abundance was expressed as animals per cubic metre, assuming 100% filtering efficiency of the drift samplers. Percentage composition by major taxonomic groups was calculated to allow comparison with the composition of the benthic macroinvertebrates sampled from tiles.

3.5 Sampling of quinnat salmon juveniles

Quinnat salmon were captured by electric fishing each channel at about four-weekly intervals (Fig. 2). Because electric fishing may affect benthic macroinvertebrate drift and colonisation (Fowles 1975), sampling for fish and invertebrates was done separately. During electric fishing, care was taken not to cause disturbance in the vicinity of tiles. Captured quinnat salmon were anaesthetized in benzocaine, measured (to the nearest mm) and weighed (to the nearest 0.01 g) before being returned to the channel. All other species caught (e.g., longfinned eels, brown trout) were released downstream of the channels. An attempt was made to capture 25 quinnat salmon from each of the channels during each sampling period; however, this was not always possible, especially in channel 1, towards the end of the experiment. Electric fishing in channel 2 was discontinued after 24.02.86 when the top screens were removed, because immigration and emigration possibilities were greatly enhanced.

3.6 Analysis of quinnat salmon gut contents

While it was intended to sacrifice five quinnat salmon for gut analysis from each channel during each electric fishing period, this was not possible due to the low numbers of fish caught. We therefore had to restrict stomach content analysis to three sampling periods only (March, April and June). No analysis was done for channel 2 (see Section 3.5). Fish to be analysed for stomach contents were preserved in 5% formalin. Later, stomachs were removed, a visual assessment of stomach fullness (arbitrary scale from 0 to 10; 0 = empty, 10 = full) was made and individual items in the stomach were identified and counted. Results were expressed as mean percentage composition (by number) and occurrence as well as by mean stomach fullness.

4. RESULTS

4.1 Benthic macroinvertebrates

4.1.1 Abundance

Mean numbers of benthic macroinvertebrates per tile and overall means (all sampling periods combined) are shown in Figure 3. Highest densities in each channel were recorded in the March sample with the exception of channel 2, which reached a peak in April. Subsequently, densities declined through May and June in channels 2, 3 and 4, but in channels 1 and 5 densities again increased in June. Overall, channel 4 (fortnightly fresh) had the highest densities of macroinvertebrates with a mean of 247/tile; this result was strongly influenced by the large peak in March, when a density of 543/tile was recorded. Next highest benthic macroinvertebrate densities were found in channel 3 (196/tile) followed by channels 5 (165/tile), 2 (146/tile) and 1 (130/tile).

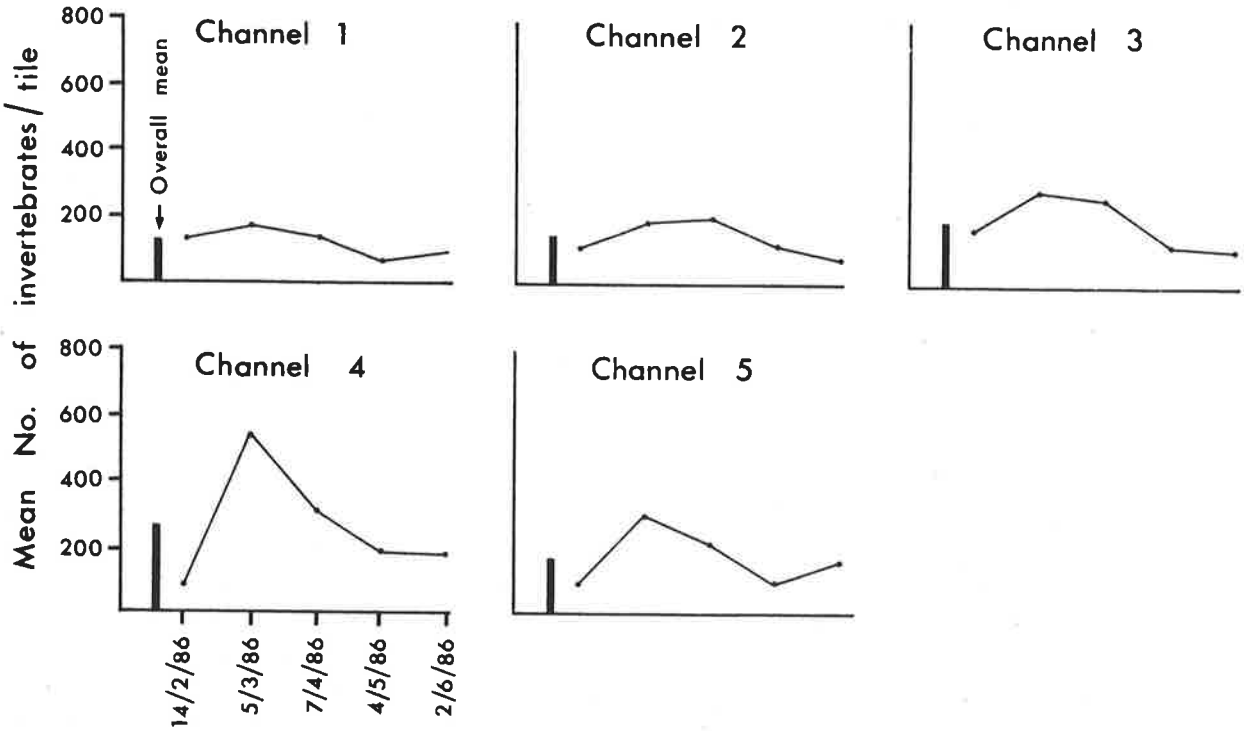

FIGURE 3. Mean number of invertebrates per tile for the five sampling periods and overall mean (vertical bar).

4.1.2 Community composition

The percentage composition of benthic macroinvertebrates by major taxonomic group for each sampling occasion, in each channel, is illustrated in Figure 4. Appendix II lists abundances of each taxon found in each channel. Hydroptilid caddisflies (mostly *Oxyethira*) dominated the macroinvertebrate fauna in all five channels, although their contribution varied considerably between months. In channels 2 and 3 the proportion of hydroptilids peaked in April, while in channels 4 and 5 the greatest numbers occurred in March. In channel 1, on the other hand, the peak occurred in February. Overall, the proportion of hydroptilids in the macroinvertebrate communities in channels 3, 4 and 5 was very similar, ranging from 58.1 to 61.2%; in channel 2, hydroptilids comprised 43.7 and in channel 1 35.4% of the community (Fig. 4).

After hydroptilids, the molluscs (mostly *Potamopyrgus* and *Physa*) formed the next most abundant group and reached a maximum in either May or June in each channel. Overall, their proportion was very similar in channels 2-5, ranging from 18.2 to 23.4%. In channel 1, however, they formed much higher proportion (31.2%).

