Physico-chemical parameters and invertebrate faunas of three lake inflows and outlets in Westland, New Zealand

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Abstract Selected physico-chemical factors and the composition of faunas in inflow and outlet streams of three South Westland lakes (Kaniere, Mapourika, and Wahapo) were investigated from December 1988 to January 1990. Three sampling sites were used in each river system, the first 1 km above the inlet, another immediately below the lake, and the third 1-5 km further downstream. Dissolved organic carbon concentrations, alkalinity, and conductivity were only slightly influenced by the presence of a lake. Summer and winter water temperatures were elevated at lake outlets, but generally declined again downstream. Substrate size, stability, and homogeneity were also greater at artificial lake outlets. Invertebrate taxonomic richness was lowest at lake outlets, intermediate in inlets streams, and greatest at downstream sites. Inflow stream faunas were dominated by Deleatidium (Ephemeroptera: Leptophlebiidae), whereas lake outlets were dominated by Hydropsychidae, Simuliidae, and Mollusca; downstream Simuliidae, Chironomidae, and Hydropsychidae remained dominant and plecopteran taxa increased. Species of Coleoptera, Ephemeroptera, and Plecoptera were poorly represented at lake outlets but numerous at inlet and downstream sites. Substrate heterogeneity and stability, mean depth, water velocity, and water temperature were implicated as important physical environmental factors affecting community composition in lake outlets.

Keywords benthic invertebrates; lake outlets; regulated rivers; New Zealand

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INTRODUCTION

Physico-chemical and faunal characteristics of lake outlets have been widely investigated in the United States, United Kingdom, Canada, and Sweden (Cushing 1963; Armitage 1976; Carlsson et al. 1977; Gore 1977; Sheldon & Oswood 1977; Wotton 1979; Ward & Stanford 1979; Ward 1987); however, the benthic invertebrate communities of inflow and outlet rivers have rarely been compared (MacFarlane & Waters 1982; Novotny 1985; Ziser 1985; Ward & Voelz 1988).

Northern Hemisphere studies have indicated that macroinvertebrate communities are markedly influenced by the impoundment of lotic reaches (Lehmkuhl 1972; Armitage 1976; Ward & Stanford 1979; Armitage 1984; Novotny 1985; Ward & Voelz 1988) which result in major shifts in community composition. These shifts have been attributed to the alteration of thermal and flow regimes, substrate conditions, and biotic interactions in impounded rivers (Ziser 1985; Ward 1987). Reservoirs and other artificial impoundments exert influences on flow and temperature regimes unlike those observed in natural lake-river systems (Spence & Hynes 1971). Surface release dams (such as those considered in this study) can cause higher thermal consistency in outlet streams, and this can result in higher invertebrate densities, but lower species diversity (Fraley 1979). Warming of outlet waters may also cause early emergence of some insect taxa and exclude the presence of cold water species (Lehmkuhl 1972, 1974; Fraley 1979).

Previous New Zealand studies of lake outlet macroinvertebrate communities have been carried out on the Hawea River that drains Lake Hawea (Biggs & Malthus 1982; Irvine & Henriques 1984). Biggs & Malthus (1982) recorded high periphyton and invertebrate standing crops, but low invertebrate diversity immediately below the lake outlet. High densities of net-spinning hydropsychid larvae were found directly below the dam, whereas Chironomidae and *Deleatidium* spp. (Ephemeroptera: Leptophlebiidae) dominated sites further downstream. High-



Fig. 1 Location of sampling sites on the three river systems on the west coast, South Island, New Zealand.

standing crops of filamentous algae and diatoms were found throughout the river.

This study addresses three questions:

- Is the composition of macroinvertebrate communities in these Westland lake outflows similar to those observed outside New Zealand?
- 2) Do the outlets of lakes regulated by dams with epilimnetic outfalls have faunas different from those found in a natural lake-river system?
- 3) What environmental factors contribute to differences in the faunas of inflow and outlet streams?

