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BIOLOGICAL COMMUNITIES AND POWER DEVELOPMENT IN THE LOWER CLUTHA RIVER, OTAGO

B.J. Biggs and B.I. Shand

PUBLICATION No. 10 OF THE HYDROLOGY CENTRE CHRISTCHURCH

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B.J. Biggs and B.I. Shand
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PREFACE

Hydro-electric power developments are being considered for the Lower Clutha River, Otago. This report describes the results of an aquatic resources study carried out by the Water and Soil Directorate, for Power Directorate, Ministry of Works and Development, as part of the preliminary development investigations. The objectives of the study were to:

(a) document the communities and their habitats in the area as a record for scientific purposes and posterity;

(b) identify any unique habitats and organisms in the river, so that enhancement measures for public use or preservation can be considered;

(c) predict the type and extent of effects, and the biological communities in the system, following the completion of the developments to enable more informed debate on the relative effects and merits of the proposals;

(d) identify possible ameliorative and/or enhancement measures that could be used during construction to reduce detrimental impacts.

The report is divided into two sections: Part A discusses objectives (a) and (b) and Part B objectives (c) and (d) with respect to periphyton, macrophyte and invertebrate communities. Fish studies carried out by Fisheries Research Division, Ministry of Agriculture and Fisheries, are reported elsewhere.

Evaluations such as this are relatively new in New Zealand, and it is therefore hoped that, as well as providing the information required for the Lower Clutha development, this report will also provide a useful basis for planning future power development investigations.

SUMMARY

The Lower Clutha River, Otago, between Roxburgh and Tuapeka Mouth, is being investigated for hydro-power development. This reach is 75 km long and has a mean annual flow of 504 $m^3.sec^{-1}$ A study has been carried out to characterise periphyton, macrophyte and invertebrate communities, and their habitats, and to predict the biological effects of various hydro-power development options.

Because of the large and deep flow in the Lower Clutha River, only 24% of the riverbed area could be biologically characterised. Few benthic organisms were observed in the remaining area.

During 1983-84, the Lower Clutha River study area was populated with a moderate to low abundance of filamentous periphyton (mean cover = 25.4%, mean standing crop = 6.85 $g.m^{-2}$), aquatic macrophytes (mean cover = 5%, mean summer standing crop = 1.08 $g.m^{-2}$), and invertebrates (mean density = 1,019 $organisms.m^{-2}$, mean standing crop = 4.81 $g.m^{-2}$). The aquatic macrophytes and invertebrates were most abundant in the backwater habitats (mean macrophyte cover = 35%, mean summer standing crop = 11.0 $g.m^{-2}$, mean invertebrate density = 6,229 $organisms.m^{-2}$, mean standing crop = 14.6 $g.m^{-2}$), whereas the filamentous periphyton development was highest in the bedrock habitat (mean cover 45.3%, mean standing crop = 14.02 $g.m^{-2}$).

The filamentous periphyton communities were dominated by *Rhodochorton violaceum* (dominating 33% of the area), *Oedogonium* spp. (19%), *Ulothrix zonata* (17%), *Vaucheria* spp. (8%), and *Phormidium* spp. (5%). The aquatic macrophyte communities were dominated by *Elodea canadensis* (covering 2.4% of the area), *Potamogeton* spp. (0.82%), *Myriophyllum elatinoides* (0.71%), and *Ranunculus fluitans* (0.66%). The benthic invertebrate communities were dominated by *Potamopyrgus antipodarum* (42% of the community abundance), Sphaeriidae (0.96%), *Pycnocentrodes* sp. (0.32%), and *Zelandobius furcillatus* (0.31%). The macrophyte and invertebrate communities had a low diversity. None of the communities appeared to be proliferating and causing problems for water users.

The Lower Clutha River has several features which are of scientific interest. These are:

- the major habitat types normally found in many different rivers in New Zealand are located together in the one reach of the Lower Clutha. There is thus an unusual mixture of organisms, which includes populations normally found in lakes and a range of river types.

- the presence of extensive areas of backwater and bedrock habitat, both of which are poorly represented in other New Zealand rivers.

- the presence of extensive areas of the mat forming red algae *Rhodochorton violaceum* which has only been recorded as a minor component of a few small streams elsewhere in New Zealand.

- the presence of extensive areas of aquatic mosses.

The possible effects on the biological communities of constructing one, or a combination, of eight different impoundments on the river were assessed. Predictions were based on communities currently found in the upstream Roxburgh reservoir and the physical character of each proposed reservoir. The new impoundments are expected to go through a succession in their development from a riverine to a lake ecosystem, with the loss of most existing riverine communities. This would be expected to include a 1-2 year period of 'trophic upsurge' in the sheltered embayment areas. After about 5 years, when the ecosystems stabilise, periphyton are expected to be a minor component of the plant communities, while macrophytes, particularly *Elodea canadensis* and *Lagarosiphon major*, are expected to predominate. *Lagarosiphon* proliferations could cause future problems for water use and power generation in the system. Therefore, weed control measures should be considered before construction commences.

Invertebrate communities in the reservoirs are expected to be typical of other lakes in New Zealand, but because of the (probable) extensive cover of aquatic macrophytes, they will be dominated by macrophyte inhabiting fauna (e.g., *Potamopyrgus antipodarum*, *Physa acuta*, Sphaeriidae). Rich riverine communities could develop in the Dumbarton residual river.

A reservoir management policy that re-regulates the river to natural flows (e.g., equivalent to inflows at Clyde) below Birch Island is supported to help maintain productive biological communities in downstream reaches. However, the associated reservoir lake level fluctuations will result in some areas of barren shallows in the reservoirs.

There was approximately a 25% difference between the least and greatest ecological effects of the schemes considered here in terms of the amount of big gorge habitat being flooded, area of barren 'tidal' zone, and area of obstructive weed beds.

Scheme C (dams at Dumbarton Rock and above Birch Island) is likely to result in the least detrimental impacts for the existing periphyton, macrophyte and invertebrate communities, and is likely to have the least development of weed beds. This scheme will retain approximately 14 km of river with its unusual bedrock and backwater habitats, and thus examples of their associated red algae/moss communities and productive off-stream macrophyte beds.

PART A

CHARACTERISATION OF THE MAJOR BIOLOGICAL COMMUNITIES IN THE CLUTHA RIVER

1 INTRODUCTION

Although there are many communities in a river which could be included in resource investigations, it is generally only practical to study a few. Periphyton (microscopic and filamentous algae attached to the river bed), macrophytes (large, vascular plants), invertebrates (insect larvae and organisms such as snails) and fish represent the major groups of organisms living in aquatic ecosystems. All are sensitive to changes in water quality and habitat structure, assist with the purification of waters, and can be an exploitable resource. Given suitable habitat conditions, some may proliferate and interfere with public usage. This study was confined to periphyton, macrophyte and invertebrate communities.

Species lists are fundamental to the documentation of biological communities and were thus a major concern of the study. As impact predictions and management recommendations were to be made, it was also necessary to define ecological interactions and carry out semi-quantitative and quantitative determinations of community structure and standing crop. Because of the current state of our knowledge, impact predictions can only be general, so only a moderate level of precision was considered necessary for these quantitative data (±20-40%).

The magnitude of the flow in the Lower Clutha River (up to 2000 $m^3.sec^{-1}$), the length of the study reach, and its diverse morphology were expected to cause difficulties for characterising the communities. To help overcome these, the river was subdivided into physically similar units (habitats), their areas determined, and a selection of separate sites in each sampled. This approach, similar to that used for power development impact assessment in the Upper Clutha River (Biggs and Malthus, 1983), enabled the relative richness of the habitats and the proportion of the study area that they occupied to be included in the calculation of average study area values for each community.

Riverbed armouring, reduced diversity - but increased standing crop - of invertebrates, and proliferation of plant communities, have been reported from many Northern Hemisphere rivers following upstream impoundment (Ward and Stanford, 1979). It is likely, therefore, that regulation of the river at Roxburgh (fig. 1) has already affected the physical environment of, and thus biological communities in, the Lower Clutha. It is unfortunate that no information was collected on the river biota prior to the Roxburgh development, since it is the largest river in New Zealand and may have had some unique biological features. Therefore, this study characterises an already modified environment and does not present a true 'baseline' condition. This should be recognised when comparing the nature and value of the biological resource with the potential impacts of the various development proposals.

The lack of information on the periphyton, macrophyte or invertebrate communities in the Lower Clutha River and other large New Zealand rivers caused difficulties when evaluating the status of the Lower Clutha communities (e.g., how high is the standing crop of macrophytes relative to other large rivers?), and thus the uniqueness of the communities in the Lower Clutha.

1.1 STUDY AREA

The study area extends 75 km from the Roxburgh Dam to Tuapeka Mouth (fig. 1). The region between Roxburgh and Beaumont is characterised by a "basin and range" topography (Shepard, Rout Associates 1983), forming interspersed gorges and river flats. Below the fertile Beaumont basin, the valley becomes narrower, forming the bush-clad Beaumont-Rongahere Gorge. The valley widens at the Tuapeka River to become the fertile flood plains of Tuapeka Mouth and Clydevale.

The climate in the north of the study area is similar to the continental climate of Central Otago, whilst the southern region experiences the temperate climate of south Otago. This gradation results in the southern part of the study area receiving nearly double the rainfall of Roxburgh in the north, and less sunshine hours.

Most of the Clutha River originates as outflow from Lakes Wakatipu, Wanaka and Hawea, from where it flows south-east through Central Otago, entering the sea near Balclutha. The river is generally a deep single thread flow through much of the study reach, with a mean annual

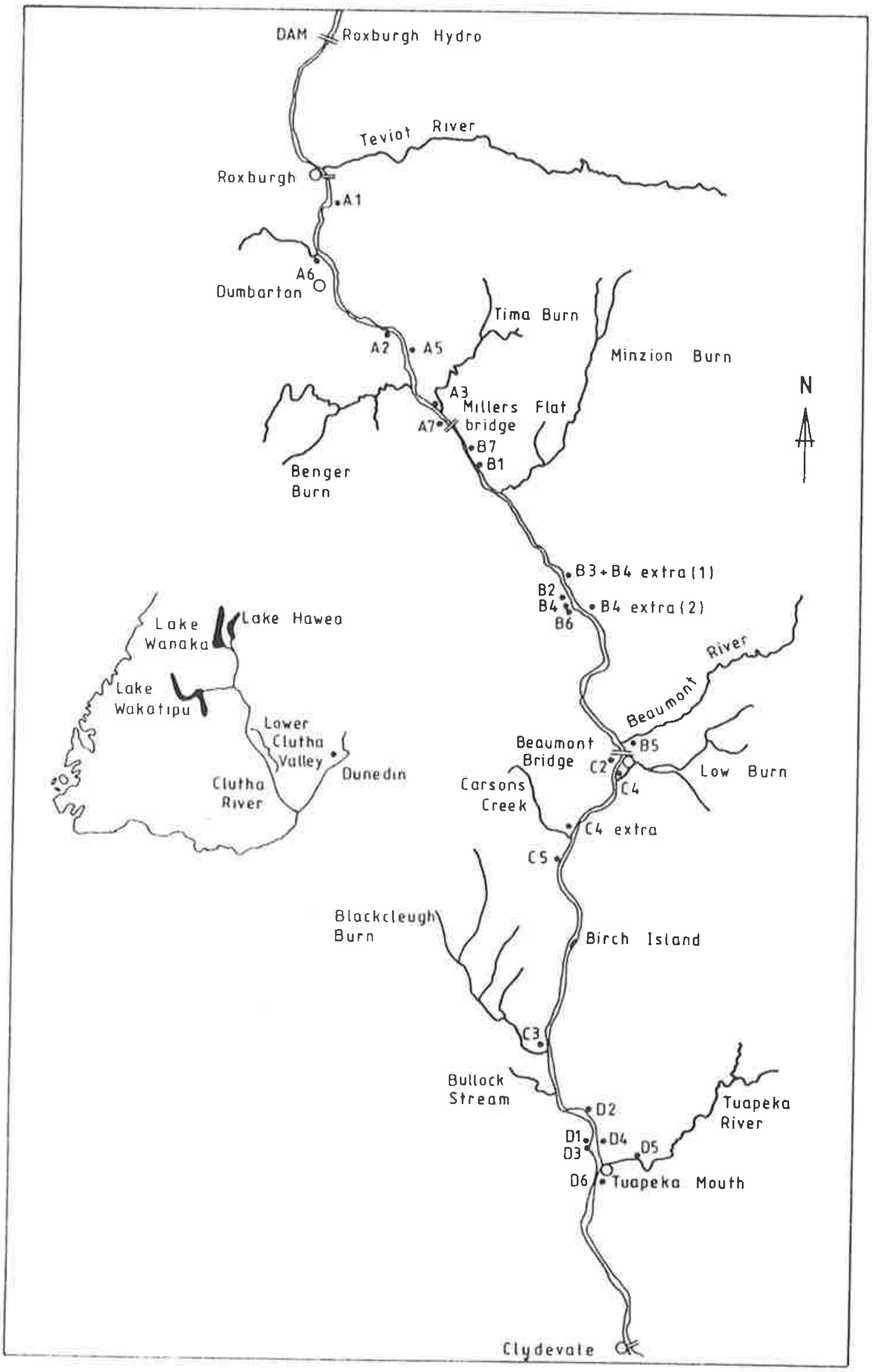

Figure 1 Lower Clutha River study area, showing the location of sampling sites

discharge of 504 $m^3.sec^{-1}$. Although seasonal differences are not large, flows are generally highest in spring and early summer (fig. 2a). Many small tributaries enter the river in the study reach, the largest of these being the Teviot, Beaumont and Tuapeka Rivers, and the Blackcleugh Burn. These tributaries seldom contribute significantly to the flow of the main river.

The Clutha River is regulated for power generation at Roxburgh, and the average difference between the lowest and highest flow each day since 1975 is 329 $m^3.sec^{-1}$ (Jowett, 1984). The daily changes in flow were observed to have a major effect on water depth in the study reach (changing up to 2 m), but relatively minor effects on water velocity.

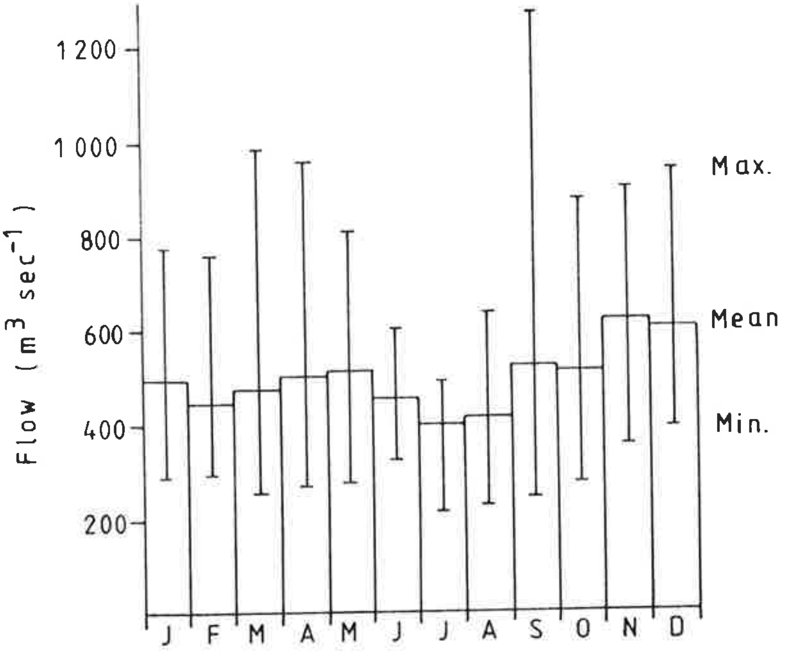

Figure 2a Mean, maximum and minimum monthly flows in the Lower Clutha River (1965-1981)

Large amounts of the river's littoral zone are, therefore, exposed at night and in the early morning on many days. Daily variations in flow through regulation tend to be greater and more frequent in the winter than in summer. Prior to the summer sampling programme, there had been prolonged periods of high flow (fig. 2b).

The water in the Lower Clutha River is generally of high quality, with low concentrations of nutrients (D.R.P. < 3 ppb, NO_3-N < 50 ppb) and dissolved ions (conductivity < $7 mS.m^{-1}$), and near saturation for dissolved oxygen (Davies-Colley, 1985). However, clarity is generally low because of high levels of suspended solids from upstream tributaries (e.g., Shotover River). No marked seasonal variations appear to occur in the water quality of the river. There was also little change in water quality down the study reach (Davies-Colley, 1985).

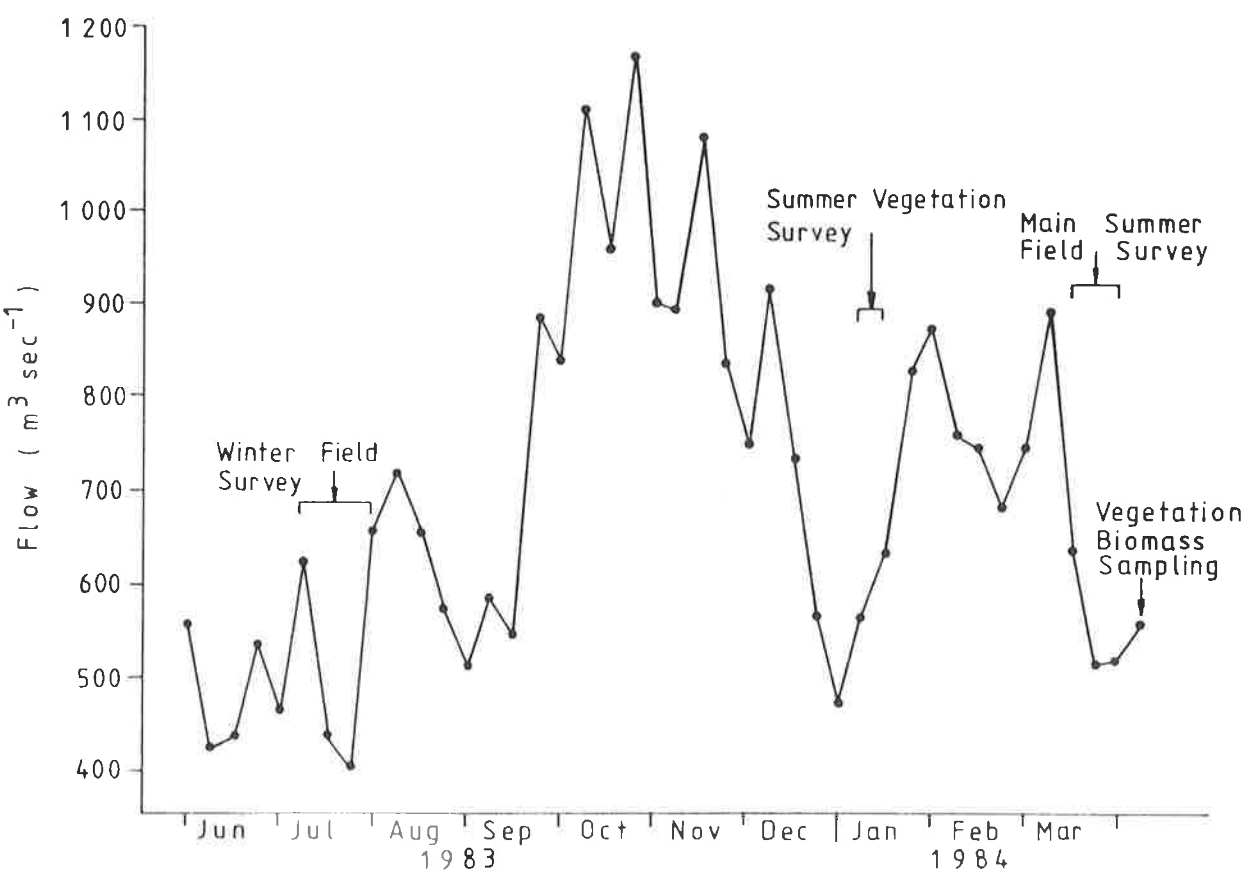

Figure 2b Mean weekly flows in the Lower Clutha River during the study period

Six habitat types were characterised in the area during average flows (fig. 3 and tables 1 and 2):

1 backwaters - generally a depositional environment with silty-sand sediments,

2 silty banks - forming the boundary for much of the flood channel and extending into deeper waters in depositional areas,

3 braids - peripheral to the main channel, generally an erosional environment with gravel-stone sediments,

4 shoulders - an erosional environment adjacent to the main channel with gravel and cobble sediments,

5 bedrock - an erosional environment of sheet bedrock, mainly in the shallow parts of the central channel, along banks, and on the upstream end of some islands,

6 tributaries - an erosional environment with gravel and cobble sediments, and areas of bedrock. Riffles and runs are the most common micro-habitat features.

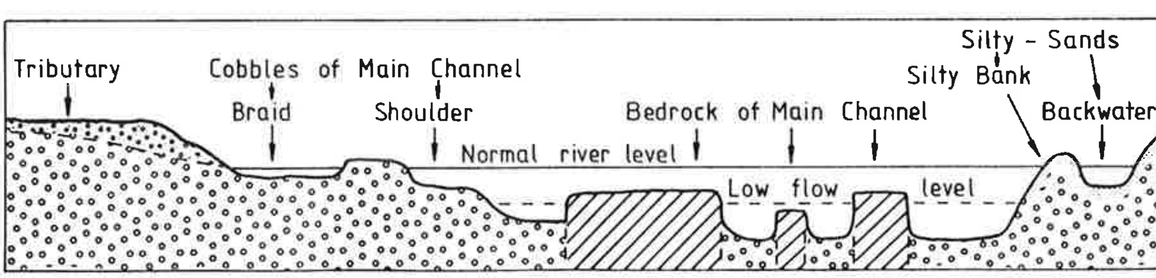

Figure 3 Diagrammatic cross-section of the Lower Clutha River showing the location and nature of the habitats

Table 1 Summary of mean percentage substrate composition in habitats of the Lower Clutha River July 1983, and January and March 1984.

	BACKWATERS			BRAIDS			SHOULDERS			SILTY BANKS		
	Jul 1983	Jan 1984	Mar 1984	Jul 1983	Jan 1984	Mar 1984	Jul 1983	Jan 1984	Mar 1984	Jul 1983	Jan 1984	Mar 1984
Clay Silt	77.9	86.2	76.5	49.7	19.4	42.4	4.3	-	14.2	46.2	54.7	51.4
Sand	16.4	11.0	16.0	14.5	26.3	24.5	21.0	10.6	15.1	36.5	34.9	35.9
Gravel	2.3	1.2	2.3	19.7	42.6	16.9	47.7	49.3	47.5	13.9	6.4	6.3
Small cobbles	3.4	1.6	5.2	16.1	11.7	16.2	27.0	40.1	23.2	3.4	4.0	6.4

Table 2 Estimated area of each habitat type

Habitat	Area (ha)	% of study area
Backwaters	9	3.8
Silty banks	69	29.1
Braids	21	8.9
Shoulders	62	26.2
Bedrock	72	30.4
Tributaries	4	1.7
Main channel - not sampled	746	-

All habitats had flowing water, except the backwaters. The main central channel, occuping 76% of the river, proved difficult to characterise physically or biologically because of the deep and swift flowing water. When observed during a brief period of very low flows this area appeared to consist mainly of mobile gravels and had few resident organisms. The term 'study area' in the text, therefore, refers to the 24% of the river which could be characterised. The average standing crops of the communities are expressed in the text on a 'study area' basis. These values are considerably higher than would have been obtained had it been possible to sample the whole river.

2 METHODS

2.1 SAMPLING PROGRAMME

Twenty-five sites were selected for sampling (fig. 1) to cover the length of the study area and include examples of each habitat type down the main river (7 backwaters, 5 silty banks, 3 braids, 6 shoulders, 2 bedrock, 2 tributaries). The character of the sampling sites is summarised in appendix 1A.

The sites were surveyed in winter (July 1983) and late summer (March 1984). Sampling twice was considered to be adequate for the characterisation of the communities and it would have identified any major seasonal differences. A point transect survey of vegetation cover during early January 1984 was interrupted by high river levels and therefore was repeated in March 1984.

Eight additional tributaries were sampled in summer (March 1984). These sites, all within 1 km of the confluence with the main river, are described in appendix 1B. Because of the deep and swift nature of the river, most of the sites (excluding tributaries) could be sampled only while exposed during early morning residual flows in winter, and during flows that were greatly reduced, for bridge maintenance, in late summer. The communities were, therefore, subject to major changes in flow, and in winter they were often above water level for prolonged periods at night and in the early morning.

The area of each habitat in the river was determined using scaled colour aerial photographs, taken during very low flows in winter, and planimetry (Biggs and Malthus, 1983). The planimetry assessments were the average of two sets of separate recordings.

2.2 FILAMENTOUS PERIPHYTON SAMPLING

Samples were obtained by defining a 0.0028 m^2 area on the surface of arbitrarily selected rocks, or on the silty-sands, and then scraping the surface community off with a scalpel. Five samples were collected at each site and preserved in 10% formalin. A range of site information was also collected to assist with data interpretation, including: type and amount of overhead cover, sediment type beneath each sample, water conductivity and temperature. The percentage cover of the sites by periphyton in the bedrock and tributary habitats was estimated visually.