Amphipoda formed the third most abundant taxonomic group. In channels 1, 3, 4 and 5, the proportion of amphipods declined from February through to April, then peaked in either May or June. In channel 1 the proportion of amphipods increased to a minor peak in March, then declined in April, before rising to a maximum in June. The overall proportion which amphipods comprised was the same (16.3%) in channels 1 and 2 and very similar in channels 4 and 5 (7.6% and 7.7% respectively). In channel 3 the overall proportion they comprised was 12.0%.

Deleatidium and "other" caddisflies, including *Pycnocentria*, *Pycnocentrodes*, *Aoteapsyche*, *Polyplectropus*, tended to decline in their proportional contribution over time in each of the channels. Overall, channel 2 had the highest proportion (5.9%) of "other" caddisflies, while the highest proportion of *Deleatidium* (2.8%) occurred in channel 4, followed by channel 2 (1.8%). Both Elmidae and the "other" (mostly chironomids and oligochaete worms) categories comprised a relatively small proportion of the faunas in each of the channels. Macroinvertebrates in the "other" category generally increased over time in channels 1, 2, and 4, but remained fairly constant in channels 3 and 5. Overall, channel 1 contained the highest proportion of macroinvertebrates in both the "other" and Elmidae categories.

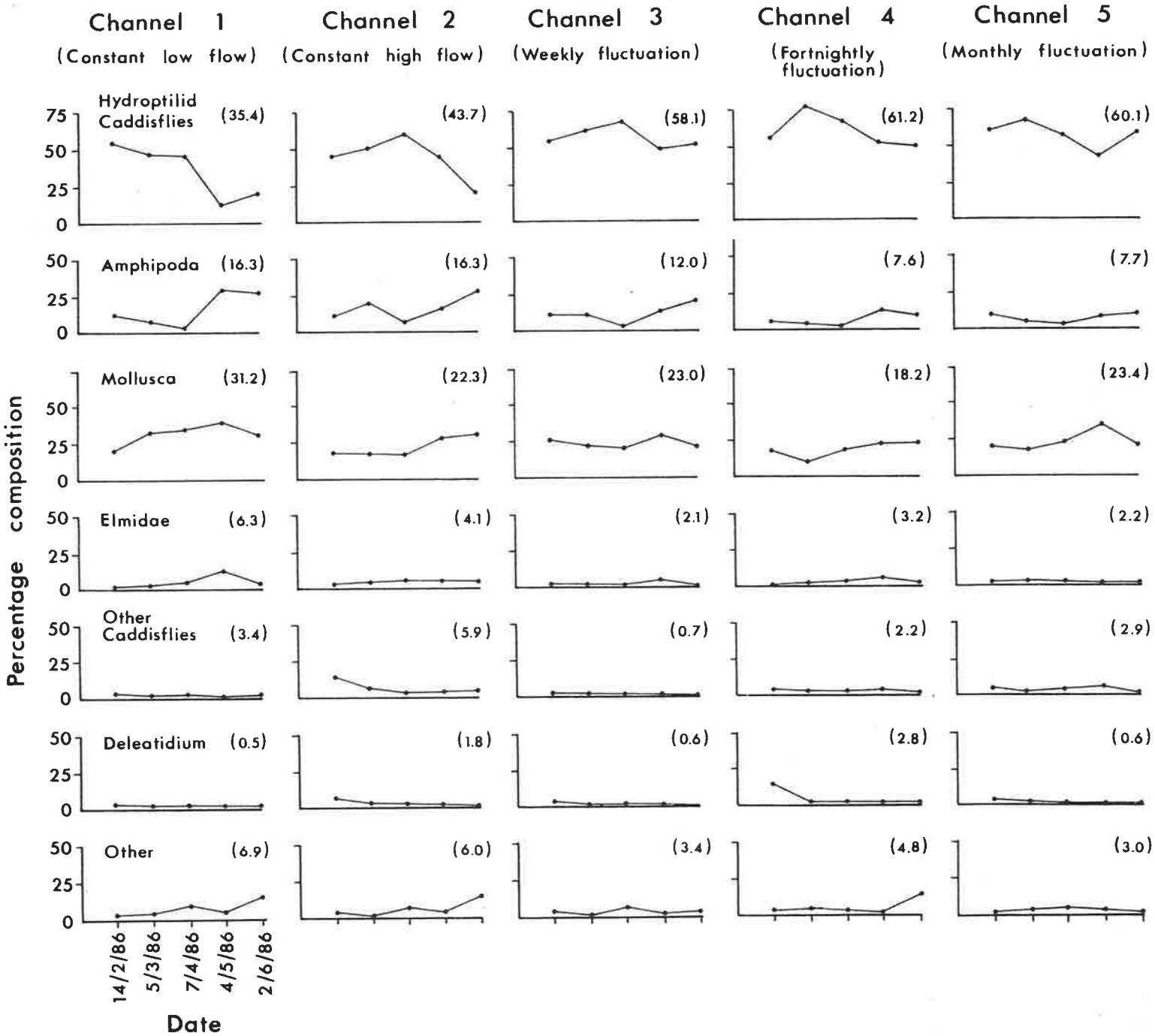

FIGURE 4. Percentage composition of benthic macroinvertebrates by major taxonomic groups for the five sampling periods and overall mean percentage composition for the five sampling periods combined (in parenthesis).

Mean taxonomic richness as assessed by the number of taxa recorded each sampling period (refer Appendix II) was greatest in channels 1 and 4, each with 19.2 taxa/sample. Channel 2 had 18.8 taxa/sample followed by channels 5 (16.2) and 3 (15.2). The total number of taxa recorded (all sampling periods combined) was greatest in channels 1 and 2, with 30 taxa each, and least in channel 3 (22 taxa), while channels 4 and 5 recorded 25 taxa each.

4.1.3 Macroinvertebrate drift

There were variations in macroinvertebrate drift density among sampling periods at both the upstream and downstream ends of all channels (Fig. 5). Fluctuations were more pronounced at the downstream ends of the channels than at the upstream ends. In the same sampling periods large differences in drift density were evident between the downstream ends of the channels. However, at the upstream ends, densities generally were similar among channels in the same sampling period (Fig. 5).

With the exception of the February and March samples in channel 2, mean drift densities were consistently higher at the downstream ends of each of the channels than at the upstream ends. It is assumed that the difference in drift density between the upstream and downstream samples is accounted for by invertebrates originating in the channels themselves whereas, at the upstream end drift may have originated from the header pond. Channel 2 (constant high flow) showed the least difference in mean density between the upstream and downstream ends (means of 7.4/m^3 and 10.5/m^3 respectively) while channel 1 (constant low flow) showed the greatest difference (means of 5.2/m^3 and 25.9/m^3 respectively).

In all five channels highest drift densities at the upstream ends occurred in May, a smaller peak occurred in March in channels 1, 3, 4, and 5, but not in channel 2. Peak drift densities at the downstream ends of channels 1, 3 and 5 occurred in March, while in channels 2 and 4 they occurred in May.