STUDY SITES

South Westland is a narrow lowland region on the west coast of the South Island, New Zealand, bounded in the east by the Southern Alps. It is characterised by high rainfall (4950 mm at Franz Josef in 1989), mild temperatures below 300 m (average annual temperature 12°C), and podocarp-broadleaf forests. Three lake-river systems were investigated. Lake Kaniere (15 km south-west of Hokitika) was formed by glacial action and is fed by Geologists Creek and eight other inlet streams. It has an artificial weir

across part of its outlet and a hydroelectric power scheme intake, operating during peak load conditions, across the remainder. Lake Wahapo, 80 km to the south, has a similarly modified outlet, operating at base load conditions. Lake Mapourika, 5 km further south, remains in its natural state (Fig. 1). The Waitangi-taona River is the largest of two inflows into Lake Wahapo; the lake is drained by the Okarito

Table 1Mean water velocity, depth, channel width, andtemperature at the nine sites for December 1988 to January1990.

Site	Mean velocity (m s ⁻¹)	Mean depth (m)	Mean width (m)	Mean temp. (°C)	Temp. range (°C)
K1	0.32	0.2	4	10.7	11.3
K2	0.58	0.3	7	15.2	11.5
K3	0.50	0.5	18	14.9	14
W1	0.65	0.35	11	11.0	9.5
W2	0.69	0.5	12	14.4	15
W3	0.62	0.48	15	13.5	10
M 1	0.45	0.18	19	11.7	15.2
M2	0.52	0.51	12	15.3	17.5
M3	0.89	0.38	26	15.0	13

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River. Lake Mapourika has nine main inflow streams including MacDonalds Creek at its northern end. It is drained by a separate branch of the Okarito River. One site was positioned about 1 km above each impoundment, one at each outlet, and one 1–3 km downstream. Each downstream site had flow variability and substrate conditions influenced by numerous small tributaries joining the river below the lake. Inlet rivers varied in size between first- and third-order streams whereas the outlet rivers were generally wider and faster-flowing (Table 1).

METHODS

Sampling was conducted at the nine sites each month from December 1988 to January 1990. Water samples were collected in opaque, polyethylene bottles and kept cool until analysed within 3 days. Dissolved organic carbon (DOC) concentration was determined as described by Collier (1987), and pH, conductivity, and alkalinity were determined by standard procedures (Mackereth 1963; Golterman & Clymo 1969). Temperatures were measured monthly, both with a thermister-thermometer and with a maximumminimum thermometer. Water depth and velocity were estimated each month from three readings taken at a transect across the river at the invertebrate sampling site. Velocity was estimated by timing a float over a 2 m distance.

Channel stability was evaluated by using the procedure of Pfankuch (1975) which allocates values for 15 characteristics of upper bank, lower bank, and stream bed condition. Substratum size classes (Wentworth classification; Cummins 1962) were estimated by measuring the longest axis of 100 stones from points along a randomly selected transect (Newbury 1984). From these data, geometric mean particle diameter (d_g) and geometric variance of particle size (σ_g) were calculated (Shirazi & Seim 1979).

Invertebrate collections were made by disturbing the substrate to a depth of 10 cm in front of a triangular net (0.5 mm mesh). As many microhabitats as possible were sampled at each site during a 5-min period. Samples were preserved in 10% formalin and sorted under a microscope.

Invertebrate presence/absence data for each site were compared using two-way indicator species analysis (TWINSPAN: Hill 1979a), and detrended correspondence analysis (DECORANA: Hill 1979b). DECORANA axes were correlated (Pearson's correlation coefficient) against 11 environmental variables.

RESULTS

Physico-chemical factors

Water temperatures were generally higher in lake outlets than inflows, and the former exhibited wider temperature ranges. Highest water temperatures were recorded in January at the three lake outlets (Mapourika, 26.0°C; Wahapo, 24.0°C; and Kaniere, 22.0°C), whereas temperatures were lowest in July in the three inflows (Geologists Creek, 4.7°C; Waitangitaona River; 7.5°C; and MacDonald Creek, 5.8°C). Mean temperatures and temperature ranges were generally lower at inflow sites than at outlets and downstream sites (Table 1).