Samples were thoroughly mixed (using an homogeniser if more than one filamentous alga was abundant) and analysed by scanning three pooled sub-samples. The dominant taxon, and any others that occurred frequently (associants), were listed. Although only a slight modification of the simple presence/absence method of enumeration, this approach gave considerably more information about the structure of the community.

Loss-on-ignition (dry weight at 105°C - ash weight at 550°C) was determined for each sample as a measure of the total amount of periphyton present. Where large amounts of silt occurred in the samples, they were re-hydrated after ashing to replace water lost from the clay fraction which can be removed during ashing.

2.3 MACROPHYTE SAMPLING

2.3.1 Estimation of percentage cover of aquatic and semi-aquatic plant communities

A modification of the point sampling method described by Wright *et al.* (1981) was used to estimate the percentage cover of aquatic and semi-aquatic plants at the sites. The proportions of the different plant species were recorded in approximately 200, 7.5 cm diameter circles; the circles being evenly distributed within a grid pattern so that the entire area of the sampling site was surveyed.

Where more than one plant species was found in a circle, an estimate was made of the proportion of the area that was occupied by each species. As the area of the circles was small, compared with the 0.25 x 0.2 m quadrat used by Wright *et al.*, it was considered unnecessary to compensate for the variable density of the different plant species. An estimate was made of the proportion of the circles that contained no plant cover. Water depth and an estimate of substrate composition (after Mosley, 1982) were also recorded at each grid point.

A record of aquatic and semi-aquatic plant taxa observed, but not intercepted, during the grid sampling survey was made to obtain a more complete species list. Although the majority of the sampling sites were bordered by a variety of rushes and sedges, only plants recorded during the grid surveys were included in the species list.

A summary of the survey dates is included in the description of the sampling sites in appendix 1. Several sites were not examined during one, or other, of the winter or summer surveys because of inaccessibility due to high water levels. No grid sampling surveys were carried out in the bedrock habitats because of the flow regime, or in the tributaries because of a lack of macrophyte growth.

2.3.2 Estimation of aquatic macrophyte standing crop

Sampling was carried out during March 1984. A 0.25 m^2 quadrat frame was used to define the sampling area. The plants were cut close to ground level, using shears, and placed in large plastic bags. After thorough washing in water to remove sediment and invertebrates, the biomass was determined by weighing after drying at 105°C for at least 24 hours.

All aquatic macrophyte populations, with the exception of *Chara* sp., were sampled for standing crop. Because of a general scarcity of macrophytes no samples were collected from bedrock or shoulder habitats.

2.4 INVERTEBRATE SAMPLING

Samples were collected from a range of micro-habitats at each site to obtain a comprehensive species list and an assessment of invertebrate abundance. Sampling included:

(a) A minimum of five quantitative invertebrate samples at each site collected using:

(i) a Surber sampler (area = 0.0625 m^2, collecting net mesh size = 0.425 mm), used on submerged gravel and rock substrates,

(ii) a core sampler (area = 0.0079 m^2, depth 0.125 m), used on submerged or exposed soft substrates, or

(iii) quadrats (area = 0.0625 m^2), used on silt overlying exposed boulders.

(b) Three qualitative invertebrate samples at each site:

(i) one interstitial sample - obtained by the collection of water and migratory invertebrates that entered a hole dug in the river bank (collected during winter survey only),

(ii) one sample of small debris piles, and

(iii) one sample of decomposing wood.

Samples were stored at -15°C, and for analysis, the sediment retained by a 0.5 mm mesh was sorted and invertebrates identified to the lowest taxonomic level possible. The organisms were preserved in 4% formalin.

After sorting, identification and counting, the invertebrates from each sampling site were grouped into two, molluscs and all others, and the biomass of each combined sample determined by weighing after drying at 105°C for at least 8 hours. The biomass of molluscs was adjusted for the weight of shell material (average of 90% of the mollusc dry weight - Forsyth and McCallum, 1981).

2.5 DATA ANALYSIS

The data from the two surveys were pooled for each habitat type for the general community descriptions. As macrophyte and periphyton sampling were stratified within habitats, sample standing crops were determined as the sample dry weight (or loss-on-ignition) multiplied by the proportion of the site covered by the community. These 'averaged' figures were then pooled to determine the overall average for the habitat type.

The data for all aspects of the assessment, except macrophyte cover, were log-normally distributed, and were therefore transformed to calculate geometric means ($\bar{x}$) (Elliott, 1977). The summations of the geometric mean species densities do not equate to the geometric mean total densities of organisms in habitats (e.g., table 8) because of the skewed distribution of the data. The geometric standard deviation (s) of the data ($\bar{x}_i$) was approximated as:

$$S = \frac{\text{antilog } [(\bar{x} \text{ of logged data} + s \text{ of logged data}) - (\bar{x} \text{ of logged data} - s \text{ of logged data})]}{2}$$

and the standard error (S.E.) as:

$$S.E. = \frac{s}{\sqrt{n}}$$

As the sampling was stratified, the habitat means were weighted according to the proportion of the study area occupied by each strata to give an overall habitat weighted mean (Elliott, 1977):

$$\bar{x} = \frac{\sum_{i=1}^{k} n_i \bar{x}_i}{\sum_{i=1}^{k} n} = \frac{n_1\bar{x}_1 + n_2\bar{x}_2 + \ldots\ldots + n_k\bar{x}_k}{n}$$

and the standard error:

$$S.E. = \sqrt{\sum_{i=1}^{k_1} \left(\frac{Ni}{N}^2\right) \left(\frac{Si^2}{ni}\right)}$$

The significance of differences in the various community determinands between the habitats was calculated using the non-parametric Mann-Whitney U test. Differences in quantitative community structure between habitat types were determined graphically using cluster analysis. The percentage similarity of community index and average linkage algorithm (Sokal and Sneath, 1973) were used to determine community similarities and construct dendrograms.

3 RESULTS AND DISCUSSION

3.1 FILAMENTOUS PERIPHYTON

The study area had a moderate to low abundance of filamentous dominated periphyton. The (geometric) mean cover of the substrate was 25.4% and the (geometric) mean standing crop 6.85 $g.m^2$, which are comparable to levels recorded from other large rivers in New Zealand (B J Biggs, MWD, unpublished data). The estimated total standing crop was 14.8 tonnes, approximately 85% of the standing crop of plants in the study area. The periphyton community was thus the dominant primary producer in the river.

Of the 62 periphyton taxa recorded in the survey (appendix 2), Bacillariophyceae (diatoms) was the largest taxonomic group (79% of the taxa), followed by Chlorophyceae (green algae) (16%). In terms of relative abundance, there was a diverse assemblage of dominant filamentous taxa, with *Rhodochorton violaceum* the single most abundant, dominating 33% of the study area (table 3). Other abundant taxa included *Oedogonium* spp., *Ulothrix zonata*, *Vaucheria* sp., and *Phormidium* spp.

The 15 non-filamentous taxa, commonly found as associants of the filamentous communities, were mainly diatoms. Of note was the high abundance of *Frustulia rhomboides*, *Synedra ulna*, *Navicula viridula* var. *avenacea*, and *Cymbella kappii* (table 3). These taxa are common in many other New Zealand rivers (Foged, 1979; B J Biggs, MWD, unpublished data).

3.1.1 Community characteristics of each habitat

The bedrock and braid habitats had well developed communities of filamentous dominated periphyton, with the bedrock having a significantly higher percentage cover and standing crop than the other habitats (tables 3 and 4). By comparison, the (silty) backwaters, with their low water currents, were poorly colonised, and most other habitats had significantly higher levels of cover and standing crop

Table 3 Percentage of samples from each habitat in which common periphyton taxa dominated the community (D), or were just found abundantly (A). (The figures do not add up to 100, as several taxa could dominate and many could occur abundantly in any one sample.) The geometric mean cover, standing crop, and total crop for each habitat are also given. (BW = Blackwaters, SB = Silty Banks, B = Braids, S = Shoulders, BR = Bedrock, T = Tributaries, SA = Study Area).

Periphyton	BW		SB		B		S		BR		T		SA	
Taxa	D	A	D	A	D	A	D	A	D	A	D	A	D	A
Filamentous	0	13	0	27	3	0	0	19	0	52	31	17	1	29
Melosira varians	13	0	1	3	0	13	19	8	7	14	0	5	19	8
Oedogonium spp.	39	7	3	8	5	6	3	11	0	0	14	5	5	6
Rhodochorton violaceum	3	23	5	19	5	16	19	53	79	7	0	9	33	24
Schizothrix sp.	3	3	3	3	9	13	3	11	0	24	5	4	3	12
Ulothrix zonata	3	3	3	14	6	9	31	17	21	28	22	26	17	18
Vaucheria sp.	10	0	7	0	0	0	0	0	0	4	7	4	8	1
Unicellular associants														
Achnanthes minutissima	0	0	0	8	0	16	0	17	0	4	0	0	0	9
Cocconeis placentula	0	19	0	11	0	3	0	3	4	4	0	14	1	6
Cymbella kappii	0	23	3	32	19	19	8	25	0	31	0	0	4	29
Cymbella minuta	0	3	0	0	0	3	0	8	0	7	0	10	0	5
Fragilaria sp.	0	10	0	3	0	22	0	0	0	17	0	2	0	8
Fragilaria vaucheriae	0	16	0	11	0	0	0	19	0	17	0	26	0	15
Frustulia rhomboides	0	32	3	32	0	28	0	42	0	93	0	12	1	53
Gomphoneis herculeana	0	3	0	3	0	6	0	11	0	14	17	29	<1	9
Gomphonema subclavatum	0	0	0	5	0	0	0	6	0	0	0	16	0	3
Navicula rhyncocephala	0	48	0	5	0	0	0	6	0	0	0	26	0	5
Navicula viridula Var. *avenacea*	19	23	8	32	3	34	3	33	4	59	9	55	5	41
Nitzschia sp.	0	3	0	0	0	6	3	14	0	14	0	0	1	8
Rhoicosphenia curvata	0	10	0	0	0	0	0	0	0	0	2	17	<1	1
Synedra minuscula	0	3	0	11	0	3	0	19	0	0	0	0	0	9
Synedra ulna	0	39	3	60	0	75	3	44	0	48	4	40	2	52
% Cover of Habitats	3.13		11.4		21.3		15.0		45.3		19.5		25.4	
Standard Error	0.92		2.7		7.1		8.2		16.9		7.1			
Number of Samples	15		14		8		11		4		12		64	
Standing Crop ($g.m^{-2}$)	1.35		2.67		4.17		2.92		14.02		2.33		6.85	
Standard Error	0.46		0.79		1.30		0.89		2.51		0.46			
Number of Samples	32		32		31		44		21		59		219	
Total Habitat Crop (tonnos)	0.12		1.84		0.88		1.81		10.1		0.05		14.8	

Table 4 Differences between habitats in the median percentage cover of the substrate and standing crop of filamentous dominated periphyton in the Lower Clutha River, given as significance values for the Mann-Whitney U statistic. This varies from 0 for medians that are very dissimilar to 1 for medians that are the same (* = the difference is significant, $p < 0.05$; ** = highly significant, $p < 0.01$; * = very highly significant, $p < 0.001$).**

	Backwaters	Silty Banks	Braids	Shoulders	Bedrock	Tributaries
			Standing Crop			
Backwaters	-	0.025*	0.002**	0.017*	0.000***	0.050*
Silty Banks	0.002**	-	0.194	0.632	0.000***	0.730
Braids	0.001***	0.082	-	0.515	0.001***	0.078
Shoulders	0.010**	0.311	0.710	-	0.000***	0.214
Bedrock	0.004**	0.009**	0.149	0.133	-	0.000***
Tributaries	0.002**	0.143	0.729	0.644	0.203	-
			% Cover			

than the backwaters. The bedrock harboured just under 70% of the total crop of filamentous periphyton in the study area (table 3).

Each habitat had distinctive periphyton assemblages (fig. 4), which reflected their physical differences. Tributaries, although physically similar to braids, had a very different assemblage to that found in the other habitats. This probably reflects their different water quality and flow regimes. Overall, tributaries had the highest taxonomic richness (45 taxa), followed by shoulders (33 taxa), backwaters (31 taxa), silty banks and braids (30 taxa), and bedrock (21 taxa).

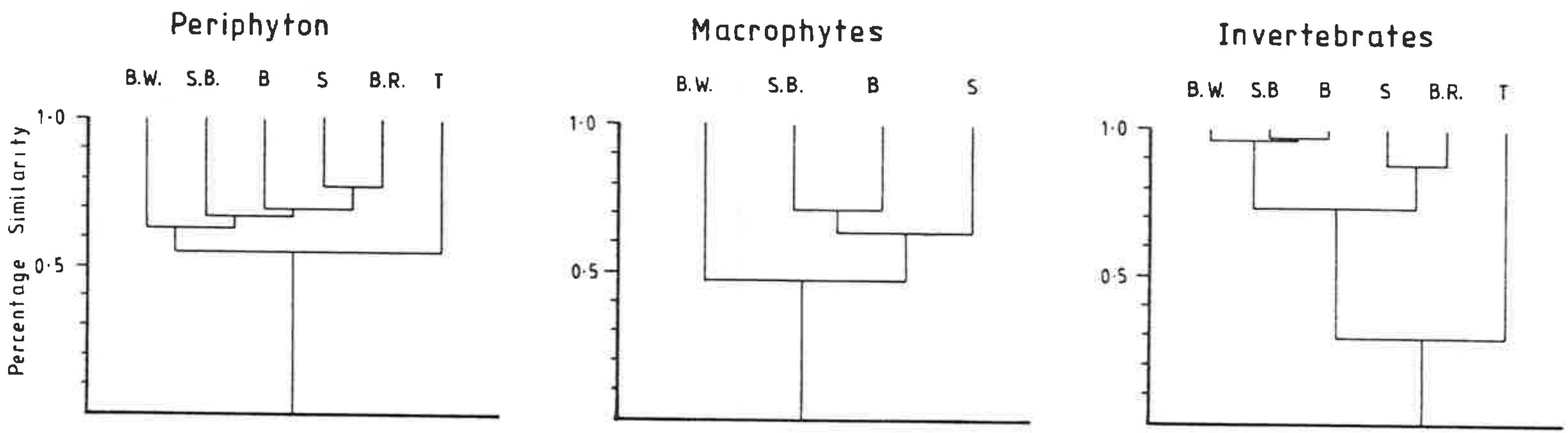

Figure 4 **Dendrogram of the affinity that the habitats have to each other based on similarities in composition of the periphyton, macrophyte and invertebrate communities (B = braids, B.R. = bedrock, B.W. = backwaters, S.B. = silty banks, S = shoulders, T = tributaries).**

The following is a summary of the taxa most frequently found dominating each habitat and thus those which characterise each habitat (fig. 5):

Backwaters - *Phormidium* spp; *Navicula viridula* var. *avenacea*; *Oedogonium* spp;

Silty banks - *Vaucheria* sp; *Rhodochorton violaceum*; *Navicula viridula* var. *avenacea*;

Braids - *Cymbella kappii*; *Schizothrix* sp.; *Ulothrix zonata*;

Shoulders - *Ulothrix zonata*; *Rhodochorton violaceum*; *Oedogonium* spp.;

Bedrock - *Rhodochorton violaceum*; *Ulothrix zonata*;

Tributaries - *Melosira varians*; *Ulothrix zonata*; *Phormidium* spp.

Diatoms abundant in specific habitats included: *Navicula viridula* var. *avenacea* (backwaters), *Cymbella kappii* (braids), *Frustulia rhomboides* (bedrock), and *Gomphoneis herculeana* (tributaries).

The *Phormidium* spp. formed a dark 'leathery' skin on top of silts in backwaters, binding the silt particles together. *Navicula viridula* var. *avenacea* also formed a thin layer on the surface of silts, giving them a green-brown colouring. The other common taxa on silty substrates of backwaters (and silty banks) were *Oedogonium* spp. and *Vaucheria* sp. Both developed 'rhizoid-like' anchoring structures, which would have assisted their development on these unstable substrates.

3.1.2 Seasonal differences in periphyton communities

The mean standing crop of filamentous dominated periphyton in the study area was 91% higher in winter than summer (x = 11.42 $g.m^{-2}$ cf. 5.97 $g.m^{-2}$), and percentage cover was 172% higher in winter (x = 15% in summer and 40% in winter). In terms of individual habitats, these

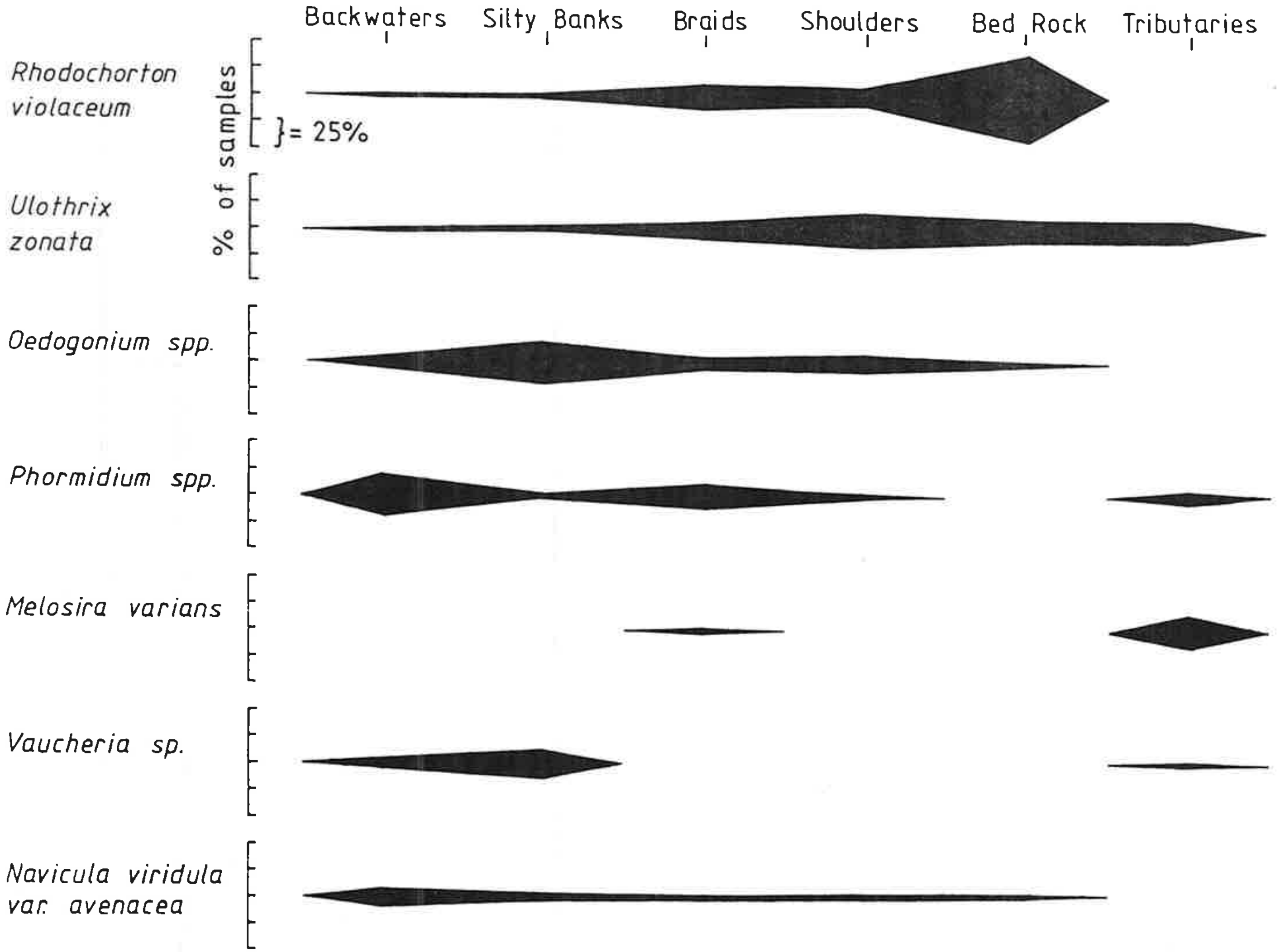

Figure 5 **Kite diagram demonstrating changes in the abundance of the common periphyton taxa between habitats. The width of the shaded area at each habitat point represents the percentage of the samples from that habitat dominated by each of the taxa.**

differences were all confined to the main river, with the backwater and braid habitats recording the largest differences (e.g., 230% higher standing crops in winter than summer). In contrast, tributaries had, on average, a 50% lower standing crop and 35% lower cover in winter than in summer. These differences are probably the result of seasonal changes in river flows. In the main river, low to medium flows occur during winter with high flows in summer following snow melt in the alpine headwaters, whereas for the foothill fed tributaries the flow pattern appears to be the reverse.

Marked seasonal differences in the abundance of two filamentous and eight unicellular taxa were recorded in all habitats (table 5).

Table 5 Seasonal differences in abundance of certain periphyton taxa in the Lower Clutha River. (D = % of the samples for the given season in which the taxa were dominant; A = % of the samples for the given season in which the taxa were associants).

Taxa	Winter		Summer	
	D	A	D	A
Filamentous				
Oedogonium spp.	7	2	27	7
Vaucheria sp.	13	2	4	1
Unicellular				
Achnanthes minutissima	-	-	-	12
Cymbella kappii	7	35	-	10
Frustulia rhomboides	1	55	-	21
Navicula rhyncocephala	-	-	-	27
Navicula viridula var. *avenacea*	18	61	-	26
Nitzschia palea	-	-	-	9
Rhoicosphenia curvata	-	-	1	10
Number of samples	95		128	

3.1.3 General discussion

The moderate to low cover and standing crop of filamentous periphyton communities probably reflect the low nutrient status of the waters (Hynes, 1970). The large extent of unstable silty-sand substrate, which can prevent substantial periphyton accrual (McConnell and Sigler, 1959), and low water temperatures are also likely to have limited their development. Most of the substantial developments were confined to areas of stable bed sediment, the populations dominating these habitats (e.g., *Ulothrix zonata* and *Rhodochorton violaceum*) showing a considerable resilience to daily flow fluctuations and de-watering. Periphyton do not appear to proliferate and cause problems for water users in any of the habitats in the study area.

Of the filamentous dominants, *Ulothrix zonata* often proliferates in New Zealand high country rivers with high quality waters, and *Phormidium* spp. is often abundant in late summer in foothills rivers of a similar water quality to the Lower Clutha. The latter community forms dark purple skins over mucilagenous diatom slimes in foothills rivers (B J Biggs, MWD, unpublished data). *Melosira varians* and *Oedogonium* spp. have wide ecological ranges and they are reported to be tolerant of mild organic pollution and high levels of suspended solids (Fjerdingstad, 1965; Lowe, 1974). The other common dominant, *Vaucheria* sp., is used as an indicator of eutrophic conditions in Europe (Israelson, 1949). It is not possible to confidently infer the water quality in the area from the total periphyton assemblage because of the diverse habitats and community composition. However, if only filamentous communities growing on "hard" rocky substrates are considered, an oligotrophic system would be suggested. This supports the water quality assessment of Davies-Colley (1985).

Apart from the preponderance of *Rhodochorton violaceum*, the periphyton communities closely resemble those found in many other high country rivers in New Zealand (B J Biggs, MWD, unpublished data). The growth of red algae, such as *Rhodochorton violaceum*, is partly dependent on the presence of a stable bed sediment (Hynes, 1970). Unlike most other New Zealand rivers, there are extensive areas of bedrock in the study reach which are likely to have assisted the development of this taxon. The extensive development of *Rhodochorton violaceum* in the study area is of considerable scientific interest due to the rarity of this taxon elsewhere in New Zealand.

3.2 MACROPHYTES

The study area supported a moderate to low cover of aquatic and wetland (peripheral to the permanently submerged areas) macrophytes. The mean cover of the study area was 18%, of which terrestrial plants fringing the waterway accounted for 38%, semi-aquatics 35%, and aquatics 28%.

Of the 70 macrophyte taxa identified during the study, 8 were aquatic, 38 semi-aquatic and 24 terrestrial. As the terrestrial species were found fringing the high water level they would only be inundated by large changes in river level or course. They are, therefore, not discussed in detail here. A summary is given in appendix 3 of taxa observed in each habitat type during the point intercept surveys, and of their cover at each sampling station. A full listing of macrophytes observed in the study area is given in appendix 4.

The common aquatic macrophytes covered 4.9% of the study area (table 6), with the introduced taxon *Elodea canadensis* being the most abundant. Other common taxa included *Potamogeton* spp., *Myriophyllum elatinoides* and *Ranunculus fluitans*. The (geometric) mean standing crop of aquatic macrophytes in the study area was 1.08 $g.m^{-2}$ (dry weight) and the total standing crop was 2.34 tonnes. The cover of aquatic macrophytes was moderately high by comparison with most other large New Zealand rivers, which tend to have few, or no, macrophyte beds (B J Biggs, MWD, unpublished data).

The common semi-aquatic plants covered 6.2% of the study area, with mosses and the sedge *Juncus articulatus* being the most abundant. Terrestrial macrophytes, with the exception of *Salix fragilis*, were recorded only where they fringed the habitats and therefore were relatively poorly represented (table 6).

Table 6 Percentage cover of the common macrophyte taxa in each habitat, together with the habitat weighted mean cover for the Lower Clutha River study area. Total mean % cover, geometric mean standing crops and habitat crops are also given.