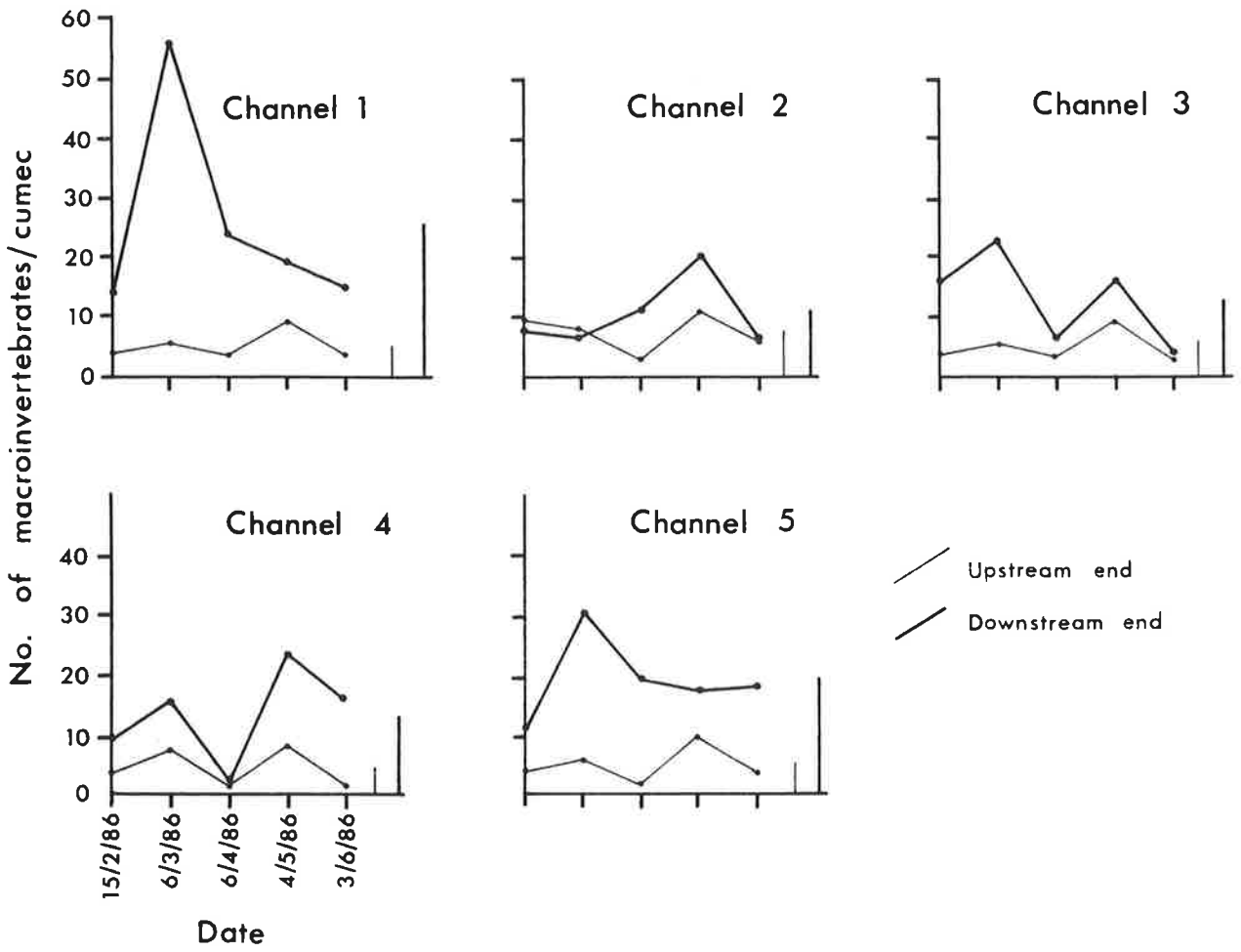

FIGURE 5. Mean densities (No./m^3) of drifting macroinvertebrates for the five sampling periods and overall means (vertical bars).

Overall (all sampling periods combined), the highest densities of drift occurred at the downstream end of channel 1 (25.9/m^3), followed by channels 5 (19.3/m^3), 4 (15.4/m^3), 3 (12.8/m^3) and 2 (10.5/m^3). Channel 2 recorded the highest densities at the upstream end (7.4/m^3), followed by channels 1 (5.2/m^3), 5 (4.9/m^3), 3 (4.7/m^3) and 4 (4.4/m^3).

4.1.4 Composition of drift fauna

In all five channels the composition of the drift fauna varied considerably over the five sampling periods (Fig. 6). There were also large differences in composition between the upstream and downstream ends of the channels. Hydroptilid caddisflies (mostly *Oxyethira*) again dominated the fauna. With the exception of channel 1, they also comprised a higher proportion of the fauna at the downstream ends of the channels. In all five channels, peaks in the numbers of hydroptilids in the drift fauna occurred in March and May at both upstream and downstream sampling sites.

Apart from a few sampling occasions, molluscs were the next most abundant taxonomic group. Molluscs were consistently more abundant at the upstream ends of the channels, with peaks occurring in April in channels 2, 3 and 4 and February in channels 1 and 5. Molluscs were most abundant at the upstream site in channel 2 (overall mean of 41.0%) and least abundant at the downstream site in channel 1 (overall mean of 7.2%).

After molluscs, "terrestrial" macroinvertebrates generally comprised the next highest proportion of the drift fauna in each of the channels. A large peak in terrestrial drift occurred in April at the downstream ends of all 5 channels. This peak was also evident at the upstream ends of channels 3, 4 and 5, but not channels 1 and 2. Overall, terrestrial drift was most abundant at the downstream end of channel 1 (comprising 18.0%) and least abundant at the upstream end of channel 2 where it comprised 2.9%.

Other macroinvertebrates (mostly chironomids and oligochaete worms) followed terrestrial drift in abundance. Generally they were more abundant at the upstream ends of the channels, particularly in channels 1, 4 and 5. Overall, they were most abundant at the upstream end of channel 1 and least abundant at the downstream ends of channels 1 and 4.

The Amphipoda, Elmidae, *Deleatidium*, and "other caddisflies" categories all comprised a small proportion of the drift fauna in each of the channels. No obvious trends in drift of these taxa were evident.

4.2 Quinnat salmon growth

Mean lengths of quinnat salmon caught during each sampling period and overall daily growth are presented in Table 2. Removal of upstream screens allowed fish to enter the channel and precluded analysis of salmon growth in channel 2. Daily growth was the same (0.09 mm/day) in channels 1, 4 and 5. In channel 3, daily growth was 0.14 mm/day.

4.3 Quinnat salmon diet

Results of quinnat salmon stomach content analysis are presented in Table 3. Hydroptilid larvae dominated the diet of fish in all channels over the three sampling periods and usually comprised over 50% of the diet. The numbers of food items and mean stomach fullness were highest in March; terrestrial Hemiptera and Diptera were also most abundant in March. In April the proportion of larval hydroptilids in the diet declined while the proportion of adult hydroptilids and amphipods increased. Mean stomach fullness and total

TABLE 2. Mean fork length (mm) and daily growth of quinnat salmon (31.01.86 - 03.06.86) in experimental channels in the lower Waitaki River. Number of fish measured are in parentheses.