Concentrations of DOC were generally lower at inflow sites than in outflows, conductivity and alkalinity were generally higher, and pH values showed no clear trends among sites (Table 2).

Channel stability was poorest in the inflows which ranked "fair" on the Pfankuch assessment scale. In contrast, all outlet and downstream sites had "good" ratings making them stable sites in a New Zealand context (Table 3; Rounick & Winterbourn 1982; Winterbourn & Collier 1987).

Cobbles and pebbles dominated the beds of inflow streams. However, in the regulated Wahapo outlet and at both the Kaniere and Wahapo downstream sites, large boulders were common. The unmodified Lake Mapourika outlet had smaller substrata (mainly pebbles and gravels) than its inflow, but substratum size increased downstream. Substrate heterogeneity, indicated by the geometric variance of particle size, was greatest in inflow streams and lowest at lake outlets (Table 3).

Macroinvertebrate faunas

Seventy-five taxa were collected from the nine sites: 58 in inflows, 37 in lake outlets, and 56 in downstream

Table 2Mean water chemistry values at the nine sitesfor December 1988 to January 1990.

Site	DOC (g m ⁻³)	Alkalinity (g m ⁻³)	Conductivity (mS m ⁻¹)	pН
K1	2.5	25	124	7.5
K2	2.6	12	101	7.4
K3	4.0	16	91	7.3
W1	2.7	23	88	7.4
W2	4.0	20	57	7.2
W3	5.1	18	74	7.4
M1	3.6	15	76	7.4
M2	3.6	14	74	7.1
M3	3.7	13	61	7.3

sites. Lake outlets had lower taxonomic richness than inlets. In particular, fewer ephemeropteran and plecopteran taxa were found immediately below lakes, but their numbers increased again downstream (Table 4).

The dominance of taxa changed markedly between inflow and outlet rivers. *Deleatidium* spp. dominated the faunas of all inflow streams, with Chironomidae (Diptera), Elmidae (Coleoptera), and Eriopterini (Diptera: Tipulidae) also common. Tanyderidae, *Neocurupira tonnoiri* (Diptera: Blephariceridae), and *Plectrocnemia maclachlani* (Trichoptera: Polycentropodidae) occurred exclusively in the inflow streams.

In contrast, lake outlet faunas were dominated by two species of Hydropsychidae (Trichoptera), *Aoteapsyche colonica* and *A. raruraru*, Simuliidae, Chironomidae, and the gastropod *Potamopyrgus antipodarum*.

Further downstream, Simuliidae, Chironomidae, and Aoteapsyche spp. still dominated the fauna, but plecopteran and coleopteran populations were also present. The hydrobiosid caddisfly, Neurochorema confusum, occurred only at downstream sites. TWINSPAN (Fig. 2) of monthly data separated the three inflow streams from the others at Division one, except for Lake Mapourika outlet during one winter and two spring months. At the second division, Lakes Kaniere and Wahapo outlet sites were separated from Lake Mapourika and the downstream sites.

Similarly, DECORANA analysis of sites based on monthly presence/absence of taxa grouped the three inlet sites and downstream sites into two distinct clusters (Fig. 3). Lake Mapourika outlet showed a closer relationship to the downstream sites than to the two regulated outlets.

Results obtained with both analytical procedures imply that inlet faunas were more similar to each other than to outlet and downstream faunas, and that downstream and natural outlet faunas were more similar to each other than to the communities found at other sites.