Macrophyte Taxa	Backwaters	Silty Banks	Braids	Shoulders	Habitat Weighted Mean
Aquatic plants					
Chara sp.	0.61	0.63	0.40	0	0.266
Elodea canadensis	20.70	4.00	2.36	+	2.370
Lagarosiphon major	1.20	0	0.18	0	0.067
Myriophyllum elatinoides	2.15	1.56	0.39	0.28	0.707
Potamogeton sp.	4.21	1.84	0.54	+	0.817
Ranunculus fluitans	6.22	0.42	2.74	+	0.660
Total % Cover - Aquatic	35.09	8.45	6.61	0.28	4.887
Semi-aquatic plants					
Agrostis stolonifera	0.04	0.14	0.20	0	0.065
Callitriche petriei	1.94	2.53	0.09	0.10	0.927
Cardamine debilis	0.26	+	+	0.02	0.016
Carex spp.	0.53	0.19	0.09	0.01	0.093
Epilobium sp.	0.04	0.01	0	0.02	0.009
Glossostigma elatinoides	0.86	0.60	0.55	0.10	0.310
Hydrocotyle sulcata	0.70	0.34	0.10	0.05	0.163
Juncus articulatus	2.58	2.45	2.06	0.13	1.128
Lilaeopsis sp.	0.01	0.14	0.39	0.02	0.090
Limosella lineata	<0.01	0.24	0.06	0.01	0.087
Musci	0.98	3.49	5.15	0.94	1.891
Myosotis caespitosa	0.45	0.13	0.04	0.08	0.085
Myriophyllum votschii	0.09	0.46	0	0	0.152
Nasturtium microphyllum	0.04	0	0	0	0.002
Pratia angulata	0.71	0.25	0.19	0.01	0.131
Prunella vulgaris	0.19	0.10	0.11	0	0.051
Ranunculus flammula	0.08	0	0	+	0.004
Rumex spp.	0.49	0.03	0.01	0.01	0.035
Tillaea sinclairii	2.23	1.94	1.94	0.04	0.912
Total % Cover - Semi-aquatic	12.31	13.04	10.98	1.54	6.145
Terrestrial plants					
Festuca arundinacea	0.24	0.94	2.08	0.10	0.540
Phormium tenax	0.02	0	+	0	0.001
Ranunculus repens	0.02	+	+	+	0.001
Salix fragilis	8.83	14.12	7.61	2.04	6.204
Trifolium spp.	0.05	0.03	0.06	0	0.016
Total % Cover - Terrestrial	9.16	15.09	9.75	2.14	6.762
% Cover of Habitats	56.5	36.4	27.5	3.97	17.8
Standard Error	3.71	4.19	3.11	1.26	1.43
Number of Samples	25	16	8	10	59
Aquatics					
Standing Crop ($g.m^{-2}$)	11.0	1.11	2.77	-	1.08
Standard Error	2.38	0.60	1.41	-	
Number of Samples	55	12	4	-	81
Total Habitat Crop - Aquatics (tonnes)	0.99	0.77	0.58	-	2.34

Many of the semi-aquatic taxa formed patches of a low-mixed community on silty substrates. This community was diverse and contained the following (in decreasing order of percentage cover): mosses, *Juncus articulatus*, *Callitriche petriei*, *Tillaea sinclairii*, *Glossostigma elatinoides*, *Hydrocotyle sulcata* and *Myosotis caespitosa* (table 6). Crack willow, *Salix fragilis*, was estimated by planimetry to cover 42.3% of total bank area. Its submerged roots often formed dense mats on the surface of the silts and prevented the growth of other macrophytes. Their predominance is also reflected in their high percentage cover values at many of the sampling sites (appendix 3).

3.2.1 Community characteristics of each habitat

Backwaters had significantly higher percentage covers and standing crops of aquatic macrophytes (42% of the total dry weight) than the other habitats (tables 6 and 7). The moderate to low developments in the silty bank and braid habitats were probably due to the higher velocity waters and rock substrates.

Table 7 Differences between habitats in the median percentage cover of the substrate and standing crop of macrophytes in the Lower Clutha River, given as significance values for the Mann-Whitney U statistic. This varies from 0 for medians that are very dissimilar to 1 for medians that are the same (* = the difference is significant, $p < 0.05$; ** = highly significant, $p < 0.01$; * = very highly significant, $p < 0.001$; N.D. = not determined).**

	Backwaters	Silty Banks	Braids	Shoulders
		Standing Crop		
Backwaters	-	0.000***	0.042*	N.D.
Silty Banks	0.003**	-	0.363	N.D.
Braids	0.008**	0.878	-	N.D.
Shoulders	0.000***	0.000***	0.000***	
		% Cover		

Aquatic macrophytes were the most prominent type of vegetation in the backwaters, whereas terrestrial macrophytes were more prominent in the silty banks and semi-aquatics in the braids, reflecting the different physical nature of the habitats, their associated flow regimes and proximity to flowing water. The backwaters had very slow running or still water, whereas the other habitats had slow to moderately flowing water.

The silty bank and braid habitats had the most similar macrophyte assemblages (fig. 4). However, there was generally a low degree of similarity between the different communities, reflecting separation of the habitats on physical grounds. Overall, backwaters had the highest taxonomic richness (53 taxa), followed by braids and shoulders (45 taxa) and silty banks (35 taxa).

The following is a summary of the dominant aquatic taxa in each habitat, based on their percentage cover (fig. 6, table 6):

Backwaters - *Elodea canadensis*;
Silty Banks - *Elodea canadensis*; *Potamogeton* spp.; *Myriophyllum elatinoides*;
Braids - *Ranunculus fluitans*; *Elodea canadensis*;
Shoulders - *Myriophyllum elatinoides*.

The dominant semi-aquatic taxa in each habitat, determined by their percentage cover, were (fig. 6, table 6):

Backwaters - *Juncus articulatus*; *Tillaea sinclairii*; *Callitriche petriei*;
Silty Banks - Musci; *Callitriche petriei*; *Juncus articulatus*;
Braids - Musci; *Juncus articulatus*; *Tillaea sinclairii*;
Shoulders - Musci.

Because of the flow regime and location of the bedrock habitats in the central river, it was not possible to adequately characterise their aquatic macrophyte communities. However, during short periods of very low flow, when the bedrock was visible, extensive mats of aquatic mosses were observed, some covering up to 50% of the substrate.

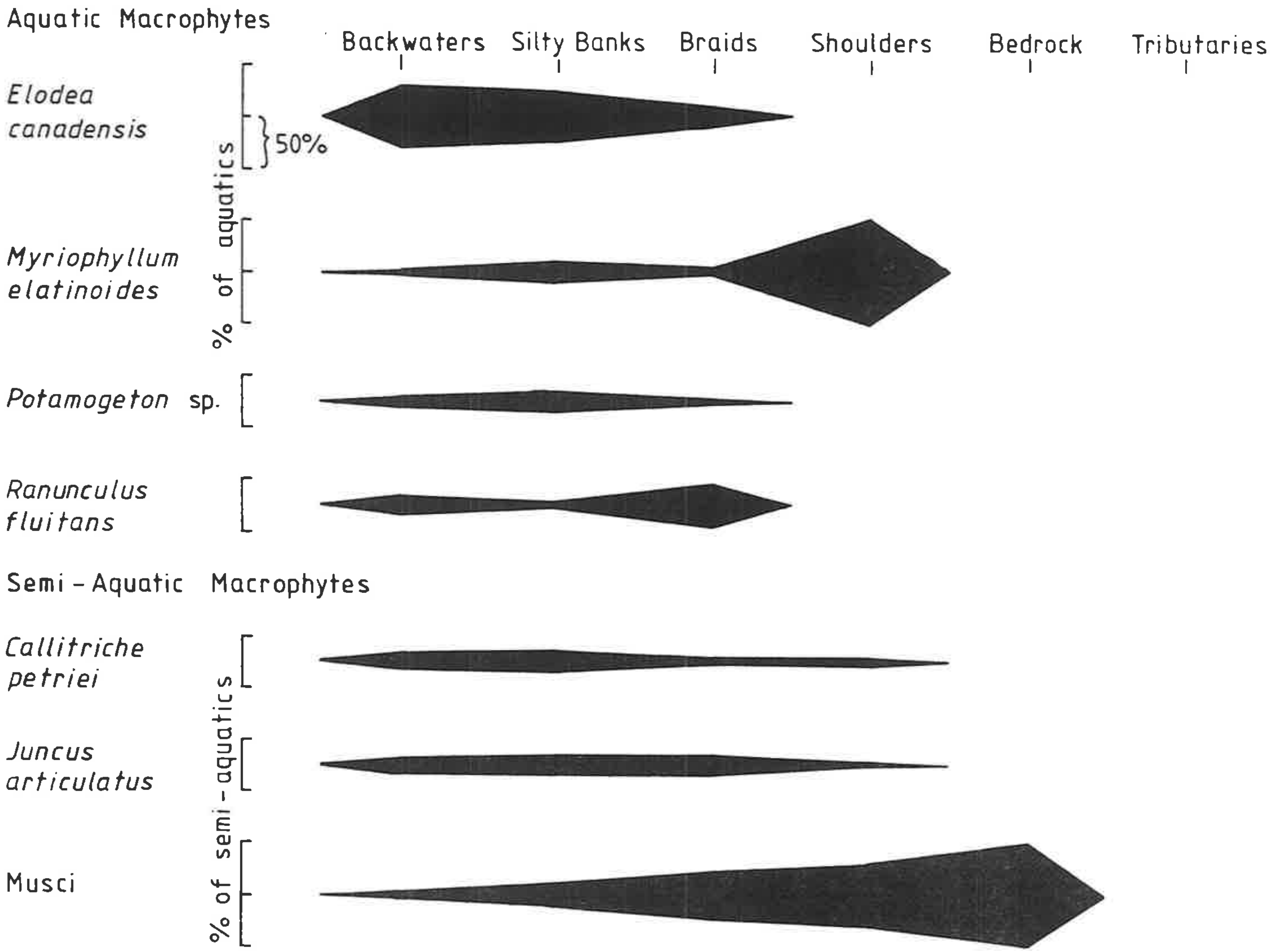

Figure 6 Kite diagram demonstrating changes in the abundance of the common macrophyte taxa between habitats. The width of the shaded area at each habitat point represents the percentage of the macrophyte cover in the habitat accounted for by each taxa.

3.2.2 Seasonal differences in macrophyte communities

There was no difference in the total percentage cover of the study area by macrophytes between sampling occasions (17.7 and 17.8%). There were also no major differences when habitats were examined individually. The resident macrophytes were generally firmly attached to the substrate and thus were able to endure the high flows prior to the summer sampling. Taxa which had a lower abundance during winter (*Potomageton* spp., *Lagarosiphon major* and willow roots) were compensated for, in terms of the overall percentage macrophyte cover, by an increase in the abundance of other taxa (*Elodea canadensis* and mosses) during the winter sampling.

3.2.3 General discussion

Macrophyte development in the Lower Clutha River was highest in areas sheltered from flowing waters especially backwaters, where dense pockets of vegetation were recorded. As with the periphyton of the braids and bedrock, these communities showed a remarkable resilience following daily de-watering. The macrophyte communities do not appear to be causing any problems for water use in the area at present.

The deposition of silts in backwaters, providing a rich substrate on which the macrophytes can develop, appears to have particularly favoured *Elodea canadensis*, and is expected to aid the future proliferation of *Lagarosiphon major*. Presumably, both of these plants have caused significant changes in the distribution of native communities in the river, as has been reported for New Zealand lakes (Brown, 1975). However, because of their higher growth stature they will also have provided additional habitat for invertebrates such as *Potamopyrgus antipodarum*.

Semi-aquatic macrophyte communities are more widespread in the Lower Clutha River than are aquatics, and are evenly distributed over the backwater, silty bank and braid habitats. They appear to play an important role in the ecosystem by stabilising river bank silts in the zone above average river level that is periodically inundated by flood flows.

Taxa dominating the semi-aquatic communities were mainly natives (Musci, *Callitriche petriei*, and *Tillaea sinclairii*), with only *Juncus articulatus* being introduced. However, where present, this latter plant usually formed thick clumps that excluded other plants.

Extensive areas of silty banks and backwaters (30% and 60%, respectively) were devoid of any macrophyte development. As these were mainly areas directly exposed to the current at times of high flow, scouring by the water would have prevented macrophyte colonisation.

Growth of the problem weed *Lagarosiphon major* was not extensive in the river and was confined to six backwaters and one braid. These are the first confirmed findings of this exotic weed in this section of the river, although its spread is to be expected considering that *Lagarosiphon* infestations have been recorded in Lake Roxburgh (B I Shand and B J Biggs, MWD, unpublished data.) Although not yet common in the river, it is important to note that in the relatively short time span of the field work the percentage cover of *Lagarosiphon* increased approximately two-fold; this increase being most marked in sites B7 and D1 (appendix 3). It also had the highest standing crop per square metre of the various plant taxa. Similar standing crop values were recorded by Biggs (1981) in studies of the Upper Clutha River. The *Lagarosiphon* beds were not fully developed and could be expected to attain considerably higher biomass in the future.

Overall, the macrophyte communities are very similar to those recorded in the Upper Clutha River (Biggs, 1981) and in many New Zealand lakes (Brown, 1975). They do not appear to have any unique taxonomic components, and as in other parts of the country, are generally low in diversity.

3.3 INVERTEBRATES

The study area supported a moderate to low standing crop of invertebrates. The (geometric) mean abundance for the study area was 1019 organisms.m^{-2} and the mean standing crop was 4.81 g.m^{-2} (dry weight). Their abundance is comparable to that found in other large

New Zealand rivers (e.g., Sagar, 1983), but was much lower than in smaller foothills fed rivers (e.g., $4200.m^{-2}$ in the Upper Clutha River tributaries - Biggs and Malthus, 1981).

Seventy-four invertebrate taxa were recorded from the Lower Clutha River, with insects forming the single largest group (80%). Many of the identifications were not to species level and thus these figures underestimate the true species richness of the communities. Primary data obtained from the two field surveys are summarised in appendix 5. When examining these data it is important to note that more tributaries were sampled during the 1984 summer survey than the 1983 winter survey.

The communities had a comparatively low diversity, with the snail *Potamopyrgus antipodarum* being the dominant taxon (table 8). It is very uncommon for a mollusc to dominate a riverine invertebrate community. The dominance of *Potamopyrgus antipodarum* probably results from the generally low velocity of the waters in the study area, the prevalence of plant taxa, and the presence of Lake Roxburgh upstream which could be a significant source of individuals.

3.3.1 Community characteristics of each habitat

The backwaters were a very rich habitat for invertebrates compared with the other habitats, having significantly higher densities and standing crops (tables 8 and 9). Moderate to large communities were also recorded on silty banks, while the shoulder, bedrock and tributary habitats harboured much lower densities (table 8). These differences did not always occur for invertebrate dry weights (tables 8 and 9), indicating that the organisms in the backwaters and silty banks were generally smaller than those in the other habitats. The high abundance of invertebrates in the backwaters and, to a lesser extent, silty banks is likely to be due to the relatively high cover provided by aquatic macrophytes in these habitats. In particular, *Potamopyrgus antipodarum* was found in high numbers on the macrophytes and accounted for 60% of the total abundance of backwater organisms.

Table 8 Geometric mean abundance (organisms.m^{-2}) of the common invertebrates in each habitat together with the habitat weighted mean abundance for the Lower Clutha River study area. Total geometric mean abundances, standing crops and habitat standing crops are also given. (BW = Backwaters, SB = Silty Banks, B = Braids, S = Shoulders, BR = Bedrock, T = Tributaries).

Invertebrate Taxa	BW	SB	B	S	BR	T	Habitat Weighted Mean %
Mollusca							
Lymnaea tomentosa	1.06	0	1.13	1.11	+	0	0.05
Gyraulus corinna	3.01	+	1.30	1.07	0	1.48	0.06
Physa acuta	16.4	1.40	1.30	1.20	0	+	0.16
Potamophrgus antipodarum	3754	524	606	5.7	83.1	20.9	42.4
Sphaeridae	154	7.99	4.97	1.27	0	1.07	0.96
Insecta							
Aoteapsyche colonica	1.12	1.17	0	1.65	2.07	3.88	0.16
Aoteapsyche tepoka	1.06	0	0	1.59	1.45	1.27	0.10
Chironomus "*sp a.*"	1.92	0	0	1.31	0	0	0.04
Deleatidium sp.	0	0	1.62	1.27	1.18	36.4	0.12
Elmidae	0	0	1.36	1.71	+	4.59	0.07
Empidae	0	0	1.19	1.44	1.84	1.70	0.11
Hydrobiosis sp.	0	0	1.09	0	0	2.32	0.01
Maoridiamesa spp.	0	0	1.33	2.07	4.07	6.12	0.21
Olinga feredayi	+	0	0	+	0	4.55	<0.01
Orthocladiinae	+	1.17	1.86	2.55	4.52	8.48	0.28
Oxyethira albiceps	3.13	2.31	2.29	1.19	3.41	1.85	0.25
Pycnocentria evecta	*1.06*	*+*	*1.23*	*2.21*	*1.18*	*2.37*	*0.09*
Pycnocentrodes sp.	+	+	1.88	2.85	6.82	1.43	0.32
Tanytarsus vespertinus	1.06	+	1.60	2.75	1.45	3.49	0.15
Zelandobius furcillatus	+	+	2.43	6.79	2.90	1.36	0.31
Density (organisms.m^{-2})	6229	2105	910	436	406	401	1019
Standard Error	1863	277	920	146	325	136	
Number of Samples	93	26	28	46	16	42	251
Standing Crop (g.m^{-2})	14.6	5.33	4.29	2.42	4.11	2.14	4.81
Standard Error	4.99	2.51	1.80	0.78	1.77	0.39	
Number of Pooled Samples	17	7	6	10	3	13	56
Total Habitat (tonnes)	1.31	3.68	0.90	1.50	2.96	0.04	10.4

Table 9 Differences between habitats in median standing crop (as dry weight) and density of invertebrates in the Lower Clutha River, given as significance values for the Mann-Whitney U statistic. This varies from 0 for medians that are very dissimilar to 1 for medians that are the same (* = the difference is significant, p < 0.05; ** = highly significant, p < 0.01; * = very highly significant, p < 0.001).**

	Backwaters	Silty Banks	Braids	Shoulders	Bedrock	Tributaries
			Standing Crop			
Backwaters	-	0.066	0.027**	0.001***	0.090	0.002**
Silty Banks	0.009**	-	0.830	0.107	1.000	0.048*
Braids	0.000***	0.029*	-	0.303	0.897	0.148
Shoulders	0.000***	0.000***	0.017*	-	0.272	0.877
Bedrock	0.000***	0.009**	0.174	0.823	-	0.139
Tributaries	0.000***	0.000***	0.058	0.757	0.965	-
				Density		

Comparatively few other taxa (2-10) were present at the backwater sites. No attempt was made to count individual oligochaete worms from the organic rich silts. They were present in large numbers and would have increased the mean total abundance values for the backwater and silty bank habitats appreciably.

At times, major portions of the backwater and silty bank habitats were bare sediment due to large fluctuations in the water level of the river. Molluscs were often found to have burrowed into the sediment during these periods.

The densities and standing crops of invertebrates for tributary habitats (table 8) are considerably lower than for similar small streams elsewhere in New Zealand (e.g., Graynoth, 1979). The reason for this is not known.

The silty banks occupied a high proportion of the study area, and this habitat accounted for the largest proportion of total invertebrate standing crop (35% of the total dry weight - table 8).

A high degree of similarity was found between the invertebrate communities inhabiting backwater, silty bank and braid habitats (fig. 4). These habitats were dominated by a number of ubiquitous taxa that were not sensitive to mild differences in physical conditions (e.g., water velocity and sediment type) and contrasts with the strong inter-habitat separation found for periphyton and macrophyte communities. Shoulder and bedrock habitats also had similar invertebrate assemblages, whereas tributaries had quite distinct assemblages (fig. 4). Overall, tributaries had the highest taxonomic richness with 61 taxa, followed by shoulders (34 taxa), backwaters (31 taxa), braids (27 taxa), bedrock (22 taxa) and silty banks (20 taxa). The tributaries had a high diversity of stream bed sediment, and thus micro-habitats, and were often overhung by banks and terrestrial vegetation. These features would aid the establishment of diverse assemblages of organisms.

The following is a summary of the dominant invertebrate taxa in the habitats, arranged for each habitat in decreasing order of mean abundance (fig. 7, table 8):

Backwaters - *Potamopyrgus antipodarum*; Sphaeriidae;

Silty Banks - *Potamopyrgus antipodarum*; Sphaeriidae; *Oxyethira albiceps*;

Braids - *Potamopyrgus antipodarum*; Sphaeriidae; *Zelandobius furcillatus*;

Shoulders - *Potamopyrgus antipodarum*; *Zelandobius furcillatus*; *Pycnocentrodes* sp.;

Bedrock - *Potamopyrgus antipodarum*; *Pycnocentrodes* sp; Orthocladiinae;

Tributaries - *Deleatidium* sp.; *Potamopyrgus antipodarum*; Orthocladiinae.

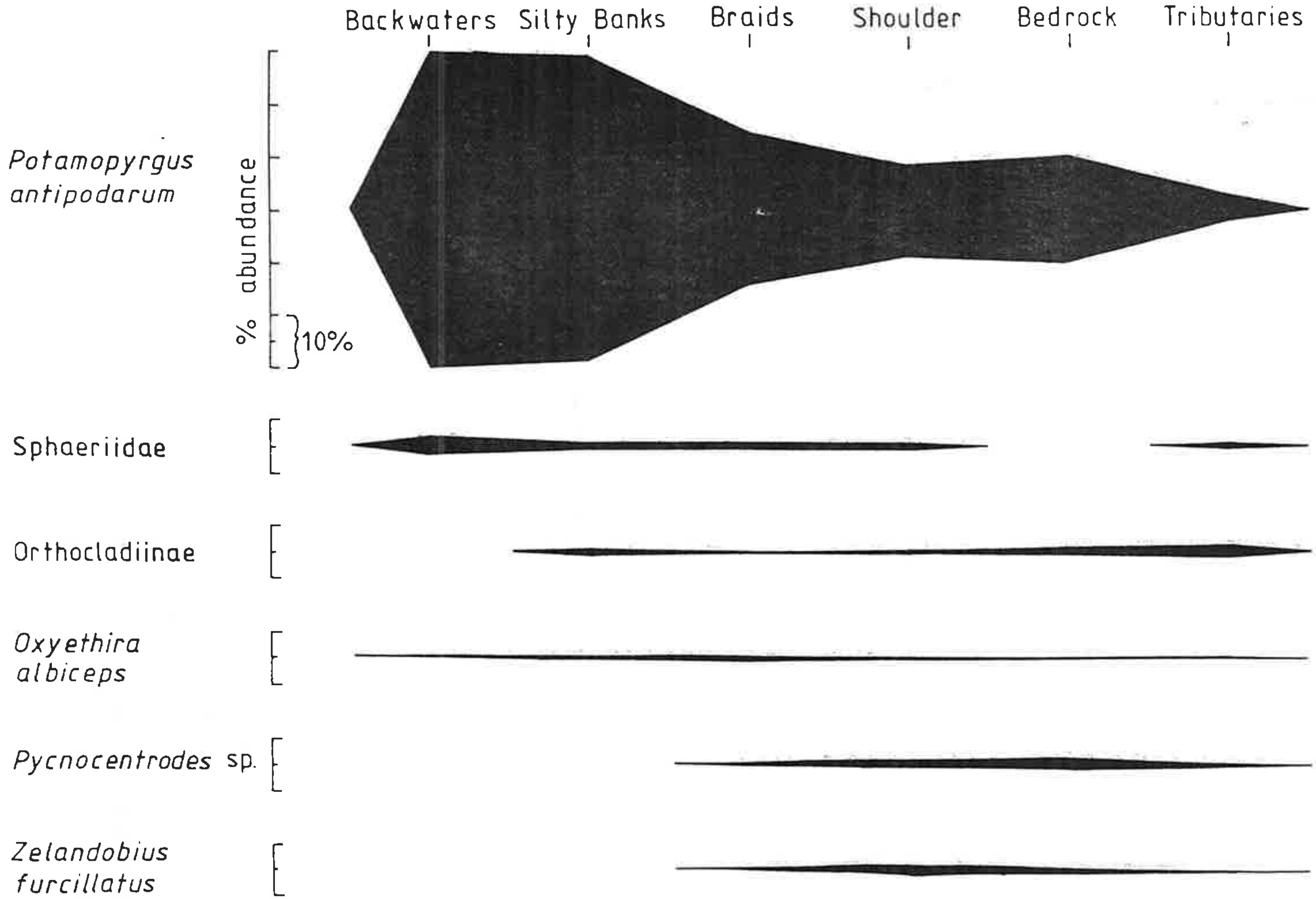

Figure 7 Kite diagram demonstrating changes in the abundance of the common invertebrate taxa between habitats. The width of the shaded area at each habitat point represents the percentage of the total abundance of invertebrates in that habitat accounted for by each taxa.

3.3.2 Seasonal differences in invertebrate communities

The average abundance of invertebrates in the study area was 9% higher in summer than winter. Dry weight standing crop was 16% higher in summer than winter. However, these differences are not considered important as they are not consistent when the habitats are considered individually. The braid, bedrock and tributary habitats had higher abundances and standing crops in summer, whereas the backwaters, silty banks and shoulders had greater numbers in winter.