	Sampling date						Daily growth
Channel	31.01.86	24.02.86	11.03.86	07.04.86	05.05.86	03.06.86	(mm)
1	68.5(25)	72.1(24)	73.1(25)	74.4(23)	82.8(18)	79.9(11)	0.09
2	65.1(25)	-	-	-	-	-	-
3	61.7(25)	63.9(25)	70.1(25)	71.1(25)	77.8(25)	79.4(24)	0.14
4	65.1(25)	67.3(25)	70.8(25)	77.0(25)	77.8(25)	76.6(23)	0.09
5	67.4(25)	70.9(25)	72.5(24)	72.6(25)	78.8(25)	78.0(26)	0.09

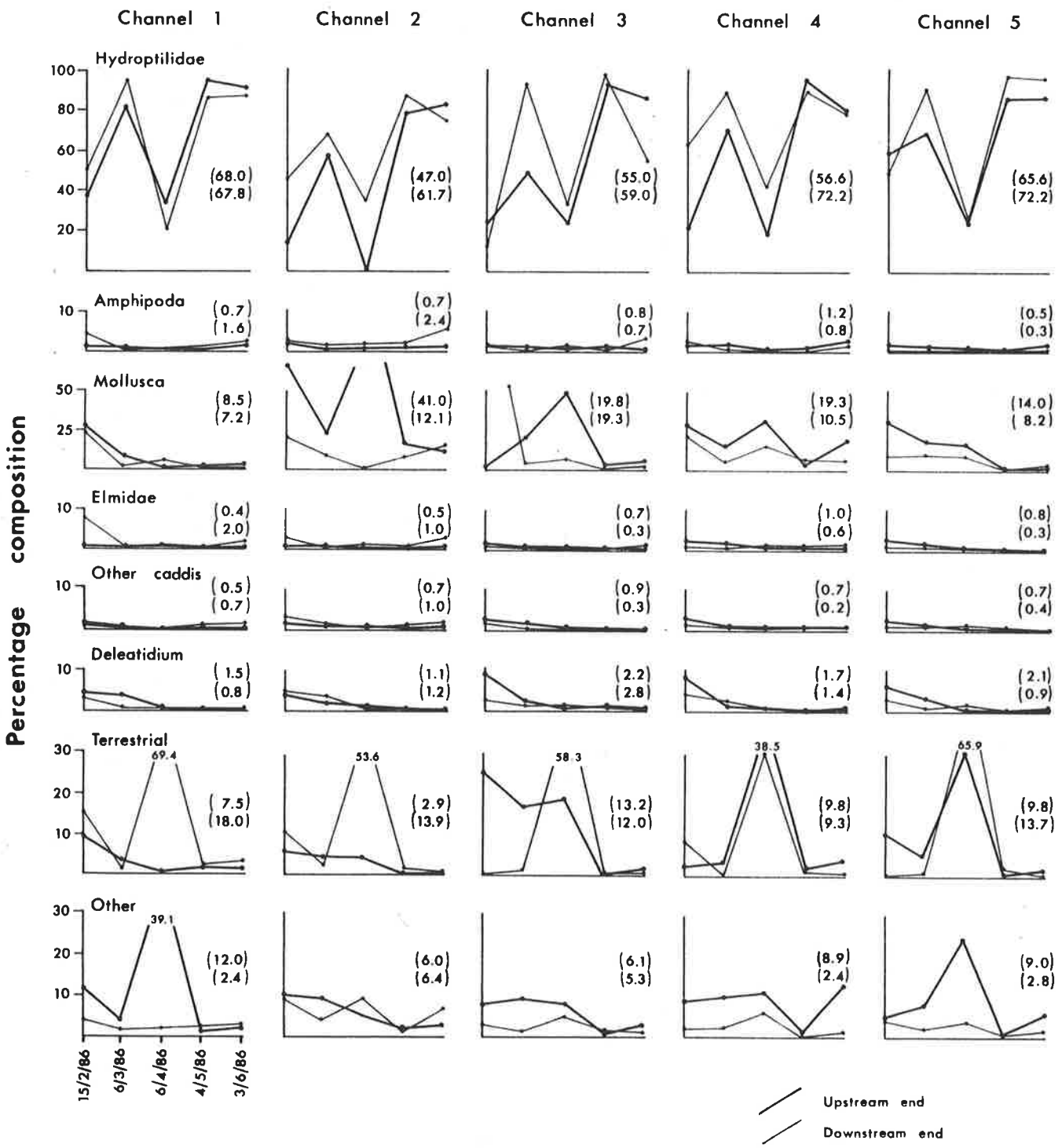

FIGURE 6. Percentage composition of macroinvertebrate drift, by major taxonomic groups, for upstream and downstream ends of channels. Overall means in parentheses.

TABLE 3. Number and percentage composition of food items recorded in quinnat samon stomachs from channels 1, 3, 4 and 5 on 11.03.86, 07.04.86, and 03.06.86.

	Channel 1		Channel 3		Channel 4		Channel 5	
Food item	No.	% comp.	No.	% comp.	No.	% comp.	No.	% comp.
11.03.86								
Deleatidium larvae	1	0.4	-	-	1	0.5	-	-
Aoteapsyche larvae	14	5.8	1	0.4	-	-	7	3.8
Hydroptilid larvae	181	75.4	256	93.7	170	80.2	163	89.6
Hydroptilid adults	5	2.1	2	0.7	2	0.9	-	-
Hydrobiosis larvae	2	0.8	-	-	2	0.9	-	-
Other Trichoptera larvae	4	1.7	-	-	-	-	-	-
Hemiptera (aquatic)	1	0.4	-	-	-	-	-	-
Hemiptera (terrestrial)	2	0.8	2	0.7	6	2.8	6	3.3
Elmidae larvae	-	-	-	-	1	0.5	-	-
Elmidae adults	2	0.8	-	-	-	-	-	-
Chironomid larvae	10	4.2	6	2.2	20	9.4	4	2.2
Other Diptera	2	0.8	5	1.8	1	0.5	2	1.1
Amphipoda (aquatic)	16	6.7	3	1.1	9	4.2	-	-
Total No. items	240		273		213		183	
Mean stomach fullness	7.4		5.6		5.0		5.0	
No. fish examined	5		5		5		5	
Mean fork length (mm)	77.2		77.2		68.8		74.6	
07.04.86								
Aoteapsyche	-	-	2	2.5	-	-	-	-
Hydroptilid larvae	3	37.5	43	53.7	63	69.2	47	43.9
Hydroptilid adults	-	-	12	15.0	12	13.2	32	29.9
Hydrobiosis	-	-	1	1.3	-	-	1	0.9
Other Trichoptera	-	-	-	-	1	1.1	-	-
Hemiptera (terrestrial)	5	62.5	4	5.0	-	-	-	-
Chironomid larvae	-	-	10	12.5	3	3.3	15	14.0
Chironomid pupae	-	-	-	-	1	1.1	-	-
Amphipoda (aquatic)	-	-	8	10.0	11	12.1	11	10.3
Other	-	-	-	-	-	-	1	0.9
Total no. items	8		80		91		10	
Mean stomach fullness	4		4.6		4.4		4.8	
No. fish examined	1		5		5		5	
Mean fork length (mm)	75.0		78.6		79.0		77.2	
03.06.86								
Aoteapsyche	-	-	-	-	-	-	1	1.1
Hydroptilid larvae	32	97.0	13	100.0	63	98.4	78	83.9
Hydrobiosis	1	3.0	-	-	1	1.6	-	-
Other Trichoptera	-	-	-	-	-	-	1	1.1
Hemiptera (terrestrial)	-	-	-	-	-	-	10	10.7
Amphipoda	-	-	-	-	-	-	3	3.2
Total no. items	33		13		64		93	
Mean stomach fullness	1.6		0.8		3.8		4.4	
No. fish examined	5		5		5		5	
Mean fork length (mm)	84.8		87.0		82.2		82.0	