DECORANA eigenvalues indicated that Axis 1 accounted for 48%, Axis 2 for 29%, and Axis 3 for 22%, of the total variance explained by the three axes. The first DECORANA axis was positively correlated with Pfankuch stability scores and pH values, and negatively correlated with substrate size

Site	dg	σ_{g}	Boulder (> 256 mm)	Cobble (64–256 mm)	Pebble (16–64 mm)	Other (< 16 mm)	Pfankuch value
K 1	21.9	7.3	11	26	40	13	103
K2	50.6	3.2	8	37	34	9	63
K3	74.8	4.6	26	31	34	9	49
W1	21.9	7.3	6	35	38	21	99
W2	236.6	1.5	69	23	7	0	43
W3	74.8	4.6	59	23	17	1	48
M 1	21.9	7.3	0	17	67	16	96
M2	6.9	2.3	0	4	58	38	47
<u>M3</u>	50.6	3.2	14	38	35	13	67

Table 3 Mean geometric particle diameter (d_g) , geometric variance of particle size (σ_g) , proportions of four substrate types, and Pfankuch stability values for the nine sites.

Table 4 Numbers of macroinvertebrate taxa taken from all nine sites between December 1988 and January 1990.

	Inflow sites		Outlet sites			Downstream sites			
	K1	W1	M1	K2	W2	M2	<u>K3</u>	W3	M3
Ephemeroptera	5	2	3	0	1	2	5	6	5
Plecoptera	10	12	10	2	2	4	6	7	7
Trichoptera	18	10	16	8	6	11	18	14	13
Diptera	8	6	8	4	5	5	7	5	7
Coleoptera	2	1	1	1	0	1	1	1	1
Megaloptera	1	0	1	0	0	1	1	1	1
Others	3	2	2	2	6	3	3	4	7
Total species	45	33	41	17	20	27	41	38	41

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Fig. 2 Site separation by TWINSPAN analysis of monthly faunal presence/absence data. Indicator species are shown at each bifurcation (* indicates all months; wi, winter; au, autumn; sp, spring su, summer months).



and heterogeneity, mean water temperature, mean depth, and mean water velocity (Table 5). Axes 2 and 3 were negatively correlated with water temperature.

DISCUSSION

The presence of impoundments on rivers considered in this study resulted in alterations to physico-chemical conditions in their outlet waters, by increasing DOC concentrations, reducing conductivity and alkalinity values, and increasing outlet river bed stability as a result of armouring of substrate. Such changes are generally typical of those reported elsewhere (Fraley 1979; Armitage 1984; Ward & Stanford 1987), but the elevation of summer and winter outlet water temperature was distinctive, and not frequently recorded elsewhere.

The taxonomic richness and composition of benthic invertebrate communities in the inflow and outlet rivers were substantially different, whereas downstream from impoundments, faunas consisted of a mixture of taxa that occurred in both inflows and outlets. Regulated outlets also had invertebrate communities that differed from those found below the natural impoundment. The proximity of the inflow stream to the outlet of the natural impoundment meant that during high flow conditions, inlet waters would flow directly into the outlet. However, this phenomenon only occurred on three occasions and its modifying effect would seem to be limited, as indicated by the differences in substrate size, heterogeneity, and water chemistry between inflow and outlet sites.

Inflow streams had faunas dominated by *Deleatidium*. This is also frequently the situation in small, west coast streams (Winterbourn & Collier 1987), in braided rivers east of the Southern Alps (Sagar 1986), and rivers with relatively undeveloped catchments and enriched waters throughout New Zealand (Quinn & Hickey, 1990).

In contrast, lake outlets had reduced taxonomic richness, as observed in the Hawea River (Biggs & Malthus 1982) and in numerous studies overseas (Spence & Hynes 1971; Ward 1974; Novotny 1985;



Fig 3 Patterns of similarity shown by DECORANA ordination of monthly invertebrate presence/absence data. Centroids for each site are shown.