There were also few clear differences in the abundance of individual taxa between the winter and summer samplings. *Zelandobius furcillatus*, *Paroxyethira hendersoni* and Orthocladiinae were slightly more abundant in winter. Mollusca, particularly *Potamopyrgus antipodarum*, were considerably more abundant in the backwater, silty bank, braid and shoulder habitats during winter. However, as these taxa were more abundant in the bedrock and tributary habitats during summer, the above differences are unlikely to be due to seasonal fluctuations in the development of the populations. High flows in the main river prior to the summer sampling may have been a factor causing this difference. The bedrock communities would have been least affected by high flows as these areas are continually exposed to rapid water velocites, and presumably the resident organisms have adapted to such conditions. This possible explanation was investigated in more detail by sampling two backwater sites following a further period of high (flood) flows in the winter of 1984. Mean densities were 2188 organisms.m^{-2} (site B7) and 8014 organisms.m^{-2} (site D1-downstream). These values are comparable to the summer data and thus markedly below the winter densities recorded at the sites one year earlier. Therefore, they reinforce the suggestion that high flows may have reduced the invertebrate abundances in the backwaters prior to the 1984 summer sampling by washing the organisms away.

3.3.3 General discussion

Benthic invertebrate communities in the study area were comparatively sparse in the bedrock, shoulder, braid and silty bank habitats. Some of these communities could have been detrimentally affected by de-watering associated with the large daily changes in flow resulting from the operation of the Roxburgh hydro station. Similarly, impoverished invertebrate communities have been recorded in Northern Hemisphere regulated rivers with large flow fluctuations (e.g., Trotsky and Gregory, 1974).

Another equally important factor contributing to the poor development of invertebrates in the main river cobble sites would be the deposition of silt. The river carries high concentrations of silt which was observed to clog the interstices of stable cobbles. This reduces habitat quality for many invertebrates (Winterbourn, 1981) and thus is also likely to reduce abundances.

The backwaters and silty banks had invertebrate communities that were typical of lakes, being dominated by molluscs, and with very few insect taxa. As also found by Biggs and Malthus (1983), backwater invertebrates were present at much higher abundances than those recorded in lakes (cf. Forsyth, 1978). These backwater habitats are among the richest for invertebrates in New Zealand freshwaters. A peculiar feature of the invertebrate communities in the silty bank, braid, shoulder and bedrock habitats was the dominance of the normally lake dwelling snail - *Potamopyrgus antipodarum*.

The tributaries had communities more typical of riverine habitats, being dominated by insects. However, abundances of invertebrates were comparatively low for this type of environment (density - 401 organisms.m^{-2} compared with 5557 organisms.m^{-2} in the Lindis and Cardrona River tributaries of the Upper Clutha River - B J Biggs and T J Malthus, MWD, unpublished data). Also, unexpectedly, *Potamopyrgus antipodarum* was a co-dominant and the presence of this large organism may account for the relatively high standing crop in this habitat (2.41 g.m^{-2} compared with 2.73 g.m^{-2} in the Lindis and Cardrona Rivers). This indicates that the Lower Clutha tributaries were inhabitated by relatively low densities of large organisms.

There appeared to be no unique invertebrate populations or communities in the study area.

3.4 THE IMPORTANCE OF THE BIOLOGICAL COMMUNITIES IN THE LOWER CLUTHA RIVER

The Lower Clutha River appears to be ecologically unusual as it contains, in one relatively small area, nearly all the major habitats for biota that can be distinguished clearly in New Zealand rivers. Further, from studies reported in the literature and in the authors' experience, the bedrock and backwater habitats, found so extensively in the study area, are less common in other New Zealand rivers. This diversity of habitat has resulted in an unusual mixture of biological communities in the study area.

The invertebrate communities are dominated by taxa that are frequently lake dwellers, but also have representatives of most taxa commonly found in New Zealand rivers (cf. Towns, 1976; Cowie, 1980). The backwaters are a particularly rich habitat for biota, with large standing crops of aquatic macrophytes and invertebrates. Although only occupying 4% of the study area, the backwater habitat contained 42% of the total macrophyte crop and 13% of the total invertebrate crop. These areas are thus potentially important as fish feeding grounds and as a source of colonising organisms for the remainder of the river.

Bedrock provides a very stable substrate for the development of periphyton, and communities with moderate to high standing crops, dominated by the red alga *Rhodochorton violaceum*, were recorded in these habitats. These extensive growths of *Rhodochorton* sp. are of considerable scientific interest as this taxon has only been recorded as a minor component of a few small streams elsewhere in New Zealand (B J Biggs, MWD, unpublished data).

The bedrock also harboured very extensive communities of aquatic mosses which are normally confined to small and stable streams in rain forests and high country areas (e.g., Cowie and Winterbourn, 1979). Thus, the proliferation of these plants in such a large alpine fed river is potentially of scientific interest. As it was not possible to properly characterise these communities, additional sampling by a bryophyte specialist should be carried out.

It is difficult to gauge the effect of the Roxburgh hydro on the biological communities of the study area (and thus assess how 'natural' the communities are). Daily flow fluctuations from the Roxburgh dam did not appear to cause major sloughing of biota in the river. This was probably due to the low gradient of the bed and thus low changes in water velocity with changes in flow, and/or the system was in equilibrium with the peak flows. However there were major changes in depth which resulted in extensive periodic de-watering of peripheral areas. This may have been detrimental to invertebrates, but the periphyton and macrophyte communities appeared to be more resilient. The dam has also reduced the supply of bed and suspended sediment to the lower river (Jowett and Hicks, 1980), which could be favourable to the biota, particularly periphyton. The abundance of the invertebrate *Potamopyrgus antipodarum* could also be aided by colonisation from the Roxburgh impoundment.

PART B

THE POTENTIAL EFFECTS OF THE PROPOSED POWER DEVELOPMENTS ON THE AQUATIC BIOTA OF THE LOWER CLUTHA RIVER

4 INTRODUCTION

Much is known overseas about the biology of reservoirs (e.g., Lowe-McConnell, 1966) and their downstream reaches (Ward and Stanford, 1979). However, only a few studies have been carried out documenting the changes that occur in the creation of a reservoir from a river, or to determine whether it is possible to predict the biological effects of impoundment with reasonable accuracy.

4.1 THE POTENTIAL FOR PREDICTING THE BIOLOGICAL EFFECTS OF RESERVOIR DEVELOPMENT

From an extensive review of the literature, Baxter (1977) has identified the general limnological effects of riverine impoundment. Biggs (in press), Henriques (in press) and Winterbourn (in press) have updated these understandings and related them to New Zealand systems.

The physical and biological effects of riverine impoundment depend on factors such as the hydraulic structure, basin morphology, climate, water quality, reservoir hydrology and the surrounding ecosystem (Brocksen *et al.*, 1982). Unfortunately, the quantitative theory for relating these various aspects to biological communities is still largely lacking. The number of quantifiable changes is therefore small and mainly relate to the primary production level. Even qualitative changes above this level may be difficult to predict.

In a post-impoundment study to verify the predicted effects of raising the level of an existing lake, Heckey *et al.* (1984) found that, although there were few incorrectly predicted effects, the number of significant unpredicted effects tended to increase with trophic level. They considered that, at present, the most successful approach to predicting development effects is to study an analogous system that has similar climate, morphometry, terrain, extent of flooding, biological communities, etc. Because the Roxburgh reservoir fulfils most of the requirements of Heckey *et al.* (1984), it was decided to use it as a model for the Lower Clutha predictions. Data collected on the lake over several years were collated and reviewed (B I Shand and B J Biggs, MWD, unpublished data).

5 PREDICTED UPSTREAM EFFECTS OF THE PROPOSED POWER DEVELOPMENTS

Eight different reservoirs are included in the four possible power schemes (fig. 8). For the following discussion these are named as:

(a) Dumbarton reservoir (level = 86 m) - backing up from a dam at Dumbarton Rock to Roxburgh;

(b) Beaumont reservoir (level = 69 m)-backing up from a dam at Beaumont to near Dumbarton Rock;

(c) Beaumont reservoir (level = 69 m) (bunded) - same as (b) but with bunding to prevent flooding of Island Block;

(d) Birch Island reservoir (level = 69 m) - backing up from a dam at Birch Island to near Dumbarton Rock;

(e) Birch Island reservoir (level = 42 m) - backing up from a dam at Birch Island to near Beaumont;

(f) Tuapeka reservoir (level = 30 m) - backing up from a dam at Tuapeka Mouth to Birch Island;

(g) Tuapeka reservoir (level = 42 m) - backing up from a dam at Tuapeka Mouth to near Beaumont.

(h) Tuapeka reservoir (level = 69 m) - backing up from a dam at Tuapeka Mouth to near Dumbarton Rock.

These reservoirs are combined in various ways to form four main scheme alternatives:

Scheme A Dumbarton, Beaumont (unbunded), and Tuapeka (level = 42 m) reservoirs;

Scheme B Dumbarton and Tuapeka (level = 69 m) reservoirs;

Scheme C Dumbarton and Birch Island (level = 69 m) reservoirs;

Scheme D Dumbarton, Beaumont (bunded), Birch Island (level = 42 m), and Tuapeka (level = 30 m).

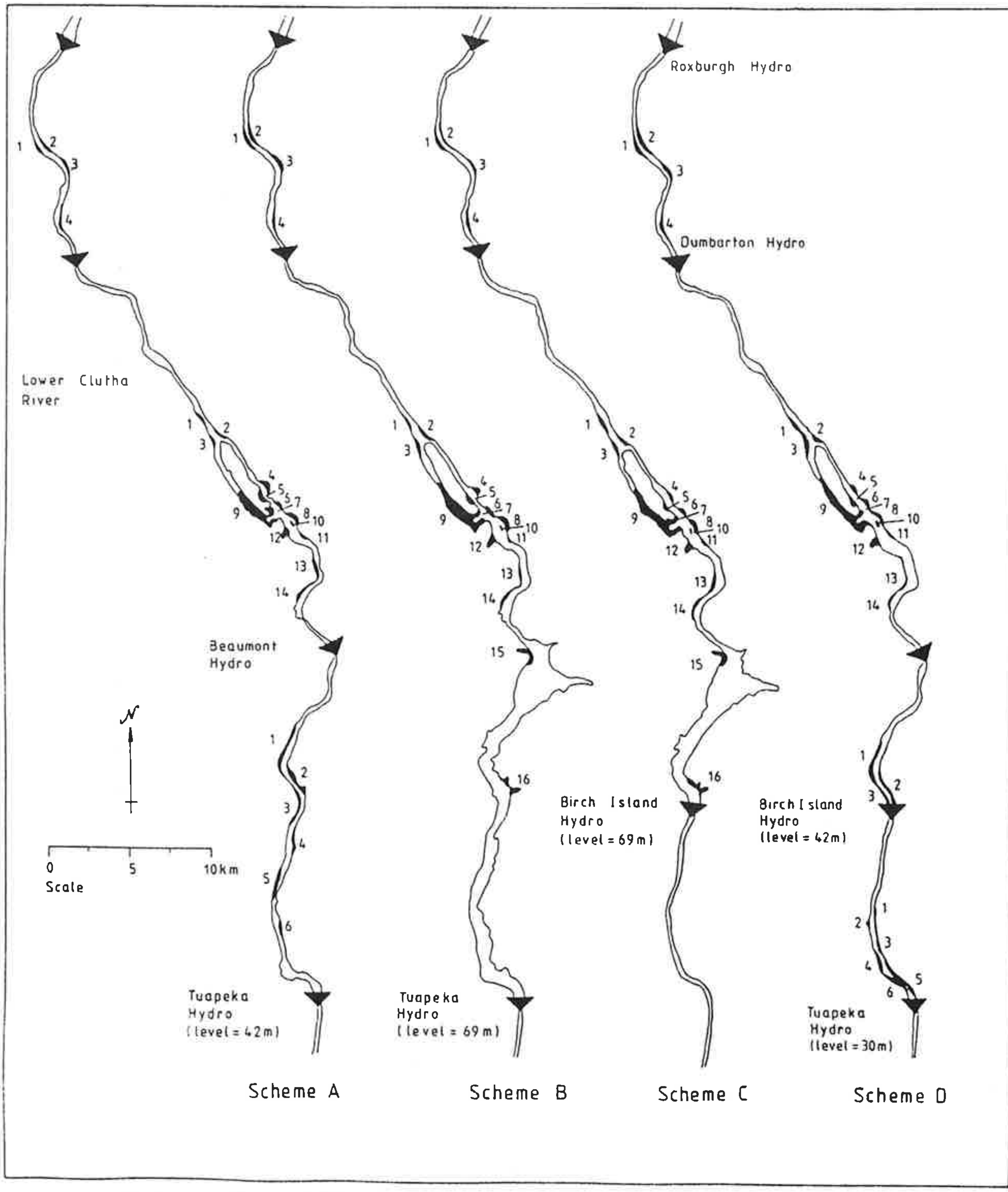

Figure 8 Location and approximate extent of potential weed beds in each of the Lower Clutha hydro scheme options (only major beds are shown). The lateral extent of the beds has been exaggerated to assist in their definition (refer to table 12 for details of their dimensions).

Morphometric data on each of the reservoirs is summarised in table 10. They would all be long, narrow and sinuous because they would be generally confined to the existing flood channel of the river. The littoral zones will, therefore, be predominantly steep (around 80%). The Beaumont, Birch Island and Tuapeka (level = 69 m) reservoirs would have a high number of small sheltered embayment areas. Only the Island Block backwater would be large in area. All reservoirs would have short residence times. The Beaumont reservoir would have a relatively long length of shoreline compared to the reservoir length because of the higher concentration of embayment areas in this reservoir .

The creation of reservoirs usually causes major changes in the hydrological and water quality features of valleys. Major changes in biological communities usually ensue and eventually the original running water (lotic) organisms are replaced by slow and stillwater (lentic) species. These can be catagorised as benthic, marginal (littoral) or planktonic forms, depending on the habitat they occupy. Diversion of water to maintain generating head may also be carried out for 4.5 km below Dumbarton, causing major changes to the character of the existing river. A checklist of the major effects of riverine impoundments is given in appendix 6.

Phytoplankton blooms frequently occur soon after initial flooding of large reservoirs, as nutrients in the organic matter of the drowned vegetation and in the flooded soils are released to the water. Ostrofsky (1978) termed this the period of 'trophic upsurge'. Blooms of blue-green algae can occur during this period (Duthie and Ostrofsky, 1975). Following this initially productive phase, a trophic depression may occur, followed, in turn, by a slow increase and subsequent stabilisation of planktonic production (Ostrofsky and Duthie, 1978). These events may affect higher trophic levels in the ecosystem and will be referred to again in later sections.

The biological communities may not respond to the trophic upsurge if the inflow waters are highly turbid and/or the impoundment has a fairly short retention time (Duthie, 1979). A low retention time

Table 10 Physical characteristics of the Lower Clutha impoundments options (1 = central flow path, 2 = for average flow, 3 = including islands, 4 = 'compromise' deregulation option).

	Area (ha)	Length[1] (km)	Max. Width (km)	Max. Depth (m)	Mean Depth (m)	Residence Time[2] (days)	Length of Shore[3] (km)	% of Shore With Steep Littoral	% of Shore With Gentle Littoral	Embayments	Reservoir Fluct.[4] (m)
Dumbarton (level 86 m)	254	12	0.45	11	8.7	0.52	27	78	22	1	0.7
Beaumont (level = 69 m)	1,089	23	0.60	27	9.1	2.28	84	80	20	15	0.4
Beaumont - bunded (level = 69 m)	1,004	23	0.60	27	9.2	2.20	77	87	13	14	0.5
Birch Island (level = 69 m)	2,363	36	2.15	37	16.3	8.79	137	81	19	21	0.4
Birch Island (level = 42 m)	325	13	0.70	27	10.8	0.80	24	60	40	1	1.3
Tuapeka (level = 42 m)	945	27	0.70	20	12.0	2.58	61	72	28	1	0.7
Tuapeka (level = 30 m)	280	14	0.45	12	7.6	0.46	34	58	42	2	0.6
Tuapeka (level = 69 m)	3,205	49	2.15	47	20.5	14.97	186	86	14	31	0.3

means nutrients are flushed away before they can be fully utilised by plants.

5.1 PERIPHYTON

Following impoundment of the Lower Clutha, the density of periphyton will probably be severely reduced and they will probably become a minor contributor to the total primary production. The taxa most severely affected will be the rheophilic populations, such as *Rhodochorton violaceum* and *Ulothrix zonata*, which appear to depend on water movement for nutrient replenishment in high quality waters (as in the study area). The communities in all lotic habitats (i.e., braids, shoulders, bedrock, accounting for 65.5% of the study area) are therefore likely to be lost.

Colonisation of the new impoundments by lake dwelling periphyton is expected to be rapid because of the availability of propagules from upstream reaches (e.g., Lake Roxburgh) and backwaters. However, the rate of colonisation in any particular area will depend on factors such as availability of suitable substrate, nutrient levels and light intensity.

Conspicuous growths of filamentous taxa, such as *Spirogyra* sp. and *Oedogonium* spp., are expected in the shallows of all impoundments in the first few years after flooding. These could be particularly luxuriant in the many sheltered embayments (e.g., around Island Block) created by the Tuapeka (level = 69 m), Birch Island (level = 69 m) and Beaumont impoundments. During this initial colonisation phase, diatom communities composed of taxa such as *Nitzschia*, *Synedra* and *Navicula* are expected to develop on the bare mud and plant residues in deeper areas. Long term filamentous periphyton proliferations are unlikely to occur, except perhaps close to a few settled areas, such as Millers Flat, where septic tank seepage to the reservoirs could occur.

Littoral periphyton communities will probably be displaced by vascular macrophytes after a period of 4-5 years (see section 5.2), changing the nature of the periphyton communities to that more typical of lakes. 'Soft' periphyton substrates in the mature reservoirs, such as the macrophytes and silts, will probably be colonised by taxa that are capable of rapid reproduction and dispersal, such as the diatoms *Achnanthes* sp., *Cocconeis* sp., and *Synedra* spp. Stony substrates in the wave zone may be colonised by several remnant taxa from the old river, such as *Ulothrix zonata* and *Phormidium* spp. However, their standing crop is expected to be considerably less than previously found in the river. Only small areas of deep water solid substrates are expected below the littoral in all reservoirs, except Dumbarton. Where solid substrates do occur, several taxa of blue-green algae, such as *Scytonema* sp. and *Schizothrix* sp., may develop, together with diatoms.

In areas of all reservoirs where there is considerable substrate instability there is likely to be only poor periphyton development. These areas include the bed of the main channel, areas of siltation from tributaries or bank erosion, areas of shallow water exposed to the prevailing winds, or in the operating zone of the upper littoral.

Periphyton are not likely to present problems for reservoir management or recreation. They are currently an inconspicuous component of the flora in Lake Roxburgh.

5.2 MACROPHYTES

The reduction in river water velocity and expansion of the area of submerged surface is likely to allow considerable expansion of the existing macrophyte communities. It is also likely that these communities will eventually form extensive weed beds in some areas. The development of weed beds will be aided by:

(a) the extensive presence of several taxa of exotic macrophytes within the backwaters of the study area, i.e., *Lagarosiphon major*, *Elodea canadensis* and *Ranunculus fluitans*;

(b) the presence of large beds of these exotic macrophytes upstream in Lake Roxburgh which will act as a continual source of infestation for any new reservoirs;

(c) the relative ease of vegetative spread of these aquatic plants and, once established, the extremely invasive nature of their growth;

(d) the presence of fertile soils on the inundated terraces.

The development of macrophytes in the hydro-lakes will be much slower than for periphyton, and will probably occur in a similar sequence to that described by Coffey (1974) and Clayton (1980). Eventually, mature vegetation profiles, similar to those in Lake Roxburgh (B I Shand and B J Biggs, MWD, unpublished data), are expected.

In predicting the quantitative extent of macrophyte development in the reservoirs, the following assumptions have been made:

(a) that the lower limit of macrophyte development in shallow waters would be defined by the edge of the current river channel, where the lower depth of the terrace is less than the depth of light or pressure limitation for the macrophyte;

(b) that native and exotic macrophyte profiles would be similar to those in Lake Roxburgh, possibly with slightly increased depth ranges. *Elodea canadensis* would grow to a depth of 8-9 m, with *Lagarosiphon major* displacing it in the 1-4 m depth range and possibly mixing with it to 6 m. Characeae could extend below the *Elodea canadensis* to approximately 10 m.

There will probably be an initial, patchy, colonisation of the littoral zone by a mixed native and exotic low mound community. The taller growing, native *Myriophyllum* spp. and *Potamogeton* spp. may also be present in this zone. This period will probably last for several years. Tall growing exotic macrophytes (*Elodea canadensis*, 0.5-0.8 m high; *Lagarosiphon major*, 2-3 m high) are likely to displace these communities in sheltered and silty areas, forming 60-95% bottom cover. In contrast, *Ranunculus fluitans* will probably grow in discontinuous, sparse beds in areas of higher water velocities and rockier substrates in the upstream areas of the reservoirs. Based on the rate of macrophyte spread in Lake Roxburgh, colonisation of the major part of the littoral in the reservoirs is expected to take at least 5 years (B I Shand and B J Biggs, MWD, unpublished data).

Depending on the success of any upstream and local weed control measures, *Lagarosiphon* sp. could rapidly replace the *Elodea* sp. and *Ranunculus* sp. communities in the 1-4 m depth range in the reservoirs (fig. 9). The maximum depth of colonisation is likely to be light limited, and if there is a slight improvement in water clarity in the proposed Lower Clutha impoundments after the Clyde Dam becomes operational, vigorous growth of *Lagarosiphon* sp. may extend to 6.5 m, a depth achieved by this plant in Lake Wanaka, where it appears to become pressure limited (Coffey, 1980). *Elodea* sp. should continue to grow in the area below *Lagarosiphon* sp. beds to a depth of approximately 8-9 m, where it also would become light limited.

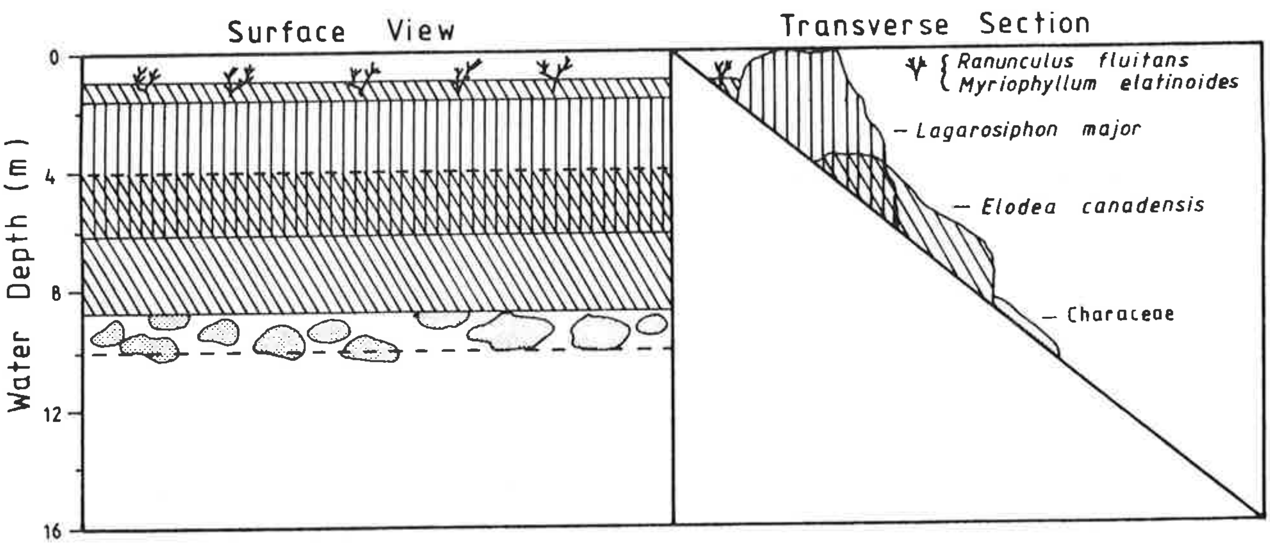

Figure 9 Stylised, long term submerged vegetation profile expected for the Lower Clutha reservoirs.

The total areas within the 1-4 m and 4-10 m depth zones (representing predominantly *Lagarosiphon major*, and *Elodea canadensis* and Characeae habitats, respectively) vary among impoundment options (table 11).

Table 11 Areas within various depth zones of the proposed Lower Clutha reservoirs. These areas represent the potential extent of development of the various communities. (Raw data courtesy of A J Pickford, Power Design, MWD).

Reservoir	'Tidal' Zone 0-1 m (ha)	% of Lake	Lagarosiphon 1-4 m (ha)	% of Lake	Mixed 4-10 m (ha)	% of Lake	Total % With Plants
Dumbarton (level - 86 m)	25	10	74	29	80	32	61
Beaumont (level = 69 m)	76	7	230	21	413	38	59
Beaumont - bunded (level = 69 m)	60	6	161	16	413	41	57
Birch Island (level = 69 m)	95	4	284	12	533	23	35
Birch Island (level = 42 m)	37	11	100	31	88	27	58
Tuapeka (level = 42 m)	78	8	178	19	298	32	51
Tuapeka (level = 30 m)	40	14	90	32	90	32	64
Tuapeka (level = 69 m)	104	3	313	10	519	18	28

Table 12 gives the location and a description of potential sites for major weed beds that could grow to the water surface and present management problems in the reservoirs. The Tuapeka (level = 42 m) reservoir was considerable sections of shoreline that may be encased by weed (28%), with the likely occurrence of many long belts (up to 4 km in places) running parallel to the flow.