number of food items consumed declined in March. In June stomach fullness declined even further and the hydroptilids dominated the diet. These changes in the diet and the measure of stomach fullness, seem to be related to seasonal changes in insect abundance and diversity, both of which generally decline as the weather gets colder.

5. DISCUSSION

5.1 Macroinvertebrate benthos and drift

Densities of benthic macroinvertebrates were higher in the three channels (3, 4, and 5) that received freshes than in the two channels (1 and 2) with constant flows. Cleaner substrates (i.e., less occluded by algae and silt) in these channels probably provides the best explanation for the higher densities of benthic macroinvertebrates. Such substrates encourage colonisation by macroinvertebrates (Winterbourn 1981; Milner *et al.* 1981; Rabeni and Minshall 1977). A fortnightly fresh (channel 4) apparently provided the most favourable conditions for benthic invertebrates. A weekly fresh (channel 3), while it was observed to maintain a relatively "clean" substrate (Fig. 7), apparently did not allow the benthos to achieve densities quite as high. Presumably, the increased frequency of fresh events led to a greater depopulation of the benthos through catastrophic drift (Waters 1972). The reduced frequency of freshes in channel 5 permitted the development of heavier accruals of periphyton which may have interfered with macroinvertebrate colonisation of the substrate. Channels 1 (constant low flow) and 2 (constant high flow) represented two extremes. In channel 1, benthic invertebrates were the least abundant of all five channels. The substrate in channel 1 was heavily colonised by periphyton (Fig. 7) which contained large quantities of silt, perhaps contributing to the low densities of benthic macroinvertebrates.

Not surprisingly, the higher velocity and greater flows in channel 2 maintained the substrate in a relatively clean condition. However, despite the clean substrate conditions, the density of benthic macroinvertebrates was only marginally greater in channel 2 than in channel 1 (mean densities of 146 and 130 macroinvertebrates/tile respectively). The perpetually high current velocity (0.9 m/s) in channel 2 may have reduced densities of benthic macroinvertebrates by causing higher rates of drift (i.e., catastrophic drift, *sensu* Waters 1972). High current velocities would also make it difficult for invertebrates entrained in a fast moving water column to settle and colonize the substrate (Elliot 1971).

It seems reasonable to expect that densities of drift would correspond with the densities of benthic macroinvertebrates. However, densities of drifting macroinvertebrates were highest in channel 1, followed by channels 5, 4, 3 and 2. In other words, the channels with the highest densities of benthic invertebrates had the lowest densities of drifting macroinvertebrates. The order of drift densities agrees with that expected on the basis of dilution associated with the differing flow regimes. Several authors have reported discrepancies between drift and benthic invertebrate densities. Waters (1972) concluded that the density dependent relationship between drift and benthic standing crop was not linear and that there appeared to be no direct relationship. Britain and Eikland (1988) suggested that the discrepancy was due, at least in part, to the fact that organisms in the drift fauna were present because of reasons which often differ among species.

In the replicate channels, the observed discrepancy between densities of drift and benthic invertebrates is probably also related to both the sampling efficiency of tiles in occluded substrate conditions and the habitat requirements of the taxa that colonised the channels. The thick, bed-smothering accruals of periphyton, particularly obvious in channels 1 and 5, apparently harboured large numbers of macroinvertebrates (Irvine 1984; Dudley *et al.* 1986) which contributed to the high measured densities of drift. However, these high drift densities were not reflected in the densities measured on artificial tiles, probably because of the smothering effect of periphyton which could interfere with the ability of macroinvertebrates to colonise (Dudley *et al.* 1986). Nocturnal drift sampling will also preclude sampling those organisms, e.g., *Oxyethira albiceps* that drift during the day (Sagar and Glova 1992). In the other channels (2, 3, and 4) where the substrate appeared less occluded, larger numbers of animals colonised the tiles even though densities of macroinvertebrates was less (as indicated by drift sampling) than in either channels 1 and 5. Densities of drifting macroinvertebrates may provide a more accurate reflection of the abundance of fauna in the replicate channels. Assessing benthic invertebrates using tiles alone may produce a biased conclusion which fails to account for the association between periphyton and invertebrates.

The results of this study have been strongly influenced by the invertebrate taxa which were able to successfully colonise the replicate channels. Even though the fauna introduced from nearby rivers and steams was typical of New Zealand streams, many of the taxa were rare even at the first sampling in February. Taxa originating from the impoundment upstream of the channels dominated the fauna. These taxa, dominated by hydroptilid caddisflies (mostly *Oxyethira albiceps*),