Munn & Brusven 1987). Trichopteran species richness was strongly reduced in lake outlets, and the Kaniere outlet had 10 fewer trichopteran species than its inflow. Similarly, the Wahapo outlet had four fewer trichopteran species, and the Mapourika outlet five fewer than the main inlet stream. Tanyderidae, Neocurupira tonnoiri, and Plectrocnemia maclachlani were present in inlet streams but absent from lake outlets; the presence of reduced numbers of Coleoptera at outlet sites is consistent with the findings of Ward & Voelz (1988) in the Blue River, Colorado. In the United Kingdom, Armitage (1977) also observed that fewer species of Coleoptera, Ephemeroptera, and Plecoptera were present below a dam with an epilimnetic outfall, but that many of them reappeared downstream. Such a pattern was displayed by Coloburiscus humeralis and Megaleptoperla grandis in the present study. The absence or scarcity of some species below impoundments may have been a consequence of altered thermal regimes, as observed

Table 5 Pearson's correlations of DECORANA axes with environmental variables (* P < 0.05; ** P < 0.01; *** P < 0.001).

	Axis 1	Axis 2	Axis 3
Water temperature	-0.36**	0.30**	-0.21**
Pfankuch stability	0.79***		
Mean depth	-0.51***		
Water velocity	-0.51***		
d _a	0.56***		
σ _α	-0.83***		
pĤ	0.20**		

by Fraley (1979) in the Madison River, Montana, United States. Summer and winter minimum temperatures were higher in the outlets than inlets of the Westland lakes by an average of 3.8°C and, therefore the altered temperature regime below impoundments may have affected taxa by not providing adequate thermal cues or thresholds for development (Lehmkuhl 1972, 1974; Kondratieff & Voshell 1981; Ward & Voelz 1988). Coldwater species, particularly many plecopterans, may be eliminated by high summer and autumn water temperatures that occur below epilimnetic impoundments (Walburg et al. 1981). Quinn & Hickey (1990) concluded that stonefly biomass was greatly reduced in New Zealand sites with mean temperatures above 13°C, a value exceeded at all sites below impoundments in this study.

The occurrence of relatively high densities of hydropsychid larvae at lake outlets is similar to the condition observed elsewhere in New Zealand (Sukolski 1981; Biggs & Malthus 1982), and in numerous Northern Hemisphere studies (Cushing 1963; Oswood 1979; MacFarlane & Waters 1982; Parker & Voshell 1983). Similarly, the occurrence of relatively high densities of simuliids is characteristic of many lake outlets (Carlsson et al. 1977; Wotton 1979; Novotny 1985; Wotton 1988). It has been suggested that a rich supply of suspended food items, particularly zooplankton, might favour the development of large populations of filter feeders in lake outlets (Carlsson et al. 1977; Oswood 1979; Perry & Sheldon 1986; Valett & Stanford 1987; Wotton 1988), and it has been suggested that species of Simuliidae in Swedish lake-riverine systems are able to withstand high population densities to avail themselves of an optimal food supply (Carlsson et al. 1977; Wotton 1979). Higher mean water temperatures than in inlet streams may also favour increased production of some species as found for several hydropsychids by MacFarlane & Waters (1982), Parker & Voshell (1983), and Ward (1987).

The natural outflow of Lake Mapourika had the highest taxonomic richness of the three outlets and cluster analysis indicated that the fauna at this outlet was similar to downstream communities, but substantially different from those living below the regulated impoundments. Modifications to lake outlets associated with dam formation may therefore have an effect in their own right, possibly through increase in substrate armouring which may have resulted from flow modification.

Characteristically, species diversity and richness are reduced below impoundments, but gradually they

100

Harding-Invertebrates of lake inflows and outlets

approach pre-impoundment levels with increasing distance downstream (Spence & Hynes 1971; Ward 1974, 1976; Novotny 1985; Ward & Voelz 1988). My findings were generally consistent with this scenario although the shortness of the rivers below the lakes (13–18 km) made sampling of further downstream sites difficult.

In summary, the invertebrate communities in the outflow streams of the three surface-release lakes differed from those in their principal inlet streams and appeared to be affected by the presence or absence of a dam. Several taxa had geographical distributions either extended or reduced by lakes. Substrate heterogeneity and stability, and annual water temperature regime were implicated as important physical environmental factors affecting lake outlet community composition.

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