Table 12 Location, size and character of major terraces in the proposed reservoir options which could harbour problem weed beds TR = true right, TL = true left).

Bed	MWD Map Ref. Sheet	Co-ord.	Area (ha)	Length of Shore (km)	Site Description	Bank	Flow Exposure	Comments
Dumbarton (86 m)								
1	3	222,100 - E 551,325 - N	4.25	0.75	Terrace sheltered from flow, mid-way down reservoir.	TR	L-M	Willows cover perimeter, could have a weed belt 80 m wide x 0.4 km long.
2	3	222,125 - E 551,300 - N	4.20	0.65	Terrace protruding into reservoir, opp. site of Bed 1.	TL	H	Terrace covered in scrub and willows, weed belt 80 m wide x 0.45 km long.
3	4	222,225 - E 551,240 - N	5.35	1.10	Terrace running parallel to the flow, partial embayment.	TL	M	Abundant willows, sheltered embayment on downstream end.
4	4	222,255 - E 551,025 - N	12.05	2.50	Terrace running parallel to main flow 0.5 km u/s of dam.	TL	M-H	Partly covered in trees, could have a weed belt 100 m wide x 1.5 km long.
Beaumont (69 m)								
1	14	223,150 - E 549,655 - N	9.05	2.20	Terrace parallel to flow, upper end of reservoir, small island in embayment.	TL	M	Covered in willows, sheltered embayment on downstream end, could have a weed belt up to 100 m x 1 km long.
2	14	223,225 - E 549,553 - N	3.63	2.00	Backwater area up an old braid.	TL	L	Farmland with willows at mouth of backwater, high colonisation potential.
3	14	223,220 - E 549,525 - N	13.88	2.15	Terrace parallel to flow in upper end and exposed in lower embayment.	TR	M-H	Covered in willows, could have a weed belt up to 60 m wide x 1.5 km long.
4	16	223,540 - E 549,275 - N	9.30	1.30	Backwater area at the back of an island, probably an old braid.	TL	L	Moderate cover of willows, floods two large ponds, high colonisation potential.
5	17	223,520 - E 549,157 - N	4.35	0.90	Terrace on inside of bend, sheltered from flow embayment.	TR	L	Sparse cover of trees, high colonisation potential.
6	17	223,635 - E 549,155 - N	6.40	2.35	Small stream valley on outside of bend, a backwater.	TL	L	Moderately vegetated, high colonisation potential.

Table 12 Continued

Bed	MWD Map Ref. Sheet Co-ord.	Area (ha)	Length of Shore (km)	Site Description	Bank	Flow Exposure	Comments
Beaumont (cont.)							
7	17 223,600 - E 549,100 - N	13.05	2.60	Sheltered terrace on inside of bend, partly boggy, extends around a point adjacent to flow path, at entrance to Island Block corridor embayment.	TR	L-M	Grassland, high colonisation potential over 50% of terrace, could have a weed belt up to 100 m wide x 1.5 km long.
8	18 223,750 - E 549,075 - N	20.10	2.20	Ox-bow loop, behind a hillock, opposite Island Block corridor, partly boggy, a backwater.	TL	L	Grass and swampland, high colonisation potential.
9	17 223,350 - E 549,255 - N	109.09	10.25	Corridor behind Island Block, extensive area of fertile flats, a backwater.	TR	L	Intensively farmed flats, high colonisation potential. Much of the backwater could be choked with weed.
10	17 223,640 - E 549,052 - N	7.20	1.55	Terrace exposed to flow at entrance to Island Block corridor.	TR	M-H	Pastoral land, moderate colonisation potential, could have a weed belt 50 m wide x 1.5 km long.
11	17 223,657 - E 549,050 - N	2.53	0.70	Terrace exposed to flow opposite Island Block corridor.	TL	M-H	Terrace covered by willows, moderate exposure to flow.
12	19 223,630 - E 548,925 - N	11.23	4.25	Perimeter of embayment/backwater, sheltered from flow.	TR	L	Could have a weed belt up to 50 m wide x 3 km long.
13	20 223,850 - E 548,750 - N	7.98	0.75	Terrace formed by small tributaries, sheltered embayment.	TR	L	Partly pastoral land, island in the middle of embayment, high colonisation potential, could have a weed belt up to 200 m wide x 0.5,km long.
14	21 223,825 - E 548,660 - N	11.87	1.15	Terrace on upstream side of flow path, sheltered embayment, low lying island in middle.	TR	L	Boggy in parts, pastoral, high colonisation potential, could have a weed belt 150 m wide x 0.65 km long.
Beaumont (69 m) - bunded - all areas as defined for Beaumont, with the exception of bed number 9.							
Birch Island (69 m) - all areas as defined for Beaumont, with the addition of the following.							
15	23 223,900 - E 548,255 - N	13.10	2.75	Narrow valley formed by a tributary, backwater area.	TR	L	Abundant willows, high colonisation potential, could have a main weed belt up to 150 m wide x 0.5 km long.

Table 12 Continued

Bed	MWD Map Ref. Sheet Co-ord.	Area (ha)	Length of Shore (km)	Site Description	Bank	Flow Exposure	Comments
Birch Island (cont.)							
16	26 224,250 - E 548,055 - N	11.18	3.10	Top end of a tributary valley opp. Beaumont, backwater area.	TL	L	Pastoral land, high colonisation potential.
17	31 223,830 - E 547,500 - N	12.53	3.80	Narrow valley formed by a tributary, backwater area.	TL	H	Pastoral land, high colonisation potential.
Birch Island (49 m)							
1	30 223,700 - E 547,650 - N	26.43	2.65	Long terrace running parallel to the flow.	TR	M-H	Forested in places, moderate colonisation potential, could have a weed belt up to 100 m wide x 2 km long.
2	31 223,740 - E 547,475 - N	51.30	4.00	Long terrace on the inside of a bend running parallel to the flow.	TL	M	Pastoral land, moderate colonisation potential, could have a weed belt up to 250 m wide x 2.5 km long.
3	31 223,780 - E 547,330 - N	23.23	2.65	Long terrace on the inside of a shallow bend, parallel to flow.	TR	M	Forested, moderate colonisation potential, could have a weed belt up to 100 m wide x 2 km long.
Tuapeka (69 m) all areas as defined for Beaumont and Birch Island (level = 69 m), with the addition of many small embayment and backwater areas formed by the drowning of minor tributary valleys. Most are steep sides and unlikely to have major weed belts that could become management problems.							
Tuapeka (42 m) all areas defined for Birch Island, with the addition of the following.							
4	32 223,730 - E 547,100 - N	31.08	3.50	Long terrace on the inside of a shallow bend, parallel to flow.	TL	M	Forested, moderate colonisation potential, could have a weed belt up to 150 m wide x 3 km long.
5	33 223,660 - E 546,850 - N	18.65	2.25	Long terrace running parallel to the flow.	TR	M	Forested, moderate colonisation potential, could have a weed belt up to 100 m wide x 2 km long.
6	35 223,725 - E 546,500 - N	13.58	2.00	Terrace running parallel to the flow.	TL	M	Partly forested, moderate colonisation potential, could have a weed belt up to 100 m wide x 1.5 km long.

Table 12 continued

Bed	MWD Map Ref. Sheet Co-ord.	Area (ha)	Length of Shore (km)	Site Description	Bank	Flow Exposure	Comments
Tuapeka (30 m)							
1	35 223,652 - E 546-660 - N	0.02	0.38	Lower end of a terrace sheltered from low flow.	TL	M	Forested, moderate colonisation potential, could be subjected to flood flows, patch is relatively small.
2	35 223,652 - E 546,600 - N	0.12	1.45	Embayment area on inside bend formed by a small tributary.	TL	L	Pastoral land, high colonisation potential
3	36 223,720 - E 546,475 - N	0.12	1.60	Terrace running parallel to the flow.	TL	M-H	Partly forested, moderate colonisation potential, short (0.9 km), narrow belt of weed.
4	36 223,720 - E 546,350 - N	0.19	2.50	Terrace running parallel to the flow.	TR	M-H	Pastoral land, moderate colonisation potential, moderate length (1.35 km), narrow belt of weed.
5	37 223,850 - E 546,300 - N	0.37	4.30	Terrace running parallel to the flow.	TL	M-H	Partly forested pastoral land, moderate colonisation potential, long (3.7 km), narrow belt of weed.
6	39 223,920 - E 546,225 - N	0.30	4.0	Terrace running parallel to the flow.	TR	M-H	Partly forested pastoral land, moderate colonisation potential, long (3.15 km), narrow belt of weed.

The highest concentration of weed beds is likely to be in the Island Block area (fig. 8), which is common to the Beaumont, Birch Island (level = 69 m), and Tuapeka (level = 69 m) reservoirs. These are mainly embayment/backwater habitats which could also make good sites for water based recreation. However, access by boat to many of these areas could be restricted or prevented by the weed.

The weed beds in the embayments and backwaters may severely restrict water circulation and stagnant areas could develop. If there is localised enrichment, discolouration of the water by algal blooms could ensue in some areas. One such area is the large Island Block backwater, which could become a productive area for wildlife, and is also likely to contain extensive marsh areas inhabited by sedges and rushes. These areas could increase if substantial siltation occurs (e.g., because of macrophyte filtering of the water). The extent of weed bed development in all the reservoirs, except Dumbarton, is expected to equal or exceed that currently found in Lake Roxburgh.

Although daily water level fluctuations of up to 1.3 m could occur in some reservoirs, they are likely to be less for much of the year (Jowett, 1984). They may inhibit the development of biological communities in the 0-1 m deep shallows of the embayment areas because of periodic drying. The Tuapeka reservoir (level = 69 m) would have the largest area in this tidal zone, followed by Birch Island (level = 69 m). This zone would also comprise a significant part of the area of the Tuapeka (level = 30 m), Birch Island (level = 42 m), and Dumbarton reservoirs (14%, 11.4% and 9.8%, respectively).

5.3 INVERTEBRATES

The proposed impoundments could cause a major reduction in the abundance of rheophilic invertebrates. Several species of mayflies (Ephemeroptera), caddisflies (Trichoptera) and stoneflies (Plecoptera) may be eliminated from the development areas of the main river. However, these organisms are only a minor component of the communities at present. Many of the organisms which currently dominate the river fauna (e.g., Mollusca and Oligochaeta) are also found abundantly in lakes, and thus might be expected to flourish in the impoundments.

A dramatic reduction in standing crop and diversity of invertebrates is expected immediately after flooding due to the shock change in habitat conditions. However, high densities of chironomids, and possibly oligochaete worms, are expected in the first few years after impoundment, as recorded in Lake Roxburgh by Winter (1964). This is due to an abundance of food and new habitats created by the drowning of vegetation. These animals may survive periodic oxygen depletion and proliferate in many sheltered embayment areas of the Tuapeka (level = 69 m), Birch Island (level = 69 m) or Beaumont reservoirs. Emergent chironomids (non-biting midges) may become a nuisance to settlements adjacent to the impoundments, particularly in the Island Block area. However, this should only occur for 2 or 3 years following flooding. The standing crop of oligochaetes and chironomids should eventually decline and a longer term succession of dominant taxa, from chironomids to oligochaetes to molluscs, is likely to occur. The rate and extent of macrophyte development should influence the rate and extent of this succession. Macrophytes are favoured by molluscs as habitat. Should extensive macrophyte development occur, as expected, the highest total crops of invertebrates would be expected in the reservoirs with the largest areas of shallow littoral macrophytes (i.e., Tuapeka (level = 69 m), Birch Island (level = 69 m).

In time, invertebrate communities in the impoundments are expected to closely resemble those now found in Lake Roxburgh. Macrophyte beds should be dominated by *Potamopyrgus antipodarum*, Sphaeriidae and *Physa acuta*, and silty sediments by the Oligochaeta, Chironomidae and Sphaeriidae taxonomic groups. The standing crop of macrophytes is also expected to be similar to that currently in Lake Roxburgh, with approximately 3000 organisms.m^{-2}, or 2-3 g.m^{-2} dry weight, and with the standing crop of the silt dwelling invertebrates of approximately 2000 organisms.m^{-2} or 0.5-1 g.m^{-2}.

The standing crop and diversity of invertebrates may be reduced in areas of shoreline erosion and in the zone where fluctuations in water level occur (see section 5.2) (Hynes, 1961).

6 POSSIBLE DOWNSTREAM EFFECTS OF THE PROPOSED POWER DEVELOPMENTS

The power developments have the potential to have both temporary and long term effects on the river below the dams.

Entry of silt to the river during dam construction could smother benthic habitats in downstream reaches. However, because of the large flow and moderate velocity of the waters, it is unlikely to occur for more than a short period following construction.

The development of an armoured substrate below reservoirs is a feature of regulated rivers in the Northern Hemisphere (Baxter, 1977). Armouring is already present in some parts of the river (e.g., braid and shoulder habitats) and may have resulted from impoundment of the river at Roxburgh. Further impoundment may increase the extent of armouring, but this cannot be predicted with confidence.

Re-regulation of the river at the most downstream reservoir to match natural river flows at Clyde (Jowett, 1984), should minimise long term detrimental effects of developments on the biota below Tuapeka Mouth. Such a reservoir management regime would help protect the downstream communities and, if adopted, the communities below Tuapeka might even attain a higher productivity and diversity than at present.

The residual river, between the Dumbarton Dam and the head of the adjoining downstream reservoir (4.5 km), will probably develop an armoured substrate in some areas, and erode down to bedrock in others. Flood flows will occasionally be released down this section of river. The riverbed profile may also change to a pool and riffle structure. The residual river may eventually be physically similar to the braid habitats in the existing river.

6.1 PERIPHYTON

If siltation of the substrate occurs as a result of construction activities, it is likely that the standing crop of periphyton in downstream reaches will be reduced over the short term as a result of smothering. However, species composition is not expected to change greatly from the existing communities, which appear to be partially silt tolerant. This is particularly the case for *Ulothrix zonata*.

If more extensive armouring of the riverbed occurs below Tuapeka, and the discharge from the lowest dam emulates natural river flows, the standing crop of periphyton could increase in downstream reaches over the long term. Diatoms and *Ulothrix zonata* are likely to form the main component of this higher crop. *Rhodochorton violaceum* is also expected to be abundant, mainly on the bedrock, if the Birch Island option is adopted. Excessive proliferations are not expected.

If the residual river flow below Dumbarton is managed with a moderate to low variability in discharge, and stable sediments occur, large standing crops of periphyton could result (20-50 $g.m^{-2}$). *Rhodochorton violaceum*, *Ulothrix zonata*, *Phormidium* spp. and *Cymbella kappii* will probably be abundant if water nutrient concentrations remain as at present. These taxa dominate analogous braids of the present river. If enrichment occurs from sources such as irrigation percolation or septic tank drainage, large mats of *Melosira varians*, *Oedogonium* spp., or, in an extreme situation, *Cladophora* sp. may develop. Green algal proliferations could cause problems for fishing in the channel and smother invertebrate habitats. Where bedrock occurs, there could possibly be some moss and red algal communities.

6.2 MACROPHYTES

Dam construction activities are unlikely to have significant effects on the macrophytes in downstream reaches. However, if siltation is severe, productivity, and thus possibly standing crop, may be reduced in the short term because of additional light attenuation. This may be particularly severe if silt settles on macrophyte leaves.

Further armouring of the downstream substrates is likely to reduce potential macrophyte habitat, as these plants prefer a soft, silty substrate. However, although *Ranunculus fluitans*, *Potamogeton cheesemanii* and *Myriophyllum propinquum* could develop among the armoured substrates if there were extended periods without flood events, their presence is likely to be sparse (< 10 $g.m^{-2}$ organic matter).

It is unlikely that the residual river below Dumbarton will harbour extensive growths of aquatic macrophytes. If there is only a moderate to low frequency of fresh events down the river, small beds of the species noted above could develop. *Ranunculus fluitans* would be particularly favoured in areas where sediments are gravel sized or finer. All the above taxa are currently established in some of the braids of the river, a habitat that is similar to that expected in the residual river. Where areas of bedrock are exposed, moss communities possibly could survive in conjunction with periphytic red algae.

6.3 INVERTEBRATES

Dam construction activities could have significant short term detrimental effects on invertebrate communities in downstream reaches. Reductions in standing crop and, to a lesser extent, diversity, are likely in the braid and shoulder habitats. Most silt-sensitive taxa are unlikely to survive high silt loads. Interstices around the gravels and cobbles could become in-filled with additional silt, which could be detrimental to taxa, such as *Deleatidium* sp. and most trichopteran larvae, which utilise undersurfaces and interstices of cobbles and gravels as resting and feeding habitats. Further, coarse plant material often collects in the interstices and can provide food for some Trichoptera (e.g., *Triplectides* spp.). Burrowing organisms, such as oligochaete worms, would be favoured by siltation.

If further armouring of the main riverbed below Tuapeka or Birch Island occurs, a reduction in habitat diversity would occur. An associated reduction in invertebrate diversity would probably ensue, with a reduction in the abundance of Ephemeropteran, Plecopteran and some Trichopteran larvae. However, this potentially detrimental effect may be balanced, to a degree, by other responses. Increased substrate stability may allow colonisation by some trichopteran larvae, such as *Aoteapsyche* spp., which appear to require stable bed materials on which to anchor their large food capture nets. The production of these organisms in downstream reaches may also be enhanced by plankton from the new reservoirs, if the residence time and productivity of the reservoirs are sufficient to allow a build up of plankton to levels higher than are currently present in the river.

If the short residual river below Dumbarton is managed with a moderate to low variability in discharge, stable sediments should occur, and be colonised by large standing crops of periphyton. In turn, there could be considerably higher production of invertebrates than currently exists in the river (an increase of up to 1-2 $g.m^{-2}$ organic matter). A change in community structure is also likely, particularly if waters are shallower and velocities increase at the substrate surface. A number of taxa currently present at low abundances would probably increase. This could occur through the increased production of periphyton, which would provide additional habitat for some species (e.g., tube forming chironomids), and by increasing food availability for others (e.g., elmid beetles and trichopteran grazers such as *Olinga feredayi*). However, these conditions could also disadvantage taxa, such as net-spinning caddisfly, stonefly and *Deleatidium* sp. mayfly larvae, which, although probably also grazing periphyton, appear to prefer a reasonably clean (hard) cobble substrate. Overall, it is likely that molluscs will still be abundant in this section of river, although it is probable that insect taxa will form a much higher proportion of the invertebrate community than they do at present. The following taxa are likely to be abundant: *Potamopyrgus antipodarum*, Chironomidae, *Olinga feredayi*, *Pycnocentria evecta*, *Pycnocentrodes* sp., Elmidae and *Aoteapsyche colonica* (or *Aoteapsyche tepoka*). The last noted taxon would probably be found preferentially in areas of the river less colonised by periphyton because it requires a "clean" substrate for net building.

7 POSSIBLE MITIGATION MEASURES FOR THE LOWER CLUTHA DEVELOPMENTS

Mitigation has been loosely defined as all measures designed to avoid or minimise impacts, rectify impacts by restoration or repair or compensate for impacts by providing replacements or substitutes (Brocksen *et al.*, 1982). A further aspect, that of biological enhancement, is also included in this definition for the current evaluation.

Mitigation approaches are many and varied and several could provide adequate answers for any one problem. The following are therefore only suggestions, and serve to highlight possible solutions to biological problem areas.

The physical habitats of biological communities are the major factor controlling community development. Habitats are therefore probably the best level for which to design mitigation measures. Further, they usually have quantifiable parameters, and any one mitigation measure can usually assist the protection and development of a number of communities. Much of the following discussion therefore focuses on habitat, rather than community, mitigation options.

7.1 THE EXISTING RIVER ECOSYSTEM

Schemes A and B (fig. 9) in combination with the upstream Roxburgh and Dunstan Reservoirs, would result in all of the riverine-gorge type habitats in the river being flooded. This is significant both locally and nationally. We are not aware of a similar assemblage of habitats in one area in any other New Zealand river. The nearest would be the Upper Clutha River (Biggs, 1981; Biggs and Malthus, 1981), but it has only minor reaches that could be considered similar and has different biotic assemblages. There would be no examples of fully riverine reaches and associated habitats and biota left on New Zealand's largest river if Schemes A, B or D were adopted.

Scheme C, with a dam situated above Birch Island, would enable a reasonable reach of the river, containing some particularly good examples of bedrock and backwater habitats, to be retained. This scheme would therefore also allow the preservation of examples of the extensive red algae, which currently appear to be rare, and beds of mosses. In addition, the re-regulation of the flow in the Birch Island reservoir will be necessary if the habitats and their communities in the Rongahere Gorge section of the river are to be maintained. It will also minimise flushing effects further downstream. If waters are discharged in response to the inflow volumes at Dunstan, as recommended by Jowett (1984), community development in the downstream reaches should proceed with little disruption: their production and diversity could even increase over current levels. Implementation of Jowett's scheme would remove the potentially detrimental effects of rapid flow changes, such as have been reported below other power generation reservoirs (e.g., Trotsky and Gregory, 1974).

In conclusion, the adoption of Scheme C and a de-regulation flow management policy are options that will result in the least detrimental impacts of the developments on the biological communities in the current river system.

7.2 THE NEW LAKE ECOSYSTEM

Impacts which need to be considered with new biological communities in the reservoirs include water level fluctuations, bank erosion and weed bed development.

Operating regimes have been proposed for the Lower Clutha dams which assume that successive and total re-regulation of the river using the downstream reservoir (i.e., de-regulation) is a worthwhile goal to minimise environmental and erosional damage (Jowett, 1984). Under this regime, outflows from the Tuapeka or Birch Island Dams would be the same as inflows to Lake Dunstan. When it is considered that: (a) aquatic macrophytes are at present surviving de-watering of up to 8 hours in the Lower Clutha backwaters; (b) proposed fluctuations in water level in the Birch Island and Tuapeka (level = 89 m) reservoirs will be less than those occurring in Lake Roxburgh at present (average daily fluctuation = 0.76 m), it is to be expected that the littoral zones of the new impoundments will be similar to those currently found in Lake Roxburgh (i.e., extensive beds of adventive aquatic macrophytes with only a narrow band of sterile shoreline).

The effects of changes in water level are likely to be most evident in very shallow parts of the reservoirs. These areas could be de-watered regularly, leaving sterile, silty flats, particularly where they are exposed to the prevailing winds and a long fetch. In sheltered areas, such as the Island Block backwater, sediments would remain moist during draw-down, and beds of semi-aquatic plants may develop (e.g., *Juncus* spp.) which could provide productive wildlife habitat. This has occurred in places along the shores of Lake Roxburgh.

Bank erosion could occur in areas exposed to a long fetch where the banks are steep and composed of soil or weak rock. These areas should be identified in detail and appropriate stabilisation measures taken during the construction phase. Siltation of the substrate and associated biological communities, as well as discolouration of the water, could otherwise occur. If very coarse material were also deposited, it may take many years before substantial aquatic plant communities could develop.

Proliferations of benthic algae could occur in areas of localised enrichment from sources such as septic tank seepage and irrigation return flows. Efforts should be made to prevent these seepage waters from entering the reservoirs by using approaches such as sewage schemes with treatment and land application of effluent away from the reservoirs.

Aquatic macrophyte growth in the reservoirs is a necessary component of ecosystem development. However, a balance must be found between production and proliferation: excessive growth in many areas is not desirable from a biological, recreational, or power generation point of view.

Experience in Lake Roxburgh suggests that extensive beds of *Lagarosiphon major*, which grow to the water surface, will occur in any sheltered areas in the reservoirs with soft, silty substrates. These could be troublesome for power generation and recreation. When more definitive development options are available a full weed management plan should be drawn up which takes generating, wildlife, fisheries and recreational interests into account. Unfortunately, many of the weed source control methods in lakes are subject to ecological, economic and practical constraints, and may also conflict with other user interests such as wildlife habitat preservation. A summary of these control methods and disadvantages associated with them is given in appendix 7.

7.4 THE DUMBARTON RESIDUAL RIVER

The potential of the planned residual river below the Dumbarton reservoir to be maintained as a productive ecosystem and fishery will depend largely on the regime of flow regulation. For example, the amount of water in relation to the riverbed profile, and frequency of high flow events, will be important. Assuming that a flow will be determined by hydraulic modelling appropriate to the maintenance of a productive fishery (which will thus probably also allow other biological communities to develop) and optimisation of the wetted area in the river, the frequency and magnitude of fresh events then becomes the most important management parameters.

There will be a high degree of variability in the flows of the residual river due to spilling of water from Dumbarton during floods and freshes. Intermediate frequency fluctuations are important for maintaining the productivity of some ecosystems (Odum, 1971, p. 268) and for maintaining high diversity (Moore, 1983). Where excessive biomass resulting from instream primary production occurs, there is likely to be habitat degredation (e.g., periphyton smothering of bed sediments, interstitial oxygen depletion, etc.) which will be detrimental to invertebrate and fish communities. A moderate frequency of fresh events would wash this accumulated periphyton away. However, a high frequency of fresh events will also be detrimental because of habitat destabilisation (e.g., reducing periphyton production, depleting sedimentary detritus, physical abrasion, etc.).