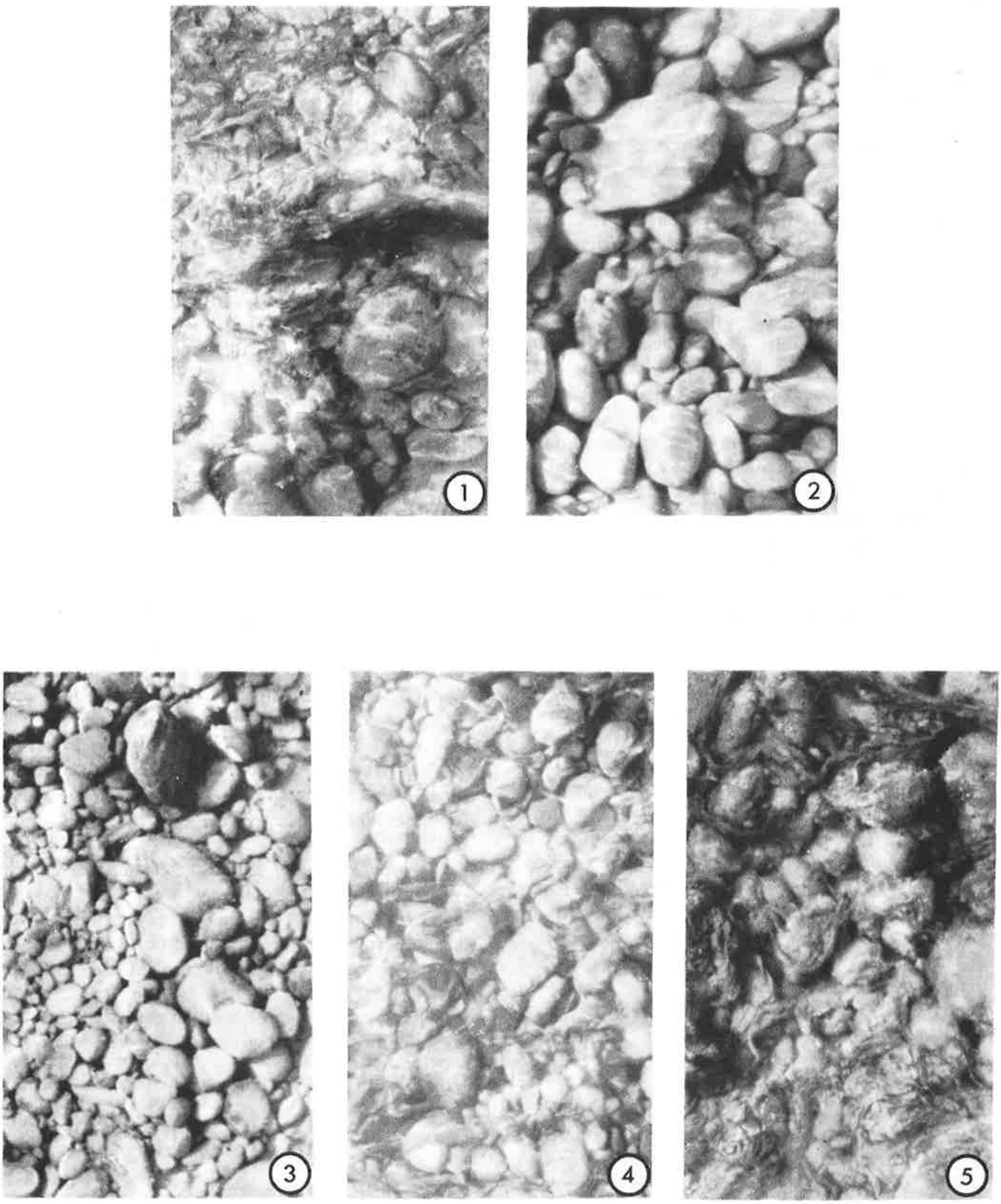

FIGURE 7. Representative substrates from channels 1, 2, 3, 4 and 5.

molluscs and amphipods are all ecologically flexible species (Winterbourn 1981) which can inhabit either hard or soft substrates, including epiphytic algae. This flexibility served to confuse the issue of abundance in the channels because the taxa were equally suited to living on either tiles or epiphytic algae. Winterbourn (1981) and Towns (1981) both reported hydroptilids (micro-caddisflies) to be often associated with filamentous algae. Dudley *et al.* (1986) also found small insect larvae to be abundant in algae.

In channels 3 (weekly fresh), 4 (fortnightly fresh) and 5 (four-weekly fresh) differences in community composition were minor. However, channels 1 and 2 (with constant low and high flows respectively) were different. The higher proportion of amphipods in channel 1 is probably related to the absence of freshes which, in the other channels, would have displaced downstream large numbers of these slow-water adapted taxa. In channel 2 the proportion of other caddisflies (mostly *Aoteapsyche, Pycnocentria* and *Pycnocentrodes*) contributed was nearly double that of the other channels. Cleaner substrates, higher current velocities (which would enhance dissolved oxygen concentrations) and better food supplies could favour these taxa in channel 2. That the mayfly *Coloburiscus humeralis* (typically associated with highly oxygenated water and clean substrates) occurred only in channel 2 tends to support this interpretation.

Taxonomic richness of the benthic macroinvertebrate community showed some variation among the channels. Both mean and overall taxonomic richness were least in channel 3, which experienced the most frequent freshes. Presumably, the frequency of freshes suppressed diversity by initiating a catastrophic form of drift, reducing the residence time of the rarer taxa and thus reducing the probability of their being sampled. Channels 1 and 2, with constant flows, had the highest total numbers of taxa (30) and the mean numbers of taxa were also similar. This is surprising considering that the mean velocity in channel 2 was about three times that in channel 1. The absence of fresh events in these channels may have played a major role in enhancing the taxonomic richness in the channels with stable flow.

In channels 4 and 5 mean taxonomic richness differed only slightly (25 taxa) from the channels with stable flow; apparently the difference in flow regime had minimal influence on overall taxonomic richness. Irvine (1985) concluded that repeated consecutive flow fluctuations increased invertebrate drift density but that density declined after repeated freshes. These studies show that, if regulated freshes are required as a residual river management tool, the frequency of occurrence is important. Freshes at approximately fortnightly intervals appeared most appropriate.

5.2 Diet and growth of juvenile quinnat salmon

The diet of juvenile salmon in each of the channels was similar. Salmon derived virtually all their nutrition from food items of aquatic origin (mostly larval hydroptilids); terrestrial food was of minor importance.

Since quinnat salmon juveniles fed almost exclusively on drifting aquatic organisms it was considered possible that their growth rates would provide an index of the abundance of drift (Waters 1972) in the replicate channels. However, this did not occur and the growth rates of fish in channels 1 and 5 (highest densities of drift) were the same as fish in channel 4 (lower densities). In channel 3, the growth rate of fish was significantly greater than that in channels 1, 5 and 4, yet drift densities in channel 3 were the lowest of all four channels. It is possible that the weekly fresh in channel 3 caused large quantities of macroinvertebrates to enter the drift. These invertebrates were then accessible to quinnat salmon as food. Irvine (1984) invoked the same explanation to account for weight gains in rainbow trout and salmon in conditions of fluctuating discharge. Brooker (1981), also suggested that flow fluctuations may benefit downstream fish populations by increasing the number of drifting prey organisms. However, long term flow perturbations without high levels of replacement would eventually deplete benthic resources without high levels of replacement. It is also possible that food resources were not limiting fish growth.

Daily growth rates of salmon in the mainstem of the Waitaki River 0.3 mm/day were greater (FFC unpublished data). The food supply in the replicate channels could, on the other hand be a limiting factor. However, repeated electric shocking of fish can reduce their growth rates (Gatz *et al.* 1986). Nevertheless, it is still clear that, among the experimental channels with differing flow regimes, growth differed minimally.

5.3 Implications for flow management strategies in a residual river

If macroinvertebrate and periphyton communities are affected by altered flow regimes in the Waitaki River, then it would be expected that both communities would respond to fresh events such as those tested in this study. A residual river will, however, still undergo

freshes and floods originating from its remaining watershed and the Hakataramea River (Graybill *et al.* 1988). If the communities which establish in a residual river are similar to those in the replicated channels, then a two-weekly fresh (which increased mean riffle velocities to around 0.9 m/s) could be employed. If freshes of this frequency were not satisfactory, more frequent and/or larger freshes could be attempted without apparent negative impacts.