Clearly, a balance in the frequency of freshes would need to be found if the residual river were to be maintained as a healthy ecosystem and a productive fishery. This balance would most easily be found by controlled experimentation after reservoir construction and an analysis of flood patterns.

8 SUMMARY AND CONCLUSIONS

8.1 SUMMARY COMPARISON OF THE BIOLOGICAL FEATURES OF THE FOUR DEVELOPMENT OPTIONS

A summary of the combined physical-limnological data for the four development options is given in table 13. Scheme B would form the largest area of lakes, have the longest shoreline, the most number of embayments and the longest cumulative residence time. Scheme A would have the highest area of productive littoral, although this area would form the highest proportion of lake area in Scheme D (60%). Scheme D would also have the highest proportion of lake area with a gently sloping littoral, which is potentially suitable for recreation.

Table 13 Combined physical-limnological characteristics of the Lower Clutha impoundment schemes

Factor	Scheme			
	A	B	C	D
Length of river flooded (km)	62	62	48	62
Length of residual river (km)	8.4	8.4	8.4	8.4
Area of impoundments (ha)	2288	3459	2617	1863
Length of shoreline (km)	172	213	164	162
Number of embayments	17	32	22	18
Cumulative residence time (days)	5.04	14.91	9.09	3.98
% of shore with gently sloping littoral	23	15	19	25
Area in 'tidal' zone (ha)	179	129	120	162
Area of productive littoral (ha) (1-10 m depth zone)	1273	986	971	1096
Area of potential weed beds (ha) (1-4 m depth zone)	482	387	358	425

Scheme C would cause the least detrimental effects for instream communities. This scheme would flood the least amount of river, have the smallest extent of weed beds, and would have the smallest area in the shallow 'tidal' zone that could be detrimentally affected by daily lake level fluctuations. The area in productive littoral is also least in this scheme, although the differences in this parameter between schemes are not major.

8.2 CONCLUSIONS

Although no endangered or unique organisms were identified in the study, the creation of reservoirs on the Lower Clutha River, as proposed in Schemes A, B and D, will result in the loss of the last of the extensive areas of 'big river' gorge habitats and communities in the Lower Clutha system. This would be a significant loss because of their unusual character and because it would leave no examples of what the gorge river environments (i.e., habitats and communities) were like in New Zealand's largest river.

Once the reservoirs are constructed, issues that will require careful attention if detrimental effects are to be minimised, are the development of weed beds, the magnitude of water level fluctuations, the extent of downstream flow fluctuations and the management of the residual river flows to balance biological diversity and production.

Overall, the maximum differences between any two of Schemes A to D for three important ecological parameters are:

- 23% (14 km) for the length of big river gorge habitat that will be flooded;

- 33% (59 ha) for the area of barren tidal zone that will be created; and

- 26% (124 ha) for the area of weed beds that would develop and obstruct recreation. Scheme C is the most favoured of the Schemes, from an ecological point of view, as it would have the lowest of these effects.

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APPENDICES

APPENDIX 1A : DESCRIPTIONS OF SAMPLING STATIONS AND SUMMARIES OF THE SAMPLES COLLECTED

Abbreviations used:

C = Core sample
S = Surber sample
W = Wood sample
D = Debris sample
I = Interstitial substrate sample

(C, S, W, D and I: Invertebrate Sampling)

P = Periphyton sample

SAMPLING STATION A1

Habitat type Braid

Location Opposite Roxburgh Golf Course on LHS of river
NZMS 1 Ref. S152 E143 085

Description of area

During low flow conditions:

(a) Upstream area - backwater type habitat, silty substrate with moderately dense cover of aquatic macrophytes. During the winter survey several strands of *Lagarosiphon* were observed growing in a dense bed of *Elodea*. These plants were removed with no re-growth being noted during the summer survey.

Marginal vegetation - crack willow trees growing along silty banks.

(b) Downstream area - water flows from backwater area into braid which flows through a gravel - rocky area approximately 9 m wide that supports moderate growths of mosses and green and brown periphyton. Nearer the willow lined riverbank is an area of semi-aquatic plants, sedges and grasses that becomes inundated during periods of high flow.

Survey data

Details	Estimated river flow m^3/s	Samples
Winter Periphyton samples 19.7.83	125	
Winter transect 26.7.83, 28.7.83	110, 140	
Winter samples 28.7.83		C(4), S(3), W, D
Summer transect (1) 6.1.84	225	
Summer samples 1.3.84	175	C(4), S(3), W, D
Summer transect (2) 28.3.84	150	
Vegetation biomass 6.4.84	150	

SAMPLING STATION A2

Habitat type Backwater

Location Upstream of Dumbarton Rock on RHS of river
NZMS 1 Ref. S152 E146 044

Description of area

Backwater arising from embayment and adjacent sand-bar; approximately 100 m long, with silty-sand, willow lined banks. This area may have been a former braid, as downstream end of backwater is obstructed by a large bank of gravel and flood debris. Five small clumps of *Lagarosiphon* were observed growing in the upstream portion of the backwater during the winter survey, although only two of these weed beds were noted in March 1984.

Survey data

Details	Estimated river flow m^3/s	Samples
Winter transect and samples 29.7.83	130	C(5), W, D, I
Summer samples 22.3.84	300	C(5), W, D
Summer transect 28.3.84	150	
Vegetation biomass 6.4.84	150	

SAMPLING STATION A3

Habitat type Backwater

Location Tima Burn (closed off branch) on LHS of river
NZMS 1 Ref. S153 E211 962

Description of area

Backwater habitat formed by diversion of Tima Burn by landowner. Evidence of grazing by cattle at this site. The backwater has steep sided, silty banks lined with low growing scrub. During low flow, a large amount of flood debris is exposed, the accumulation of which forms barriers for three deep pools.

The water is contaminated with faecal material and supports a moderately dense growth of aquatic macrophytes, periphyton and semi-aquatic plants. During the summer survey, a small stand of *Lagarosiphon* was noted growing in the pool close to the confluence of the tributary.

Survey data

Details	Estimated river flow m^3/s	Samples
Winter periphyton samples 19.7.83	125	
Winter transect and samples 27.7.83	110	C(5), W, D, I
Summer transect (1) 11.1.84	225	
Summer samples 1.3.84	175	C(5), W, P
Summer transect (2) 28.3.84	150	

SAMPLING STATION A5

Habitat type Braid

Location Opposite Craigneuk orchard on LHS of river
NZMS 1 Ref. S152 E146 037

Description of area

Braid formed by a stable shoulder. During times of low flow no water enters the upstream end of the braid, although there is a considerable back-flow from the channel into the downstream opening. The shoulder area is composed of silt covered rocks, gravel and sand, and is covered by grasses, semi-aquatic plants and mosses. Riffle areas exist along the edges and ends of the shoulder. There are no willow trees lining the river bank at this station. The area sampled was approximately 50 m up from the downstream end of the braid and was composed of large silty rocks amongst which a sparse cover of aquatic macrophytes were observed growing. During the winter survey a small clump of *Lagarosiphon* was observed growing on the rocky-silt substrate approximately 15 m downstream of the transect area. This weed bed had increased considerably in area by March 1984.

Survey data

Details	Estimated river flow m^3/s	Samples
Winter periphyton samples 19.7.83	125	
Winter samples 11.8.83	780	S(5), W, I, Moss
Winter samples repeated and transect 1.9.83	200	S(5), I
Summer samples 1.3.84	175	C(2), S(3), W, P
Summer transect 28.3.84	150	

The additional winter samples collected on the 1.9.83 were necessary as it was considered that the river had been too high and discoloured for optimal sampling on the 11.8.83.

SAMPLING STATION A6

Habitat type   Silty, willow lined river bank

Location(s)
(a) At picnic area downstream of Laurel Creek on RHS of river
NZMS 1 Ref. S152 E134 059

(b) Upstream of mouth of Tima Burn on LHS of river
NZMS 1 Ref. S153 E209 963

Description of area(s)

(a) Laurel Creek site. Gently sloping silty bank with a sparse cover of green and brown periphyton and semi-aquatic plants. At the low water level the bank became steep sided on which surface patches of *Elodea* were observed growing. Minimal environmental alterations to area due to picnic ground activities.

(b) Small silty bank immediately upstream of braid at mouth of Tima Burn. Sparse cover of periphyton observed.

Survey data

Details	Estimated river flow m^3/s	Samples
(a) Laurel Creek		
Winter samples 1.9.83	700	C(3)
Winter transect 20.9.83	235	
Summer transect (1) 10.1.84	225	
Summer samples 22.3.84	300	C(5), W, D, P
Summer transect (2) 28.3.84	150	
Vegetation biomass 6.4.84	150	
(b) Tima Burn		
Winter periphyton samples 19.7.83	125	
Winter samples 11.8.83	700	C(2)

No transects or summer samples were taken from this site.

SAMPLING STATION A 7

Habitat type Bedrock

Location 500 metres upstream of Millers Flat bridge
on RHS of river
NZMS 1 Ref. S153 E215 955

Description of area

Rocky outcrop approximately 10 m from silty river bank. The silt covered rocks and boulders support dense covers of mosses and green and brown periphyton.

Survey data

Details	Estimated river flow m^3/s	Samples
Winter periphyton samples 20.7.83	125	
Winter samples 29.7.83	130	S(1), W, D Moss, 2 quadrats of silt and gravel
Summer samples 22.3.84	200	S(2), W, D, P 3 quadrats of silt and gravel

SAMPLING STATION B1

Habitat type   Backwater

Location   Adjacent to Portuguese Hill approximately 2.5 km downstream of Millers Flat bridge on LHS of river NZMS 1 Ref. S153 E235 928

Description of area

Small backwater (embayment) area formed by a narrow projection of river bank obstructed at the upstream end by an accumulation of large flood debris. The projection of river banks is lined with willow trees in contrast to the outer bank of the backwater which is an open area of grasses and sedges. Dense covers of both aquatic macrophytes and semi-aquatic plants were observed growing on the silty substrate of the backwater. This backwater is joined by a narrow, debris filled and weed infested channel to sampling station B7.

Survey data

Details	Estimated river flow m^3/s	Samples
Winter transect and samples 28.7.83	140	C(6), W, D, I
Summer transect (1) 6.1.84	225	
Summer samples 1.3.84	175	C(5), W, D
Summer transect (2) 27.3.84	150	
Vegetation biomass 6.4.84	150	

SAMPLING STATION B2

Habitat type: Braid

Location: At the end of McCann Road on RHS of river
NZMS 1 Ref. S162 E294 850

Description of area

During low flow conditions, the upstream area becomes a backwater type habitat that is formed because of a closure at the upstream end. The sampling station is approximately 300 m long, willow lined with gently sloping silty banks that support a dense cover of aquatic macrophytes. A small polluted stream flows into this area.

Downstream area - water from the backwater flows into the main river via a channel composed of gravel and rock that is formed by a gravel mound bordering a downstream pool (i.e., permanent braid habitat).

During high flow conditions water enters the upstream end of the backwater and flows out the downstream channel. Alternatively, the water flows over the gravel mound and enters a large braid. Sampling stations B4 and B6 are situated in this downstream braid.

Survey data

Details	Estimated river flow m /s	Samples
Winter periphyton samples 19.7.83	125	
Winter transect and samples 22.7.83	100	C(4), S(4), W, D, I
Summer transect (1) 5.1.84	250	
Summer samples 2.3.84	175	C(4), S(4), W, D, P
Summer transect (2) 27.3.84	150	
Vegetation biomass 6.4.84	150	

SAMPLING STATION B3

Habitat type   Shoulder

Location   Craig Flat on LHS of river
NZMS 1 Ref. S162 E286 867

Description of area

Large gravel and rock area (56 m wide) that becomes submerged during high flow conditions in the river. During low flow a long isolated back-water is formed between the exposed gravel bed and the willow lined silty river bank. The gravel substrate of the shoulder supports a sparse cover of periphyton.

Survey data

Details	Estimated river flow m^3/s	Samples
Winter periphyton samples 19.7.83	125	
Winter transect and samples 26.7.83	100	S(4), W, I, Moss
Additional winter samples 1.9.83	200	S(2)
Summer transect (1) 6.1.84	225	
Summer transect (2) and samples 1.3.84	175	S(5), P

SAMPLING STATION B4

Habitat type Silty, willow lined river bank

Location Bank of braid at end of McCann Road on RHS of river
NZMS 1 Ref. S162 E298 847

Description of area

Steep sided bank of deep braid that supports a moderately dense growth of semi-aquatic plants and a sparse growth of aquatic macrophytes. A fringe of *Elodea* grows along the area of bank that remains permanently inundated.

Survey data

Details	Estimated river flow m^3/s	Samples
Winter periphyton samples 19.7.83	125	
Winter transect and samples 22.7.83	100	C(3), W, D, I
Summer transect (1) 5.1.84	250	
Summer samples 2.3.84	175	C(2), P
Summer transect (2) 27.3.84	150	
Vegetation biomass 6.4.84	150	

SAMPLING STATION B4 EXTRA

WINTER SITE

Habitat type — Silty, willow lined river bank

Location — Craig Flat on LHS of river
NZMS 1 Ref. S162 E286 867

Description of area

Silty bank of sandy backwater - isolated briad that is formed during periods of low flow (see sampling station B3 for further details).

Survey data

Details	Estimated river flow m^3/s	Samples
Winter transect and samples 26.7.83	110	C(1)

The site described below was preferred for the summer survey as it represented a more typical example of the river bank habitat.

SAMPLING STATION B4 EXTRA

SUMMER SITE

Habitat type — Silty, willow lined river bank

Location — Directly opposite mouth of McCann Road braid (sampling station B6) on LHS of river NZMS 1 Ref. S 162 E302 847

Description of area

Silty-sandy gently sloping bank that supports a moderate cover of semi-aquatic plants and predominantly native aquatic macrophyte species.

Survey data

Details	Estimated river flow m^3/s	Samples
Summer transect (1) 6.1.84	225	
Summer samples 1.3.84	175	C(5), W, D
Summer transect (2) 27.3.84	150	
Vegetation biomass 6.4.84	150	

SAMPLING STATION B5

Habitat type Tributary

Location Mouth of Beaumont River on LHS of river
NZMS 1 Ref. S162 E323 774

Description of area

Peaty tributary with steep sided rocky and boulder covered banks. Marginal vegetation - willow trees, broom and scrub. Sampling area situated below a small waterfall that defines the extent of the flood level of the Clutha River, approximately 500 m from the confluence of the two rivers.

Survey data

Details	Estimated river flow m^3/s	Samples
Winter periphyton samples 19.7.83	125	
Winter samples 26.7.83	110	C(1), S(4), W, D, I
Summer samples 1.3.84	175	S(5), W, D, P

Point transect surveys were not performed at this site because of a general absence of vegetation.

SAMPLING STATION B6

Habitat type Shoulder

Location Downstream end of McCann Road braid on RHS of river
NZMS 1 Ref. S162 E301 847

Description of area

Large gravel, rocky shoulder at junction of McCann Road braid and main river channel; approximately 15 m from river bank. During low flow a long backwater is formed along the bank, supporting a dense cover of macrophytes. Several small clumps of aquatic macrophytes were observed growing along the edge of the shoulder closest to the main channel of the river (i.e., in effect these plants were growing in the main river channel).

Survey data

Details	Estimated river flow m^3/s	Samples
Winter periphyton samples 19.7.83	125	
Winter samples 29.7.83	130	C(2), S(3), W, D, I
Summer samples 2.3.84	175	C(2), S(3), P

SAMPLING STATION B7

Habitat type Backwater

Location Approximately 1.5 km downstream of Millers Flat bridge on LHS of river
NZMS 1 Ref. S153 E227 938

Description of area

A moderately large and narrow backwater lined by dense covers of willow trees and blackberries growing along the gently sloping silty banks. The backwater contains moderately dense growths of macrophytes, and during low flow conditions is divided into two deep pool areas linked by a narrow weed infested channel. Five small beds of *Lagarosiphon* were observed growing in this backwater during the winter survey. A marked increase in the area of these beds was noted during the summer surveys.

Survey data

Details	Estimated river flow m^3/s	Samples
Winter transect and samples 27.7.83	110	C(5), W, D(2), I
Summer transect (1) 11.1.84	225	
Summer samples 1.3.84	175	C(5), W, D
Summer transect (2) 27.3.84	150	
Vegetation biomass 6.4.84	150	

SAMPLING STATION C2

Habitat type   Shoulder

Location   Approximately 100 m downstream of Beaumont bridge
on RHS of river
NZMS 1 Ref. S162 E323 767

Description of area

During low flow conditions - an exposed rocky and gravel shoulder area located between the river bank and a number of large, moss covered rocky outcrops situated in the main channel of the river (i.e., approximately 30 m from the bank). Large amounts of green and brown periphyton were observed growing at this sampling station.

Survey data

Details	Estimated river flow m^3/s	Samples
Winter periphyton samples 20.7.83	125	
Winter transect and samples 21.7.83	120	S(5), W, D, I
Summer transect (1) 10.1.84	225	
Summer samples 2.3.84	175	S(5), W, D, P
Summer transect (2) 27.3.84	150	

SAMPLING STATION C3

Habitat type Shoulder

Location Immediately upstream of mouth of Blackcleugh Burn on RHS of river
NZMS 1 Ref. S162 E284 594

Description of area

During periods of moderate flow - low velocity braid (28 m x 13 m) formed between steep sided silty river bank and gravel shoulder area. Under low flow conditions no water flows through the braid (i.e., area is similar to a backwater habitat). As a result of this situation the substrate of the braid is composed of gravel and sand in which several clumps of macrophytes were observed growing. During a later survey of the river on 8 September it was noted that the site had been altered considerably by the removal of gravel from the river bank by heavy earthmoving machinery and therefore this station was not included in the summer surveys.

Survey data

Details	Estimated river flow m^3/s	Samples
Winter periphyton samples 20.7.83	125	
Winter transect 19.7.83	115	
Winter samples 21.7.83	120	C(2), S(3), W, D, I

SAMPLING STATION C4

Habitat type Silty, willow lined river bank

Location Approximately 300 m upstream of mouth of Low Burn
on LHS of river
NZMS 1 Ref. S162 E318 754

Description of area

Raised silty ledge situated approximately 0.5 m above a gravel-rock interface of river bank. Low density cover of aquatic macrophytes and semi-aquatic plants observed in a silty trough situated on ledge. Polluted seepage from the main river bank was visible on the silty substrate.

Survey data

Details	Estimated river flow m^3/s	Samples
Winter transect and samples 20.7.83	120	C(5), W, D, I, P
Summer transect (1) 11.1.84	225	
Summer samples 1.3.84	175	C(3), W, D
Summer transect (2) 28.3.84	150	

SAMPLING STATION C4 EXTRA

Habitat type	Silty, willow lined river bank
Location	Approximately 500 metres upstream of mouth of Carsons Creek on RHS of river NZMS 1 Ref. S162 E295 723

Description of area

Moderately steep sided silty bank bordered by rock-gravel interface. The upper region of the bank is covered by large quantities of mosses while the lower region supports a sparse cover of semi-aquatic plants and periphyton.

Survey data

Details	Estimated river flow m^3/s	Samples
Winter transect and samples 27.7.73	110	C(2)
Summer transect (1) 6.1.84	225	
Summer samples 2.3.84	175	C(2), W, D
Summer transect (2) 27.3.84	150	

SAMPLING STATION C5

Habitat type Bedrock

Location Directly opposite Clutha Downs residence
Access from RHS of river
Sampling area - approximately in middle of river
NZMS 1 Ref. S162 E287 702

Description of area

During low flow conditions - exposed riverbed composed of large boulders, debris jams, rock and gravel accumulations, and protected fine gravel-sand bars. The large rocks support a moderately dense cover of mosses and green and brown periphyton.

Survey data

Details	Estimated river flow m^3/s	Samples
Winter periphyton samples 20.7.83	125	
Winter samples 28.7.83	140	C(2), S(3), W, D, I
Summer samples 27.3.84	150	S(3), W, D, P Quadrats of gravel (2)

Point transect surveys were not conducted because of an absence of macrophytes at this site.

SAMPLING STATION D1

Habitat type Backwater

Location Immediately upstream of gravel pit located beside
Beaumont - Clydevale Road
Sampling station on RHS of river
NZMS 1 Ref. S171 E312 538

Description of area

Large backwater that is divided into two main pools connected during high flow conditions by a flood-debris obstructed channel.

The upstream portion of the backwater arises from a small weed infested embayment and is approximately 55 m long. The backwater is tapered, being 19 m wide at the upstream end and 9 m wide at the downstream end, the latter point being defined by a debris jam. Marginal vegetation is mainly willow trees and flax bushes.

The downstream section of the backwater is a pear shaped pool (8-20 m wide - 39 m long), lined by weed infested silty banks and willow trees. During low flow, a small channel connects the main river and the upstream end of the backwater, although during periods of higher levels, water flows over the innermost silty bank into the backwater. The downstream extent of the backwater has been limited by the construction of an access road to the main river.

Both the major sections of the backwater, the connecting channel and the river bank interface are covered by dense beds of aquatic macrophytes. Several beds of *Lagarosiphon* were observed growing in the downstream region, the area of which increased markedly during the spring and summer months. Several strands of *Lagarosiphon* were found in the upstream backwater during both surveys.

Survey Data

Details	Estimated river flow m^3/s	Samples
Upstream backwater		
Winter transect 7.7.83	150	
Winter samples 20.7.83	120	C(5), W, D, I
Summer samples 2.3.84	175	C(5)
Summer transect 23.3.84	200	
Vegetation biomass 6.4.84	150	
Downstream backwater		
Winter transect 18.7.83	120	
Winter samples 20.7.83	120	C(5), W, D, I
Summer samples 2.3.84	175	C(5), W, D
Summer transect 30.3.84	400	
Vegetation biomass 6.4.84	150	

SAMPLING STATION D2

Habitat type Backwater

Location Adjacent to access road alongside LHS of river, upstream of mouth of Tuapeka River
NZMS 1 Ref. S171 E306 557

Description of area

The area selected for study was representative of the environment that exists along the LHS of the river from the downstream end of the Beaumont Gorge to Tuapeka Mouth. The site is a large narrow backwater - isolated rock pool area that is formed between large outcrops of river bedrock and the undulating river bank. In an area 20 m wide and 35 m long, five shallow, weed infested pools were observed, which were connected during low flow conditions by silty, water filled channels. Moderately dense covers of macrophytes were found growing in these pools and channels. Plants and periphyton were also observed growing on silt covering the rocks.

Areas of rock and/or sandy mounds above the low water level supported dense growths of semi-aquatic plants, grasses, scrub and small willow trees.

Downstream of the sampling station is a small silty embayment in which a small bed of *Lagarosiphon* was growing within a mixed native and adventive macrophyte community. The area of this weed bed was observed to have increased approximately threefold during the spring and summer months.

Survey data

Details	Estimated river flow m^3/s	Samples
Winter transect 8.7.83	190	
Winter samples 20.7.83	120	C(5), W, D, I, P

Because it proved impossible to dig a hole for the winter interstitial sample through the sparsely covered bedrock, a sample was obtained from a small silty pool that occurred naturally in a rocky outcrop close to the river's edge.

Summer samples 22.3.84	175	C(5), W, D
Summer transect 23.3.84	200	
Vegetation biomass 6.4.84	150	

SAMPLING STATION D3

Habitat type Shoulder

Location At end of access road beside backwater site (D1) adjacent to Clydevale - Beaumont Road on RHS of river.
NZMS 1 Ref. S171 E312 538

Description of area

During low flow conditions, riffle area approximately 10 m wide and 32 m long, bounded at the upstream end by a stable gravel shoulder and at the downstream end by a small embayment. Relatively large amounts of green and brown periphyton were observed growing in this region. The gently sloping silty river bank along this riffle area is lined with several large willow trees and supports a moderate cover of semi-aquatic plants. During high flow conditions this riffle would constitute a main channel area.

Survey data

Details	Estimated river flow m^3/s	Samples
Winter transect and samples 19.7.83	115	S(5), W, D, I, P
Summer transect (1) 9.1.84	250	
Summer samples 2.3.84	175	S(5), W, D, P
Summer transect (2) 23.3.84	200	

SAMPLING STATION D4

Habitat type Backwater

Location Opposite and marginally downstream of sampling station D1, on LHS of river. Access via road from Tuapeka Mouth. NZMS 1 Ref. S171 E314 537

Description of area

Large, flat, silty backwater (47 m long and 13 m wide) alongside a fast flowing braid. The area is lined with tall willow trees and debris jams and is bounded by small silty embayments situated at either end and silty banks on either side. Transecting the backwater is a small raised mound supporting grasses, semi-aquatic plants and a willow tree. On the river side of this mound is a small gravel area. The bank at the river's edge is steep sided and is fringed at the low water level by aquatic macrophytes. Both the flat silty plateau above the steep sided bank and the two embayments support the growth of moderately dense covers of aquatic macrophytes.

Survey data

Details	Estimated river flow m^3/s	Samples
Winter transect and samples 19.7.83	115	C(5), W, D, I, P
Summer transect (1) 10.1.84	225	
Summer transect (2) 30.3.84	400	C(5), W, D, P

SAMPLING STATION D5

Habitat type Tributary

Location Tuapeka River on LHS of river.
NZMS 1 Ref. S171 E315 531

Description of area

The area surveyed was upstream of the Tuapeka Mouth bridge, approximately 300 m from the confluence of the two rivers. The tributary is a fast flowing peaty river with a soft gravel - silty substrate and steep clay banks lined with scrub, willow and poplar trees. Both the banks and gravel riverbed support a moderately dense cover of green and brown periphyton.