6. ACKNOWLEDGEMENTS

Eric Graynoth and Paul Sagar reviewed the manuscript and the figures were drawn by Greg Kelly.

7. LITERATURE CITED

Britain, J.E., and T.J. Eikland 1988. Invertebrate drift - a review. *Hydrobiologia 166:* 77-93.

Brooker, M.P. 1981. The impact of impoundments on the downstream fisheries and general ecology of rivers. *Advances in Applied Biology 6*: 91-152.

Dudley, T.L., Cooper, S.D., and Hemphill, N. 1986. Effects of macroalgae on a stream invertebrate community. *Journal of the North American Benthological Society 5(2):* 93-106.

Elliot, J.M. 1971. Life histories and drifting of three species of Limnephilidae. *Oikos 21:* 56-61.

Fowles, C.R. 1975. Effects of electric fishing on the invertebrate fauna of a New Zealand stream. *N.Z. Journal of Marine and Freshwater Research 9:* 35-43.

Field-Dodgson, M.S. 1983. A simple and efficient drift sampler. *N.Z. Journal of Marine and Freshwater Research 19:*167-172.

Gatz, A.J., Loar, J. M., and Cada, G.F. 1986. Effects of repeated electroshocking on instantaneous growth of trout. *North American Journal of Fisheries Management 6:* 176-182.

Graybill, J.P., Palmer, K.L., Jowett, I.G., Rutledge, M.J., Pierce, L.A., James, G.D., Graham, G.D., and Bloomberg, S. 1988. Fisheries requirements and design features of a residual river within the proposed lower Waitaki power scheme. Electricorp Production PD 37. 100 p.

Irvine, J.R. 1984. Effects of varying discharge on stream invertebrates and under yearling salmon and trout. Ph.D Thesis, University of Otago, Dunedin. 254 p.

Irvine, J.R. 1985. Effects of successive flow perturbations on stream invertebrates. *Canadian Journal of Fisheries and Aquatic Science 42:* 1922-1927.

Jowett, I.G. 1983. Siltation of the lower Waitaki River bed. Power Division, N.Z. Ministry of Works and Development, Wellington. Unpublished report. 9 p.

Kirk, R.M. 1983. The physical nature of silts in the Waitaki River system. Electricity Division, N.Z. Ministry of Energy, Dunedin. Botany Laboratory Internal Report No. 83/1. 11 p.

Milner, N.J., Scullion, J., Carling, P.A., and Crisp, 1981. The effects of discharge on sediment dynamics and consequent effects on invertebrates and salmonids in upland rivers. *Applied Ecology 6:* 53-220.

Rabeni, C.F., and Minshall, G.W. 1977. Factors affecting microdistribution of stream benthic insects. *Oikos 29:* 33-43.

Rutledge, M.J. 1987. Benthic invertebrates of the lower Waitaki River and tributaries. *N.Z. Ministry of Agriculture and Fisheries, Fisheries Environmental Report No. 80.* 60 p.

Sagar, P.M., and G.J. Glova 1992. Diel changes in the abundance and size composition of invertebrate drift in five rivers in South Island, New Zealand. *N.Z. Journal of Marine and Freshwater Research 26:* 103-114.

Towns, D.R. 1981. Effects of artificial shading on periphyton and invertebrates in a New Zealand stream. *N.Z. Journal of Marine and Freshwater Research 15:* 185-192.

Waters, T.F. 1972. The drift of stream insects. *Annual Review of Entomology 17:* 253-272.

Winterbourn, M.J. 1981. The use of aquatic invertebrates in studies of stream water quality. pp. 5-16. *In:* Review of some biological methods for the assessment of water quality with special reference to New Zealand. Part 2. *Water and Soil Technical Publication No. 22.* 58 p.

APPENDIX I. Macroinvertebrate taxa introduced into replicate channels, lower Waitaki River.

Oligochaetae spp.
Austroclima jollae
Stenoperla prasina
Pycnocentria evecta
Hydrobiosis spp.
Psilochorema sp.
Aoteapsyche spp.
Limnophora sp.
Austrosimulium sp.
Tabanidae sp.
Deleatidium spp.
Coloburiscus humeralis
Pycnocentrodes sp.
Olinga feredayi
Neurochorema sp.
Oxyethira albiceps
Eriopterini sp.
Chironomidae spp.
Archichauliodes diversus
Elmidae spp.

APPENDIX II. Relative abundance (percent) of macroinvertebrates from tiles in Channel 1, 14.02.86-02.06.86. Values are means of eight replicates.

	Sampling date				
Taxa	14.02.86	05.03.86	07.04.86	04.05.86	02.06.86
Deleatidium	2.2	*	*	0.2	-
Xanthocnemis	-	0.2	0.1	-	0.1
Ostracoda	-	-	-	-	1.0
Aphrophila	*	*	*	0.2	0.1
Ephydrella	-	*	-	-	-
Oecetis	-	-	-	-	0.2
Austrosimulium	*	-	-	-	-
Nymphula nitens	-	-	*	-	-
Archichauliodes	-	-	*	-	-
Aoteapsyche	1.2	0.5	0.3	0.2	0.1
Oxyethira	54.4	45.0	43.2	10.0	18.0
Paroxyethira	0.7	1.3	2.0	1.2	1.2
Hydrobiosis	0.4	0.2	-	-	-
Polyplectropus	*	-	0.4	0.2	0.7
Hudsonema	0.3	-	-	0.3	-
Pycnocentrodes	0.3	0.9	0.6	-	0.4
Olinga	-	0.2	*	-	0.2
Pycnocentria	3.4	2.0	1.8	1.3	1.0
Lymnaea	-	-	-	-	0.2
Elmidae	0.7	5.9	6.2	13.4	5.2
Potamopyrgus	13.8	23.1	25.0	29.9	18.0
Physa	6.5	8.7	9.1	8.9	11.1
Gyraulus	0.2	0.6	-	0.5	0.6
Amphipoda	12.6	7.8	3.4	29.9	27.2
Lumbricidae	2.1	1.9	0.4	2.3	2.8
Maoridiamesa	*	-	-	0.5	0.7
Orthocladiinae purple	-	-	*	-	1.0
Orthocladiinae yellowhead	0.5	1.6	6.9	1.0	7.1
Chironominae - Tanytarsus sp.	*	-	-	-	2.0
Ceratopogonidae	-	-	-	-	0.2

\- = not present.
* = <0.1%.

APPENDIX II (Contd.). Relative abundance (percent) of macroinvertebrates from tiles in Channel 2, 14.02.86-02.06.86. Values are means of eight replicates.

	Sampling date				
Taxa	14.02.86	05.03.86	07.04.86	04.05.86	02.06.86
Coloburiscus	0.1	-	-	0.1	-
Deleatidium	6.7	1.4	0.3	0.2	0.2
Xanthocnemis	-	-	-	-	0.1
Ostracoda	-	-	-	-	0.9
Aphrophila	0.7	0.3	0.1	0.4	0.1
Oecetis	0.1	-	-	0.1	0.2
Austrosimulium	0.3	-	-	-	-
Aoteapsyche	3.6	1.8	1.2	1.8	-
Oxyethira	43.9	49.0	59.7	43.5	17.9
Paroxyethira	0.3	1.2	1.0	0.8	-
Hydrobiosis	0.7	0.6	0.2	0.1	-
Neurochorema	0.1	-	-	-	-
Polyplectropus	-	-	-	-	0.7
Pycnocentrodes	0.8	1.1	0.3	0.2	0.4
Olinga	-	0.2	0.2	-	-
Pycnocentria	9.1	3.3	0.6	0.8	0.9
Lymnaea	0.1	-	0.7	1.1	0.4
Elmidae	1.8	3.7	5.4	4.5	5.2
Potamopyrgus	15.7	11.0	12.2	12.2	17.9
Physa	3.1	5.5	4.2	14.9	11.1
Gyraulus	-	-	0.2	0.4	0.6
Amphipoda	10.9	20.9	6.0	16.2	27.6
Lumbricidae	0.4	0.1	0.1	0.6	2.8
Berosus	0.1	-	-	-	-
Sigara	-	-	-	-	0.1
Maoridiamesa	0.8	-	1.3	-	0.7
Orthocladiinae A	-	-	-	-	2.3
Orthocladiinae B	0.7	-	6.2	1.5	0.9
Chironominae - Tanaytarsus sp.	-	-	-	0.7	7.1
Ceratopogonidae	-	-	-	-	0.1

\- = not present.
* = <0.1%.

APPENDIX II (Contd.). Relative abundance (percent) of macroinvertebrates from tiles in Channel 3, 14.02.86-02.06.86. Values are means of eight replicates.

	Sampling date				
Taxa	14.02.86	05.03.86	07.04.86	04.05.86	02.06.86
Deleatidium	2.9	*	*	0.2	-
Aphrophila	0.1	-	*	0.5	0.2
Nymphula nitens	-	*	-	-	-
Aoteapsyche	3.6	1.8	1.2	1.8	-
Oxyethira	55.0	63.1	67.8	47.1	51.6
Paroxyethira	0.6	1.0	1.0	2.0	1.1
Hydrobiosis	0.1	-	-	-	-
Polyplectropus	-	0.1	-	-	-
Pycnocentrodes	0.3	-	-	-	-
Olinga	0.5	-	0.1	0.1	-
Pycnocentria	0.3	0.2	0.3	0.6	-
Lymnaea	-	-	0.3	0.4	1.6
Elmidae	1.5	1.6	1.0	5.6	0.9
Potamopyrgus	18.3	13.4	13.1	18.3	13.9
Physa	6.8	7.6	5.4	8.6	6.7
Gyraulus	0.3	0.7	0.7	0.7	-
Amphipoda	10.7	10.5	3.4	13.8	21.8
Lumbricidae	2.0	0.5	0.2	1.6	0.3
Procordulia	-	*	-	-	-
Maoridiamesa	-	*	*	0.1	0.5
Orthocladiinae A	-	-	-	-	1.1
Orthocladiinae B	0.6	0.8	3.2	0.3	0.3

\- = not present.
* = <0.1%.

APPENDIX II (Contd.). Relative abundance (percent) of macroinvertebrates from tiles in Channel 4, 14.02.86-02.06.86. Values are means of eight replicates.

Taxa	Sampling date				
	14.02.86	05.03.86	07.04.86	04.05.86	02.06.86
Deleatidium	12.8	0.2	0.5	0.2	0.2
Aphrophila	0.9	*	*	0.1	0.3
Oecetis	-	*	*	-	-
Archichauliodes	0.3	-	-	-	-
Aoteapsyche	1.5	0.7	0.7	0.8	0.6
Oxyethira	55.8	78.3	65.7	49.4	49.1
Paroxyethira	0.7	1.0	1.4	3.4	1.4
Hydrobiosis	0.5	0.1	0.2	-	0.1
Neurochorema	0.1	-	-	-	-
Polyplectropus	-	-	*	0.1	-
Pycnocentrodes	0.5	0.1	0.2	0.4	-
Olinga	-	*	-	0.1	-
Pycnocentria	1.5	0.6	0.5	1.4	0.5
Lymnaea	0.1	*	0.5	1.0	1.0
Elmidae	0.5	1.9	4.7	6.4	2.3
Potamopyrgus	12.4	4.6	12.0	15.0	13.0
Physa	4.8	4.4	5.9	5.9	9.3
Gyraulus	0.1	0.1	0.2	0.5	0.4
Amphipoda	6.1	4.5	4.0	14.0	9.2
Lumbricidae	0.1	0.2	0.2	0.7	0.1
Maoridiamesa	0.1	0.1	0.1	0.1	0.5
Orthocladiinae A	0.1	0.4	-	0.1	2.3
Orthocladiinae B	-	2.4	3.0	0.4	9.1
Chironominae - Tanaytarsus sp.	-	-	-	-	0.8
Ceratopogonidae	-	*	-	-	-

\- = not present.
* = <0.1%.

APPENDIX II (Contd.). Relative abundance (percent) of macroinvertebrates from tiles in Channel 5, 14.02.86-02.06.86. Values are means of four replicates.

	Sampling date				
Taxa	14.02.86	05.03.86	07.04.86	04.05.86	02.06.86
Deleatidium	2.4	0.4	0.1	-	-
Xanthocnemis	-	0.1	-	-	-
Ostracoda	-	-	-	-	0.1
Aphrophila	-	*	-	0.9	-
Oecetis	-	-	0.1	-	-
Archichauliodes	0.1	-	-	-	-
Aoteapsyche	0.5	0.2	*	0.6	-
Oxyethira	62.3	67.2	61.2	42.8	59.7
Paroxyethira	1.2	2.1	1.9	2.3	-
Hydrobiosis	0.3	0.2	0.3	-	-
Neurochorema	-	0.2	-	-	-
Polyplectropus	0.8	0.1	0.7	0.1	-
Pycnocentrodes	0.6	0.2	0.3	0.8	0.3
Olinga	-	-	-	0.6	-
Pycnocentria	2.2	0.3	1.9	1.0	0.6
Lymnaea	2.3	*	-	0.8	1.4
Elmidae	1.4	2.4	2.9	2.6	1.7
Potamopyrgus	7.3	8.0	12.2	20.1	8.9
Physa	9.3	9.8	9.4	15.4	11.0
Gyraulus	-	0.4	0.5	0.4	0.2
Amphipoda	8.8	5.9	3.8	9.0	11.0
Lumbricidae	1.8	0.3	1.6	1.9	0.3
Maoridiamesa	-	0.1	0.1	-	-
Orthocladiinae A	-	-	-	-	2.3
Orthocladiinae B	-	2.0	2.8	0.1	0.5

\- = not present.
* = <0.1%.