During periods of high water level in the Clutha River, water backs up into the tributary approximately 1 km from the confluence. The invertebrate samples were collected beyond this point.

Survey data

Details	Estimated river flow m^3/s	Samples
Winter transect 19.7.83	115	
Winter samples 20.7.83	125	S(5), W, D, I, P
Summer samples 22.3.84	300	S(5), W, D

SAMPLING STATION D6

Habitat type   Shoulder

Location   Immediately downstream of mouth of Tuapeka River on LHS of river
NZMS 1 Ref. S171 E314 528

Description of area

During low flow - rocky, gravel shoulder area, the downstream extent of which is defined by a large rocky outcrop. The area sampled was 47 m out from the high water level mark or alternatively 38 m from the inner edge of the silty bank. Small quantities of green and brown periphyton were observed growing on the rocks. This shoulder area becomes inundated during relatively low flow conditions (i.e., above 200 m^3/s).

Survey data

Details	Estimated river flow m^3/s	Samples
Winter transect and samples 27.7.83	110	S(5), I

As a result of the higher levels found normally in the river during spring and summer it proved impossible to gain access to this site during the summer survey. Similarly, no alternative main river channel habitat type was accessible in this division of the river during this period.

APPENDIX 1B : ADDITIONAL INVERTEBRATE AND PERIPHYTON SAMPLING OF TRIBUTARIES OF THE LOWER CLUTHA RIVER

(a) Tributaries sampled:

14.2.84	Blackcleugh Burn
	Carsons Stream
	Benger Burn
	Black Jacks Creek
21.2.84	Teviot River
	Tima Burn
	Talla Burn
	Canadian Stream

(b) Samples and data collected:

5 surber samples for invertebrates
5 periphyton samples

Water temperature and conductivity

The areas studied were approximately 500 m upstream of the confluence of the tributary and main river.

APPENDIX 2 : Raw Periphyton Data Grouped According to Habitat Type in the Lower Clutha River

PERIPHYTON TAXA	BACKWATERS				SILTY BANKS				BRAIDS				SHOULDERS				BEDROCK				TRIBUTARIES			
	WINTER		SUMMER		WINTER		SUMMER		WINTER		SUMMER		WINTER		SUMMER		WINTER		SUMMER		WINTER		SUMMER	
	D	A	D	A	D	A	D	A	D	A	D	A	D	A	D	A	D	A	D	A	D	A	D	A
Chlorophyceae																								
Bulbochaete sp.										1	1	3				2		4						
Chroococcus sp.																							2	
Cladophora (insignis)										1			1			1								
Gloeocystis sp.																								3
Microspora sp.						2																		
Oedogonium spp.			4		5		10	1		4			2	3	5	1			2	4				3
Spirogyra sp.	1																						1	4
Stigeoclonium (lubricum)						1																	2	4
Ulothrix (subtilissima)				2				1															4	2
Ulothrix zonata	1	1			1	5			3	2	2	1	6	4	5	2	6	6		2	2	1	11	14
Chrysophyceae																								
Vaucheria sp.	3				8		2											1			1	1	3	1
Bacillariophyceae																								
Achnanthes sp.																2								1
Achnanthes lanceolata				1		1										1				2				1
Achnanthes minutissima								3				5				6				1				
Amorpha sp.																						1		
Cocconeis placentula		2		4		1		3				1				1	1	1						8
Cymbella cymbiformis																								3
Cymbella kappii		4		3	1	10		2	3	6		3	3	6		3		7		2				
Cymbella minuta		1								1				3				2						6
Cymbella sinuata												1												2
Diatoma heimale var. *mesodon*						1				1														1
Diploneis subovalis			1													1						2		
Epithemia zebra var. *saxonica*												1				4		6						
Fragilaria sp.		2		1				1		6		1						5				1		
Fragilaria vaucheriae		1		4				4						1		6				5				15
Frustulia rhomboides		9		1	1	10		2		3		6		10		5		18		9		2		5
Gomphoneis herculeana		1				1				2				4				4				1	10	16
Gomphonema dichotomum																1								
Gomphonema intricatum																								1
Gomphonema parvulum												1												8
Gomphonema subclavatum						1		1								2						1		8
Gomphonema truncatum																								1
Gyrosigma sp.				1						1														
Gyrosigma acuminatum				4												1								
Melosira granulata		2				4				3												1		
Melosira varians		3		1		7		3	1					6		1		8		7		1	18	9
Meridion circulare																						1		
Navicula sp.																								2
Navicula (pusio)																								2
Navicula cryptocephala				1				1																5
Navicula radiosa																1								
Navicula rhyncocephala		3		12				2								2								15
Navicula viridula var. *avenacea*	6	5		2	3	12			1	9		2	1	10		2	1	17			5	5		27
Nitzschia sp.				1								2	1	1		4		4						
Nitzschia palea				1				1				1				2								6
Pinnularia sp.						2																1		
Rhopalodia novaezelandiae																		5						
Rhoicosphenia curvata				3																			1	10
Surirella ovalis										1												1		
Surirella tenera				3																				
Synedra (amphicephala)								2								4								
Synedra minuscula				1				4				1				7								
Synedra ulna		5		7	1	12		10		13		11	1	8		8		4		10		2	2	21
Tabellaria sp.						2																3		
Tabellaria flocculosa																1								
Rhodophyceae																								
Rhodochorton violaceum		3	1	4	1	4	1	3		1	8	4	3	13	4	6	13	2	10					5
Cyanophyceae																								
(Amphithrix) sp.											1				5									1
Calothrix sp.												1				1								
Chamaesiphon sp.												1												1
Nostacaceae			2	1																				3
Phormidium spp.	1	2	11		1	3			8	2			1	4							8	2		1
Schizothrix sp		1	1			1	1		2	3	1	1	1	1		3		7					3	2
Number of taxa found at habitat type	31				30				30				33				21				45			

D = Number of samples in which the taxa was dominant

A = Number of samples in which the taxa was an associate

APPENDIX 3a : Percentage cover, and presence (+) of plant species, estimated river flow, proportion of semi-aquatic area and substrate composition at 27 sampling stations grouped according to habitat type on the Lower Clutha River. July 1983.
(*-site mainly a shoulder, but narrow silty bank section surveyed for vegetation analysis)

PLANT SPECIES	BACKWATERS									BRAIDS			SHOULDERS					SILTY BANKS						TRIBUTARIES		BEDROCK		No. of sites at which taxa found
	A1	A2	A3	B1	B7	DIU/S	DID/S	D2	D4	A1(1)	A5	B2	B3	B6	C2	D3	D6	A6	B4	extra B4	C3*	C4	extra C4	B5	D5	A7	C5	
Agrostis stolonifera				+			+			+	+							+	+	+	+	+						9
Callitriche petriei	+	+	8.3	0.6	+	1.2	+	2.9	1.7			+		+		0.3		+	5.0	0.6	6.9	6.3			1.6			18
Carex guadichandiana	+		+	+		0.6		2.9	+		+														+			8
Cardamine debilis								5.1			+		0.2								+							4
Cerastium fontanum											+																	1
Chara sp.	1.3				+				2.3			1.2								+					+			6
Coprosma propinqua										+								+										2
Crepis capillaris								+		+	+																	3
Elodea canadensis	24.7	35.2	7.5	29.0	31.7	34.9	58.9	5.2	6.8		10.9	4.5		+				6.1	30.0	+	+							16
Eleocharis acuta											+																	1
Epilobium sp.								+													+							2
Epilobium ciliatum											+																	1
Festuca arundinacea	+	+	+	0.4	+	0.5	+	0.9		9.7	1.9	+				+		3.8	0.6	+	3.5	1.1	2.0		1.2			19
Filamentous algae (green)	10.1	5.1	42.5	2.3	5.1	11.3	1.0	0.8	2.1	32.6	3.9	11.1	15.3	+	19.8	30.1	32.5	11.7	8.3	4.2	20.5	8.9	3.7	+	36.2	+	+	27
Filamentous algae (brown)	15.9	6.2	20.4	2.4	20.7			10.4	3.1	21.0	39.6	16.4	1.8	+	22.3	19.2	4.0	38.8	8.3	0.6	5.1		18.0	+	0.7	+	+	24
Galium sp.								+																				1
Glossostigma elatinoides	+		+	3.3	+			0.6	0.2			0.7	+	+	+	+		0.2	0.9	+	2.0	+			+			17
Gnaphalium limosum																			+									1
Hebe salicifolia										+				+														2
Hydrocotyle sulcata			+	0.6	+			8.1	0.3			+							+		+	+						9
Hypericum japonicum				+						+			+															3
Hypericum perforatum											+																	1
Juncus articulatus	+	+	+	2.0	+	3.8	+	1.4	4.3	+	5.4	+		+		0.4		7.9	5.0	+	3.1	1.4	+		1.3			21
Lagarosiphon major	+	1.0			3.3	+	2.9	+			+																	7
Limosella lineata								+			+			+				2.9			+							5
Lotus pedenculatus										+																		1
Musci (unidentified mosses)	5.7		+	3.1	1.8	0.2		1.5	3.5	9.1	0.2	10.4	0.4		+		0.1	0.9	8.6	+	0.9	4.0	18.3	+	2.0	+	+	23
Myosotis caespitosa	0.8		+	0.3	+	0.4	+	3.1	0.5		+	0.3	+			0.3		0.2	+	+	0.9				0.8			17
Myriophyllum elatinoides	4.0		+	2.7	+	+	2.1	1.7	6.8			0.6		+	0.8	0.9	+		2.5	1.8	1.0	+				+		18
Myriophyllum votschii																		4.1										1
Nasturtium microphyllum			+																									1
Plantago lanceolata	+									+	+																	3
Poa sp.											+							+										2
Potamogeton spp.	7.2		+	12.3	2.7	1.1	1.7		0.7	0.3		1.9		+				0.3	2.5	1.2								13
Pratia angulata			2.4	1.2		2.9		6.8											2.8									5
Prunella vulgaris					4.3			+		+	0.9	+						1.6			+							7
Ranunculus flammula								1.2																				1
Ranunculus fluitans	12.4	0.3	3.9	9.2	1.5	5.5	9.7	6.4	7.5		0.2	15.6	+	+						3.6	2.0	+				+		17
Ranunculus repens					+					+				+							+				+			5
Raoulia tenuicaulis											+																	1
Rumex crispus			+					+		+								0.2										4
Rumex obtusifolius			+				+	+		+	+							0.2			+							7
Salix fragilis	7.9	5.1	1.1	14.3	3.2	7.9	3.3	0.6	6.9	+		7.5			+	6.0		9.2	3.3	6.0	2.0	3.5	21.2		26.0			20
Senecio jacobea								+																				1
Tetrachondra hamiltonii										+																		1
Tillaea sinclairii	1.4		6.0	2.5	+	+	10.5			9.7		0.6	+					6.4	1.7	+	+	5.2	11.9					15
Trifolium pratense								0.5		+	+							0.2										4
Trifolium repens								0.6		+								0.2										3
Typha orientalis							+																					1
% Zero Cover	8.6	47.1	7.9	7.8	25.7	29.7	9.9	39.3	53.3	17.6	37.0	29.2	82.3	ND	57.1	42.8	63.4	5.1	20.5	82.0	52.1	69.6	24.9	ND	30.2			
Semi-aquatic area	26.4	33.7	58.7	63.2	45.6	69.4	45.7	85.0	70.1	75.0	74.4	53.3	97.8	ND	59.5	25.0	ND	87.3	63.3	70.2	48.0	100	100	96.1	ND	ND	ND	
Flow at time of survey (m^3/s)	110	130	110	140	110	120	120	190	115	110	200	100	100	125	120	115	110	235	100	110	115	120	110	110				
Substrate composition																												
Clay/silt (%)	78.1	31.9	92.5	98.8	92.6	84.7	98.8	61.0	62.5	38.0	54.8	56.3	2.6	ND		10.3	ND	82.2	93.3	42.3	6.6	27.6	25.4	ND	80.0	ND	ND	
Sand (%)	12.5	68.1			7.4	15.3	1.0	18.8	24.7	6.4	17.9	19.3	32.6		19.8	10.7		17.0	5.0	55.3	48.5	29.9	63.0		12.6			
Gravel (%)	4.5		4.7	1.2					10.4	43.6	11.8	3.7	32.4		55.0	55.8				1.2	41.3	35.1	5.8		7.0			
Small cobbles (%)	4.9		2.8				0.2	20.2	2.4	12.0	15.5	20.7	32.4		25.2	23.2		0.8	1.7	1.2	3.6	7.4	5.8		0.4			
Number of taxa found at habitat type	37									40			19					31						12		5		

ND = Not determined

APPENDIX 3b : Percentage cover, and presence and absence of plant species, estimated river flow, proportion of semi-aquatic area and substrate composition at 15 sampling stations grouped according to habitat type on the Lower Clutha River. January 1984 (2=sampled 27.3.84).

PLANT SPECIES	BACKWATERS					BRAIDS		SHOULDERS			SILTY BANKS					No. of sites at which taxa found
	A1	A3	B1	B7	D4	A1(1)	B2	B3	C2	D3	A6	B4	Extra B4(2)	C4	Extra C4	
Agrostis stolonifera		0.1	+			+	0.1									4
Callitriche petriei	+	5.1	3.1	0.1	0.4		0.3					2.0	3.1	5.9		9
Carex spp.	+	0.3	0.3				0.1	0.1			0.2					6
Chara sp.	3.8	0.4	2.2	0.4	0.8	0.1					0.1		0.8			8
Elodea canadensis	19.4	2.9	15.6	28.1	23.0		0.9					10.7				7
Epilobium sp.	0.2	0.6	0.1					0.1		0.1	0.1					6
Festuca arundinacea	0.1	2.1	0.5	0.1	+	2.3	0.5	0.9	0.1		0.6	2.4	+	0.4	+	14
Filamentous algae (green)	20.2	0.7	0.4	4.7		18.0	7.7	0.8	18.6	29.9	17.0	16.6	12.7	4.9	0.7	14
Filamentous algae (brown)	6.7			0.5	1.0	10.9	0.8	0.4	47.1	22.3	1.9	2.9		1.1	10.6	12
Glossostigma elatinoides	0.1	0.5	4.3	0.8			1.3		0.6	0.1		2.2		0.1		9
Gnaphallum limosum												+				1
Hydrocotyle sulcata		0.1	1.9	0.6			0.4	0.2	0.3			1.2		0.4	0.1	9
Hypericum sp.							0.1									1
Hysela rivalis						0.1						+				2
Juncus articulatus	+	0.9	0.3	+	3.4	0.2	0.6		0.1	0.7	0.1	1.2	4.8	1.8	1.9	14
Lagarosiphon major				4.0												1
Lilaeopsis sp.							+			0.2	0.2					3
Limosella lineata						0.4				0.1	0.8					3
Lythrum portula		0.1														1
Musci (unidentified mosses)	0.7	0.5	1.0	0.5		8.4	2.1	2.0	5.0	1.8		2.4	0.5	+	7.9	13
Myosotis caespitosa		1.3								+		0.5	0.1	+		5
Myriophyllum elatinoides	6.0	1.0	1.4	0.5	4.5		0.5		+	0.6	3.9	2.9	1.4	0.7		12
Myriophyllum votschii		0.9	0.2		0.5									1.4		4
Nasturtium microphyllum		+			0.1											2
Phormium tenax		0.1				+										2
Potamogeton spp.	8.2	3.9	12.8	3.8	1.8		1.1				3.8	1.0	6.0	1.2		10
Pratia angulata			0.3				+					0.5				3
Ranunculus flammula										+						1
Ranunculus fluitans	8.2	3.6	6.4	3.2	8.7		1.8					0.7	0.3			8
Ranunculus repens		0.5														1
Rumex spp.		0.1								0.1		+		0.1		4
Salix fragilis (plant & roots)	10.2	0.1	23.8	7.4	10.1	9.0	12.7		2.0	5.3	25.0	28.3	12.2	4.4	11.6	14
Tetrachondra hamiltonii		+					0.1									2
Tillaea sinclairii	0.1	8.5	0.6	+	+	0.6	2.4		0.1	0.1	+	1.0	+	+		13
Trifolium spp.												+				1
Veronica serpyllifolia		0.1														1
% Zero Cover	16.3	65.6	24.6	45.3	45.7	50.0	66.5	95.5	26.0	38.7	46.3	23.5	57.8	77.6	67.3	
% Semi-aquatic area	34.9	69.8	77.4	55.5	80.4	84.0	76.2	100.0	46.4	23.7	94.6	63.4	80.0	100.0	75.0	
Flow at time of survey (m^3/s)	225	225	225	225	225	225	250	225	225	250	225	250	225	225	225	
Substrate composition																
Clay/Silt (%)	72.9	96.4	98.6	90.8	72.3	4.4	34.4				91.4	93.9	50.0	38.3		
Sand (%)	19.7			9.2	25.9	4.8	47.7	4.1	14.9	12.7	5.4	3.6	50.0	15.3	100.0	
Gravel (%)	0.9	2.5	1.2		1.3	82.8	2.4	48.0	52.4	47.6	2.2			29.7		
Small Cobbles (%)	6.5	1.1	0.2		0.5	8.0	15.5	47.9	32.7	39.7	1.0	2.5		16.7		
Number of taxa found at habitat type	29					24		17			26					

APPENDIX 3C: Percentage cover, and presence and absence of plant species, estimated river flow, proportion of semi-aquatic area and substrate composition at 21 sampling stations grouped according to habitat type on the Lower Clutha River. March 1984.

	BACKWATERS									BRAIDS			SHOULDERS				SILTY BANKS					
	A1	A2	A3	B1	B7	DIU	DID	D2	D4	A1(2)	A5	B2	B3	B6	C2	D3	A6	B4	extra B4(2)	C4	extra C4	No. of sites at
Agrostis stolonifera			0.4	+			0.2	0.1		1.1	0.4						0.2	0.1	1.8	0.1		10
Callitriche petriei	+		4.6	6.9	0.3	1.2	0.4	1.4	0.7			0.4				0.7		3.9		6.8		12
Callitriche stagnalis			0.5						0.1													2
Carex spp.	0.2		3.7	0.8		+	0.2	3.1	+		0.6						0.1					9
Chara sp.		1.8		1.1							1.6	0.3					1.1	0.2	7.9			7
Coprosma propinqua								0.5														1
Cotoneaster simonsii										+												1
Elodea canadensis	16.3	8.7	13.1	14.4	23.5	19.1	39.6	3.2	15.2		2.4	0.2		+			1.7	15.3	0.2			15
Festuca arundinacea	+	+	0.2	0.1	0.4	+	+	0.1	+	2.0	0.2						0.2	+	0.3	0.1	+	16
Filamentous algae (green)	5.9	1.3		0.3	0.6		0.2	1.2	0.8	22.3	2.3	8.4	0.3		4.4	13.9	3.3	2.2	1.9	1.5	1.1	18
Filamentous algae (brown)	0.7	0.6						2.0	0.1	7.5	1.1	6.4			18.2	11.3		1.8		2.6	13.1	12
Glossostigma elatinoides	0.7		2.0	4.2	0.7	0.7	0.4	0.9	0.3		0.6	1.8				0.3		2.9		1.3		13
Hydrocotyle sulcata			0.8	1.4	0.6	0.2	0.1	1.3			0.3	0.1						2.4		1.2	0.2	11
Juncus articulatus	0.2	+	0.9	1.6	0.1	1.6	0.9	36.5	1.5	+	8.5	1.8				0.1	0.2	4.2	3.5	2.0	2.1	18
Lagarosiphon major		0.6	+		11.0	+	4.8				1.4											6
Lilaeopsis sp.		0.1	0.1							2.8	0.3						1.8			0.3		6
Limosella lineata			0.1								0.1						0.2					3
Lotus pedenculatus								0.3														1
Lythrum portula		0.5																				1
Musci (unidentified mosses)	0.5		1.5	1.9	0.1					6.2		4.8	+			0.1		1.9	4.1	0.2	6.2	12
Myosotis caespitosa	+		0.6	0.3	0.1	0.7	0.1	1.6	0.5							0.5		0.1	0.2			11
Myriophyllum elatinoides	8.3	0.2	1.8	1.8	0.8	0.1	3.5	1.0	1.3	0.6	0.5	0.9		+	0.3	0.2	3.8	3.0	0.1	3.9		19
" *votschii*		0.1	0.3																1.4	0.5		4
Nasturtium microphyllum			+					0.1	0.7													3
Phormium tenax						0.3																1
Potamogeton spp.	2.0	0.7	8.7	13.5	4.2	1.6	8.7	0.1	1.2		0.1	0.9		+			2.9	1.5	6.8	2.3		16
Potentilla anserinifolia			+																			1
Pratia angulata			1.8	0.4				0.6		0.6	0.6	0.3				0.1		0.7				8
Pratia perpusilla							0.1															1
Ranunculus flammula								0.2	0.5													2
Ranunculus fluitans	10.9	0.2	11.2	4.7	2.7	7.4	10.2	5.3	4.0		0.8	3.5		+						0.1		13
Ranunculus repens								+														1
Rumex spp.					0.6			0.5			0.1									+		4
Salix fragilis (plant & roots)	22.1	12.6	0.5	25.7	16.8	11.7	6.7	0.9	14.3	21.4		10.3			0.8	6.3	33.2	23.9	20.8	5.2	16.1	18
Tillaea sinclairii	+		13.9	1.1	+	0.5	2.9	2.6	0.6		2.1	0.1				0.2	0.4	1.7	0.3	2.4		15
Trifolium spp.											0.5											1
Typha orientalis							0.2															1
% Zero Cover	32.2	73.1	32.5	19.8	37.7	54.9	20.8	36.4	58.2	35.5	75.5	59.8	99.7	ND	76.3	66.3	50.9	34.2	50.7	69.5	61.2	
% Semi-aquatic area	37.2	57.3	58.5	83.0	54.7	52.6	39.5	67.2	39.3	84.4	84.2	78.3	ND	-	50.0	29.8	76.9	71.9	75.0	96.4	100	
Flow at time of survey (m3/s)	150	150	150	150	150	200	400	200	400	150	150	150	175	175	150	200	150	150	150	150	150	
Substrate composition																						
Clay/Silt (%)	74.7	50.7	69.2	89.8	85.5	82.1	94.2	52.6	89.8	31.5	51.9	43.8	ND	ND	1.8	26.4	57.9	76.0	49.2	36.5	37.5	
Sand (%)	11.8	48.7	10.8	7.7	14.5	17.9	5.8	19.0	8.0	17.4	19.5	36.6			5.9	24.6	38.8	23.4	49.2	30.6	37.5	
Gravel (%)	8.1	0.4	8.1	2.5					2.0	40,3	9.4	0.9			70.4	24.5	0.8			25.2	5.6	
Small Cobbles (%)	5.4	0.2	11.9					28.4	0.2	10.8	19.2	18.7			21.9	24.5	2.5	0.6	1.6	7.7	19.4	
Number of taxa found at habitat type				35							24				14				23			

ND = Not determined.

APPENDIX 4A : Aquatic, Semi-aquatic and Terrestrial Plants Found Growing in the Lower Clutha River

BOTANICAL NAME	COMMON NAME
(a) Aquatic plants	
Chara sp.	
Elodea canadensis	Canadian pond weed
Isoetes alpinus	
Lagarosiphon major	South African oxygen weed
Myriophyllum elatinoides	Water milfoil
Potamogeton cheesemanii	Pond weed
Potamogeton ochreatus	Pond weed
Ranunculus fluitans	Water buttercup
(b) Semi-aquatic plants	
Agrostis stolonifera	Creeping bent
Callitriche petriei	Starwort
Callitriche stagnalis	Starwort
Cardamine debilis	
Carex spp.	
Crepis capillaris	Hawksbeard
Eleocharis acuta	
Epilobium ciliatum	Willow herb
Epilobium nerterioides	
Filamentous algae	
Glossostigma elatinoides	
Glyceria sp.	Floating sweet grass
Hydrocotyle americana	
Hydrocotyle sulcata	
Hypericum japonicum	
Hysela rivalis	
Juncus articulatus	Jointed rush
Lilaeopsis sp.	
Limosella lineata	
Lotus pedenculatus	Lotus
Lythrum portula	
Musci (unidentified mosses)	
Myosotis caespitosa	Water forget-me-not
Myriophyllum votschii	
Nasturtium microphyllum	Water cress
Portula oleracea	
Potentilla anserinifolia	
Pratia angulata	
Pratia perpusilla	
Prunella vulgaris	Selfheal
Ranunculus flammula	
Rumex crispus	Curled dock
Rumex obtusifolius	Broad-leafed dock
Salix fragilis	Crack willow
Tetrachondra hamiltonii	
Tillaea sinclairii	
Typha orientalis	Raupo
Veronica serpyllifolia	Turf speedwell

(c) Terrestrial plants - (may be inundated by changes in river level or course)

Acaena anserinifolia	Bidibid
Cerastium fontanum	Mouse-ear chickweed
Conium maculatum	Hemlock
Coprosma propinqua	
Coriaria sp.	
Cotoneaster simonsii	
Digitalis purpurea	Foxglove
Festuca arundinacea	Tall fescue
Galium sp.	
Gnaphallum limosum	Cudweed
Hebe salicifolia	
Hypericum perforatum	
Phormium tenax	Flax
Plantago lanceolata	
Poa sp.	
Ranunculus repens	Creeping buttercup
Raoulia tenuicaulis	
Rumex acetosella	Sheeps sorrel
Sagina procumbens	Pearlwort
Senecio jacobea	Ragwort
Senecio minimus	Fireweed
Stellaria alsina	Bog stitchwort
Trifolium pratense	Red clover
Trifolium repens	White clover

APPENDIX 4B : Aquatic, Semi-aquatic and Terrestrial Plants Found Growing in Ponds and Tributaries of the Lower Clutha River

BOTANICAL NAME	COMMON NAME
(a) Pinders Pond - Surveyed 12.7.83	
Chara sp.	
Carex spp.	
Elodea canadensis	Canadian pond weed
Filamentous algae	
Glossostigma elatinoides	
Isoetes sp.	
Musci	
Myosotis caespitosa	Water forget-me-not
Potamogeton spp.	Pond weed
Typha orientalis	Raupo
(b) Pond Upstream of Pinders Pond - Surveyed 3.8.83	
Azolia sp.	Water fern
Carex spp.	
Myosotis caespitosa	Water forget-me-not
Nasturtium microphyllum	Water cress
Potamogeton spp.	Pond weed
Typha orientalis	Raupo
(c) Low Burn - Surveyed 21.7.83	
Callitriche petriei	Starwort
Carex spp.	
Elodea canadensis	Canadian pond weed
Filamentous algae	
Glossostigma elatinoides	
Glyceria sp.	Floating sweet grass
Myosotis caespitosa	Water forget-me-not
Myriophyllum elatinoides	Water milfoil
Nasturtium microphyllum	Water cress
Potamogeton sp	Pond weed
Ranunculus fluitans	Water buttercup
Ranunculus repens	Creeping buttercup

(d) Benger Burn

Area surveyed - Fisheries spawning study area

Date surveyed - 6 June 1984

Agrostis stolonifera	Creeping bent
Callitriche petriei	Starwort
Carex spp.	
Cerastium fontanum	Mouse-ear chickweed
Conium maculatum	Hemlock
Digitalis purpurea	Foxglove
Epilobium ciliatum	Willow herb
Epilobium nerterioides	
Festuca sp.	
Filamentous algae (predominantly brown)	
Glyceria sp.	Floating sweet grass
Juncus articulatus	Jointed Rush
Myosotis caespitosa	Water forget-me-not
Nasturtium microphyllum	Water cress
Portula oleracea	
Rumex crispus	Curled dock
Rumex obtusifolius	Broad-leafed dock
Sagina procumbens	Pearlwort
Stellaria alsina	Bog stitchwort
Trifolium repens	White clover
Veronica serpyllifolia	Turf speedwell

(e) Tima Burn

Area surveyed - Fisheries spawning study area

Date surveyed - 6 June 1984

Agrostis stolonifera	Creeping bent
Callitriche petriei	Starwort
Cardamine debilis	
Carex spp.	
Conium maculatum	Hemlock
Festuca sp.	
Filamentous algae	
Glyceria sp.	Floating sweet grass
Hydrocotyle americana	
Hydrocotyle sulcata	
Juncus articulatus	Jointed rush
Musci (unidentified mosses)	
Myosotis caespitosa	Water forget-me-not
Nasturtium microphyllum	Water cress
Poa sp.	
Portula oleracea	
Rumex crispus	Curled dock
Rumex obtusifolius	Broad-leafed dock
Stellaria alsina	Bog stitchwort
Trifolium repens	White clover

No aquatic macrophytes were observed at either of these sites.

(f) Carsons Stream

Area surveyed - Fisheries spawning study area

Date surveyed - 5 June 1984

Acaena anserinifolia	Bidibid
Carex coriacea	
Cerastium fontanum	Mouse-ear chickweed
Coriaria sp.	
Digitalis purpurea	Foxglove
Epilobium ciliatum	Willow herb
Festuca sp.	Fescue
Filamentous algae	
Glyceria sp.	Floating sweet grass
Juncus articulatus	Jointed rush
Musci (unidentified mosses)	
Nasturtium microphyllum	Water cress
Prunella vulgaris	Selfheal
Ranunculus repens	Creeping buttercup
Rumex acetosella	Sheeps sorrel
Rumex crispus	Curled dock
Rumex obtusifolius	Broad-leafed dock
Senecio jacobea	Ragwort
Senecio minimus	Fireweed
Stellaria alsina	Bog stitchwort
Trifolium repens	White clover
Veronica serpyllifolia	Turf speedwell

No aquatic macrophytes were observed at this site.

APPENDIX 5a : The arithmetic mean number/m², presence or absence, and mean biomass/m² of invertebrate taxa at 27 sampling stations grouped according to habitat type on the Lower Clutha River. July 1983.

TAXA	BACKWATERS									BRAIDS		
	A1	A2	A3	B1	B7	D1U	D1D	D2	D4	A1(1)	A5	B2
MOLLUSCA												
Potamopyrgus antipodarum	2451	23067	12475	53572	64516	36586	51327	9675	433	2800	4149	956
Physa acuta		688	1171	658	6365	611	2291	560	+	127	51	
Gyraulus corinna			9344				306	25			25	
Lymnaea tomentosa							25	+			10	
Sphaeriidae		433	1757	2760	19401	11813	16778	1400	815		51	161
INSECTA												
MEGALOPTERA												
Archichauliodes diversus												
ODONATA												
Xanthocnemis zealandica		25	+			25	127					
EPHEMEROPTERA												
Coloburiscus humeralis												
Nesameletus sp.											51	
Deleatidium sp.											25	2
PLECOPTERA												
Zelandobius furcillatus								+	+		232	
Stenoperla sp.												
Austroperla cyrene												
TRICHOPTERA												
Aoteapsyche colonica						25						
Oxyethira albiceps	318	76	76	212	25	25	51	25		32		
Paroxyethira hendersoni			+	276							25	
Psilochorema sp.												
Hudsonema aliena								+				
Pycnocentrodes sp.								+				6
Beraeoptera roria												
Hydrobiosis sp.												2
Olinga feredayi						+		+				
Pycnocentria evecta						+		+				
COLEOPTERA												
Hydraenidae												
Staphylinidae											+	
Helodidae												
Berosus sp.												
Hydrophilidae larva											3	
Elmidae												2
DIPTERA												
Tipulidae			+									
Limonia nigrescens											3	
Aphrophilia neozelandica												
Eriopterini												
Psychodidae												
Macropelopiini								153				
Maoridiamesa spp.										5		
Lobodiamesa sp.												
Chironomus "sp.a."					25		2291	51				
Tanytarsus vespertinus				21				+			51	2
Harrisius pallidus		+										
Polypedilum					+							
Podonominae			+									
Orthocladiinae								+		5	80	
Empididae										5		
Tanyderidae											25	
Muscidae												
CRUSTACEA												
Herpetocypris pascheri			+		+							
Paracalliope fluviatilis												2
ARACHNIDA												
Piona sp.												
ANNELIDA												
Oligochaeta	+	+	+		+	+	+	+	+	+	+	+
NEMATODA							153				3	
Mean total no. of invertebrates/m² at sampling station	2769	24289	24823	57499	90332	49085	73349	11889	1248	2981	4748	1133
Number of taxa at sampling station	3	7	11	6	8	9	10	16	5	7	17	9
INVERTEBRATE BIOMASS DATA												
Dry weight Mollusca g/m² gravel-cobble substrate										0.23	0.38	1.66
Dry weight Insecta g/m² gravel-cobble substrate										0.07	0.34	0.01
Dry weight Mollusca g/m² silt-sand substrate	6.57	13.04	26.46	27.28	62.70	55.65		10.25	0.29			6.20
Dry weight Insecta g/m² silt-sand substrate	0.17	0.07	0.15	0.07	0.06	11.58		0.29	0.32			0.03

CC = Carsons Creek
BB = Blackcleugh Burn - no quantitative samples were taken from these two sites

ND = Not determined

SHOULDERS						SILTY BANKS			BEDROCK		TRIBUTARIES				No. of Sites at which taxa found
B3	B6	C2	C3	D3	D6	A6	B4	C4	A7	C5	B5	D5	CC	BB	
109	5014	176	3606	156	3	85	10248	3110	1072	223	220	26	+		26
	6		3	4			96					+			15
			6	+							108				7
	29								+						5
	127			3	4		1369	200			4	+			17
											8				1
															4
			+										+		2
											8				2
3		3		4	6					3	324	10			9
5	265	499	173	108	10		+		344	32					12
											4				1
													+		1
	3	22	3	4					+	13					7
	+		+				32	+	24						14
							32								4
											4				1
															1
+		10	141	252				+	80	22		+		+	11
				+											1
													+		2
				+							24	3		+	6
			+	112				+			4			+	7
													+		1
															1
											+				1
											4				1
												3	+		3
		13		8					+	+	4	3			7
	+														2
											+				2
		6	+	20						19					4
											+				1
														+	1
												3			2
2		10	+	+	10				+	22	4				9
									8						1
	681														4
5	10	166	+	36	16		64			6					12
			+	+				+	+						5
											+	+			3
															1
5	45	154		124	29		32		248	19	40			+	13
	3	3	3	+					66						6
				4							4				3
				+								+			2
				+											3
							32					+			3
	+								32						2
+	+	+		+		+	+	+	+	+	+	+			22
															2
129	6183	1062	3944	840	74	85	11905	3310	1874	359	764	61			
8	14	12	14	22	7	2	10	7	14	11	20	13	6	5	
0.33	3.21	0.31	1.76	1.91	0.02				1.12	0.33	0.78	0.05	0.18	ND	
0.01	0.17	0.06		0.12	0.03				0.04	0.13	0.55	0.17	0.05	ND	
	6.79		0.53			0.51	27.50	2.20		2.31					
	1.38					0.38	0.04	0.22							

APPENDIX 5b: The arithmetic mean number/m², presence or absence and mean biomass/m² of invertebrate taxa at 31 sampling stations grouped according to habitat type in the Lower Clutha River. March 1984. (BB = Blackcleugh Burn, CS = Carsons Stream, CaS = Canadian Stream, TR = Teviot River, TB = Talla Burn, BeB = Benger Burn, BJC = Black Jacks Creek)

	BACKWATERS									BRAIDS			SHOULDERS				BED
	A1	A2	A3	B1	B7	D1U	D1S	D2	D4	A1(1)	A5	B2	B3	B6	C2	D3	A7
MOLLUSCA																	
Potamopyrgus antipodarum	8484	3937	584	15596	13970	1194	2515	9906	3277	859	1287	1072	26	2137	298	70	3578
Physa acuta		+		686	+			686			3						
Gyraulus corinna			889	25		51						4					
Sphaeriidae		1143	127	1219	1828	737	178	381	991			110					
INSECTA																	
Lepidoptera																	
Nymphula nitens																	
Megaloptera																	
Archichauliodes diversus																	
Ephemeroptera																	
Coloburiscus humeralis																	
Nesameletus sp.																	
Deleatidium sp.										5	25						
Rallidens mcfarlanei																	
Ameletopsis perscitus																	
Plecoptera																	
Zelandobius furcillatus										5	3			25			
Stenoperla sp.																	
Trichoptera																	
Hydropsychidae																	
Aoteapsyche colonica							25								6	3	58
Aoteapsyche tepoka								25					3		26	16	
Hydroptilidae																	
Oxyethira albiceps		102		51	25	25	+	25	25	181	48	2		6	3		32
Paroxyethira hendersoni					51			25			3						
Rhyacophilidae																	3
Psilochorema sp.																	
Costachorema sp.																	
Neurochorema sp.																	
Tiphobiosis sp.																	
Polycentropodidae																	
Polyplectropus sp.																	
Helicopsychidae																	
Helicopsyche sp.																	
Conoesucidae																	
Pycnocentrodes sp.										85		2	3		13		70
Beraeoptera roria																	
Confluens sp.																	
Hydrobiosis sp.																	
Olinga feredayi								+									
Pycnocentria evecta										21							3
Coleoptera																	
Hydraenidae																	
Helodidae				25													
Hydrophilidae												2					
unidentified larva																	
Elmidae										27					16		
Diptera																	
Tipulidae																	
Limonia nigrescens																	
Aphrophila neozelanica																	
Eriopterini																	
Chironomidae	+								+	27	+						
Tanypodinae																	
Macropelopiini																	
Diamesinae																	
Maoridiamesa spp.										16			35		3	3	26
Lobodiamesa sp.	+																
Chironominae															6		
Chironomus sp.				51		76		25									
Tanytarsus vespertinus										3			38				
Harrisius pallidus								+				+					+
Paucispinigera approximata																	
Polypedilum sp.																	
Orthocladiinae								+		3	+		10				3
Tabanidae	+																
Ceratopogonidae																3	+
Empididae											3		10		3	3	3
Tanyderidae																	
Muscidae																	
Simuliidae																	
Austrosimulium sp.																	
CRUSTACEA																	
Amphipoda										5							
Paracalliope fluviatilis																	
Isopoda															+		
ARACHNIDA																	
Hydrachnidae																	
Pionidae																	
Piona sp.																	
ANNELIDA																	
Oligochaeta (several types)	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	
Number of taxa at sampling station	5	5	3	8	6	6	5	11	5	13	10	8	8	4	11	7	11
Mean total number of invertebrates/m² at sampling station	8484	5182	1600	17654	15823	2083	2743	11048	4293	1237	1332	1188	125	2168	374	98	4016
<u>INVERTEBRATE BIOMASS DATA</u> Dry weight Mollusca g/m² gravel-cobble substrates										3.14	5.37	1.59	0.05	0.80	0.81	0.29	7.31
Dry weight Insecta g/m² gravel-cobble substrates										0.09	0.04	4.35	0.02	0.09	0.02	0.04	0.22
Dry weight Mollusca g/m² silt-sand substrates	29.00	7.85	25.76	25.70	54.55	0.44	4.95	13.73	4.40		4.24	0.13		7.54			
Dry weight Insecta g/m² silt-sand substrates		0.40		0.39	0.20	0.08	0.16	0.09	0.07		0.19			0.17			

ROCK SILTY BANKS TRIBUTARIES

C5	A6	B4	C4	B5	D5	BB	CS	CaS	TR	TB	TiB	BeB	BJC	No. of Sites at which Taxa Found
29	2921	7910	1118	6	234		37	411	565	11	48	608		29
					•									6
		•										16		6
		18	102		•									12
					3									1
				6			32	43		21	5			5
						5	27					5		3
										21	11			2
				13	9	43	485	347	16	331	581	53	43	12
						5								1
						5								1
3				6			27	11						7
							5	21						2
								5						1
		18					507	267	5	48	21	43	5	12
					•					16	5			7
		56	51		3				32		43	43		19
														3
											11	5		3
							5	27	11	11	96	32	43	7
						11	5				5		21	4
											16			1
							5	5			11	5		4
				•	•									2
			51					1365						2
6							80							7
							5	298						2
13								32						2
							11	21		5	32	48	32	6
				•	3	32	224	234		16	5	11		9
					10		21	11	11		21	32		8
							139	43						2
					35									2
														1
				3	10		69	101		21	80	477		9
		•				5				5				3
				16										1
3								11						2
							43					16		2
													299	5
				3	•						5	5		4
48				3			69	133	21	21	229	21	75	14
														1
													4	2
														3
3	•								32		512	128	43	8
														3
				•										1
				•							59		5	3
19	•			6		5	59	32	32	75	213	144	80	16
														1
	25	•									5			5
3							21				53		11	9
							5							1
					3									1
							21	21					5	3
					•									1
											5			2
					•									1
	3				•		5			5				5
										5				1
	3							5						2
•		•	•		•				•		•	•		22
10	6	8	5	13	18	8	24	22	10	15	25	19	13	
133	2946	7982	1322	62	320	111	1917	3444	757	612	2072	1692	626	
0.36				1.76	1.22	0.07	0.37	5.46	1.95	0.06	0.09	1.51		
0.01				0.04	0.38	0.06	0.55	4.91	0.05	0.80	0.77	0.19	0.14	
	7.26	9.15	3.99											
	0.09	0.16	0.63											

APPENDIX 6: Checklist of major changes in the physical environment, and periphyton, macrophyte and invertebrate communities that have been reported for upstream reaches following river impoundment.

The potential for these changes occurring in the Lower Clutha River is also noted. Only one reference is given for each change, although some have been reported frequently in the literature.

Potential Ecosystem Change	Reference	Possible in LCR
1 Physical Factors		
- reduction in velocity of water and thus an increase in residence time of water in the system	Young *et al.*, 1972	Yes
- flow through rate of water may greatly affect the reservoir's limnology	Young *et al.*, 1972	Yes
- little flow or circulation may occur in sheltered embayments, stagnant areas can develop	Young *et al.*, 1972	Yes
- increased clarity may occur down lake due to settling out of suspended solids	Shand and Biggs, MWD, unpublished data	No
- reduction in clarity may occur due to increased phytoplankton biomass	Young *et al.*, 1972	No
- increased summer water temperature may occur down a series of impoundments due to increased residence time	Young *et al.*, 1972	?
- thermal stratification of reservoirs may occur where residence times are long	Young *et al.*, 1972	No
- if thermal stratification occurs, hypolimnetic deoxygenation is possible, particularly for periods after reservoir filling, due to organic matter from terrestrial plants	Heckey *et al.*, 1984	No
- localised deoxygenation may occur in sheltered embayments and/or near sediment/water interface for a short period after reservoir filling due to organic matter from terrestrial plants	Heckey *et al.*, 1984	Yes

Potential Ecosystem Change	Reference	Possible in LCR
- intensive shoreline erosion may cause high turbidity in some areas	Heckey *et al.*, 1984	Yes
- major changes in reservoir water levels may resuspend and redistribute bed and bank sediment	Sale, 1982	Yes
- major deposition of silt can occur in the littoral regions, particularly during flood flows	Jowett and Hicks, 1980	Yes
2 Periphyton		
- density of periphyton will probably decrease, relative to the original river, and be a minor contributor to primary production	Bowker and Denny, 1978	Yes
- the abundance of rheophilic taxa will greatly decrease and some may only survive in the wash zone if reservoir levels are stable	Levadnaya and Kuz'mina, 1974	Yes
- luxuriant growths of filamentous taxa may occur in sheltered shallows (<2m deep) during first few years due to leaching of nutrients from soil	Levadnaya and Kuz'mina, 1974	Yes
- diatom communities may develop on plant residues and mud in deeper water	Levadnaya and Kuz'mina, 1974	Yes
- longer term filamentous proliferations may develop in sheltered embayments if localised enrichment occurs (e.g., from septic tanks)	Young *et al.*, 1972	Yes
- transient substrates in reservoir, such as macrophytes and silts, will be colonised by taxa that are capable of rapid colonisation (e.g., species of diatoms such as *Achnanthes*, *Nitzschia*, *Synedra* and *Navicula*)	Bowker and Denny, 1978	Yes
- development of periphyton may be poor where there is continuous deposition of new sediments (i.e. siltation)	Hodgkiss and Tai, 1976	Yes
- areas of shallow water exposed to a long fetch may not developed substantial communities	Levadnaya and Kuz'mina, 1974	Yes

Potential Ecosystem Change	Reference	Possible in LCR
- chemical differences between inflow waters and lake waters may cause differences in community composition down the reservoir	Denny *et al.*, 1978	No
- changes in water level may preclude substantial community development in the upper littoral	Claflin, 1968	Yes
3 Macrophytes		
- reduction in water velocities after flooding may allow colonisation of aquatic macrophytes, if water clarity and substrates are suitable	Brocksen *et al.*, 1982	Yes
- colonisation and expansion may take a period of several years	Shand and Biggs, MWD, unpublished data	Yes
- given suitable conditions weed species may proliferate and considerably reduce the amount of free-flowing water if the reservoir is shallow	Chapman, 1970	Yes
- sheltered embayments may contain particularly prolific macrophyte developments	Young *et al.*, 1972	Yes
- macrophyte developments could become major habitats for invertebrates	Biggs and Malthus, 1982	Yes
- large fluctuations in reservoir levels could severely restrict development of littoral communities	Hynes, 1961	Yes
- minor fluctuations in reservoir levels may allow development of "tidal" semi-aquatic and low-mound communities in sheltered and shallow areas	Shand and Biggs, MWD, unpublished data	Yes
- increased turbidity due to shoreline erosion may retard macrophyte development	Heckey *et al.*, 1984	Yes
- the extent of the littoral that is colonised down the reservoir may be affected by gradations in clarity	Shand and Biggs, MWD unpublished data	Yes

Potential Ecosystem Change	Reference	Possible in LCR
4 Invertebrates		
- reduction in water velocities following flooding may cause a major reduction in the abundance of rheophilic taxa and an increase in lentic fauna. Organisms such as Ephemeroptera, Trichoptera and Plecoptera are detrimentally affected. Most of original fauna may perish	Sprules, 1940	Yes
- dramatic reduction in standing crop and diversity immediately following flooding compared with previous riverine communities	Brocksen *et al.*, 1982	Yes
- a proliferation of chironomids and/or oligochaetes may occur in the first few years after filling due to an abundance of food from drowned vegetation. These organisms may survive oxygen depletion at the bottom	Aggus, 1971	Yes
- emergent chironomids may become a severe nuisance in localised areas	Aggus, 1971	Yes
- standing crop of invaders eventually declines	Baxter, 1977	Yes
- longer term succession of chironomids, oligochaetes and molluscs	Kerzyzanek, 1970	Yes
- extent of macrophyte development may influence distribution of the different populations	Shand and Biggs, MWD, unpublished data	Yes
- shoreline erosion may cause a reduction in crop and diversity of invertebrates	Aggus, 1971	Yes
- longitudinal variation in sediment dwelling benthos may occur with the largest populations found in the upper end, where rich organic matter may get deposited	Nursall, 1952	No
- large water level fluctuations may cause a low diversity and standing crop of invertebrates in the littoral	Hynes, 1961	Yes

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Appendix 7: Summary of Methods for the Control of Aquatic Weeds in Reservoirs

(after Biggs, 1981 and Johnstone, 1982).

CONTROL METHOD	DISADVANTAGES
Lake drawdown	- Must be carried out annually; - Expensive because of loss of power generation - Causes loss of water for irrigation schemes - Detrimental effects on invertebrate communities and therefore fisheries - Not always effective, in that *Lagarosiphon* can remain viable even after drawdown is used in conjunction with herbicide spraying (control attempted in Lake Roxburgh) - If not removed, dessicated weed decomposes leading to the release of nutrients and de-oxygenation of water, thereby resulting in possible enhanced growth of algae - May favour survival of undesirable plants
Reduction of nutrients	- *Lagarosiphon* grows vigorously in oligotrophic water with the potential for displacing native macrophytes under these conditions - Reducing nutrient concentrations in water causes reduction in phytoplankton numbers, thereby increasing light penetration and therefore macrophyte growth; - Only viable in small lakes with high water retention times.

CONTROL METHOD	DISADVANTAGES
Light restriction by:	
(a) Lake deepening	- Only practical before formation of impoundment
(b) Floating and submerged light screens	- Impractical in lakes with large fluctuations in water level as a result of light being diffracted under screens - Difficult to erect screens - Useful for small areas only - Detrimental to fish and invertebrate populations
(c) Addition of particulates or dyes	- Only applicable to small lakes with long replacement times
Substrate covering with solid materials	- Only possible in small areas with minimal silt deposition - Detrimental to benthic invertebrate populations
Competition from:	
(a) Desirable aquatic plants	- Competitive interactions between aquatic plants poorly understood
(b) Marginal vegetation (shading effect)	- Not applicable to hydrolakes, as aquatic vegetation normally extends beyond shaded area
Predation by grass carp (*Ctenopharynogodon idella)*	- Fish show marked preferences for different weeds; many of the undesirable weeds are eaten only by large fish - Fish eat less at low temperatures, hence in cold southern hydrolakes in New Zealand feeding could cease altogether for several months of the year.

CONTROL METHOD	DISADVANTAGES
	- Fish do not breed readily under New Zealand conditions, therefore importation of stock is necessary (bringing the risk of introducing undesirable parasites or diseases)
Mechanical weeding	- Weed beds may be growing in deep water beyond the operational range of the harvesters - Breaks plants, thereby promoting vegetative spread; the roots that remain are capable of regrowth - Need for disposal of harvested weed
Manual weeding	- Expensive because it requires trained and diligent scuba divers - Useful only in small intensively used areas, although containment of weed in a large area is possible
Herbicidal control (Diquat spraying)	- Possible harmful effects to humans, fish, invertebrates, algae and stock, as the long-term effects of the residue and breakdown products of the herbicide are unknown - Applicable only to containment of lake weed; eradication of large weed beds is not feasible - Decomposing plants must be removed to prevent nutrient release and de-oxygenation of water - Moderately expensive, especially when "sticky" herbicides are applied by divers

CONTROL METHOD	DISADVANTAGES
Quarantine measures to prevent introduction of exotic macrophytes into uninfested lakes	- Although there are no disadvantages, the difficulty of promoting widespread public education and concern about lake weed must be recognised - The random spread of lake weed fragments from one water body to another by waterfowl is another uncontrollable but important management problem
Groynes to deflect flows and waves to reduce creation of flotsam by sloughing, effectively creates productive backwater type areas	- May restrict storage capacity - May restrict navigation by boats

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