IMPACT OF SLIP SEDIMENT ON THE BIOTA IN A NEW ZEALAND ALPINE STREAM

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IMPACT OF SLIP SEDIMENT ON THE BIOTA IN A NEW ZEALAND ALPINE RIVER

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EXECUTIVE SUMMARY

Introduction

Following an earthquake on 18 June 1994, a large slip occurred on 22-23 June and partially blocked the Bealey River in Arthur's Pass National Park, South Island, New Zealand. This alpine river is in the high rainfall area of the Southern Alps, and the slip introduced a large quantity of silt and terrestrial organic matter into its water course.

The effects of this slip, and in particular the effects of increased sediment loads, on the river's biota were monitored to assess likely effects of proposed road construction works in the Arthur's Pass area.

Some 30 hours after the slip occurred, an initial set of biological samples was taken from five sites, two (acting as control sites) above and three (impacted sites) below the slip. Sampling was repeated seven times.

Natural Substrate Sampling

Organic matter inputs into the river were considerably higher below the slip, but periphyton biomass was similar at all sites.

Periphyton biomass on natural substrates below the slip showed marked reductions over time, presumably caused by increased abrasion from sediments washed into the river during rainfall events. Periphyton biomass on natural substrates was suppressed below the slip for up to 7 weeks, after which it appeared to recover.

Artificial Substrate Sampling

Artificial substrates were placed at the study sites for a 40-day incubation period. Heavy rain halfway through this time washed more fine sediment from the slip into the river. Artificial substrates placed below the slip trapped more sediment, and supported younger algal communities than those placed above the slip. This difference suggested that fine sediments had removed older algal material from the artificial substrates.

Effects of Slip Sediment

Invertebrate communities appeared to have recovered only 3 weeks after the slip, but periphyton communities took 7 weeks to recover. This difference suggests that suspended sediments had a longer term effect on periphyton than on the more mobile invertebrates.

Overall effects of the slip appeared short-lived, and were reduced by the frequent high rainfall and floods typical of the area. The slip debris was finally washed away by a flood some 90 days after the debris had been deposited. This flood, however, was not unusually large and had a return interval of less than one year.

The Bealey River seems to be strongly controlled by physical processes associated with flooding, and the biota has adapted to this. Impacts of increased sedimentation appear to be short lived and are unlikely to disrupt the ecosystem very much. Other rivers of a similar, or greater, size that drain catchments in high rainfall areas like the Southern Alps, are likely to show similar reactions to physical processes.

Effects of Road Works

Proposed road works alongside the Bealey River are expected to increase sediment inputs during and following the works, and have the potential to affect aquatic biota. These impacts, however, are greatly reduced by the frequent rainfall and associated flood events which will minimise significant accumulations of fine sediments in the river.

Current road construction practices in Arthur's Pass National Park often involve dumping roadside gravels directly into the rivers. Again, dumping is unlikely to have any long-term effects on river ecosystems, as long as such dumping is occasional and carefully sited so that it does not interfere with river flows. Care is needed that suitable dumping sites are chosen as trees in riparian areas are damaged by this activity, leading to long-term instability of these areas.

Recommendations

- Research is needed to provide quantitative relationships between suspended sediment levels and in-stream biota. This needs to be done for a variety of different locations, as not all rivers will respond to sediments in a consistent manner.

- Such research will allow further monitoring of road construction activities to be made by measuring turbidity levels alone, and ensuring that they remain below established critical values where biological effects become apparent. Monitoring of turbidity would also be cheaper than conducting more labour-intensive biological monitoring programmes.

- Further research about road construction techniques, possibly using filter fabrics, is needed so that the amount of sediment entering streams during road construction is reduced.

ABSTRACT

Following an earthquake on 18 June 1994, a large slip partially blocked the Bealey River in Arthur's Pass National Park, South Island, New Zealand, and introduced a large quantity of silt and terrestrial organic matter into the river. The effects of this slip, and in particular the effects of increased sediment loads, on the biota of the river were monitored to assess likely effects of proposed road construction works in the area.

Impacts of the increased sedimentation appear to be short lived and unlikely to disrupt the ecosystem very much. Other rivers of a similar, or greater, size that drain catchments in high rainfall areas like the Southern Alps, are likely to show similar reactions to natural sedimentation episodes.

Proposed road works alongside the Bealey River are expected to increase sediment inputs, and have the potential to affect aquatic biota. These impacts, however, are greatly reduced by the frequent rainfall and associated flood events which quickly remove silt from the river, and thus minimise the build-up of fine sediments.

1. INTRODUCTION

1.1 Physical Setting

High flows in rivers have a profound impact on aquatic ecosystems, and regulate both algal biomass (Biggs & Close 1989, Biggs & Gerbeaux 1993, Biggs 1995, for example) and invertebrate density and species composition (Scrimgeour & Winterbourn 1989, Scarsbrook & Townsend 1993, for example).

In many rivers, high flows are associated with an increase in sediment load (Duncan 1987, Hicks & Griffiths 1992), especially during the rising stage of the flood. This increase in sediment has profound effects on river biota. Sediment increases turbidity and reduces light penetration into the water column by increasing the scatter of light (Kirk 1985, Van Nieuwenhuyse & LaPerriere 1986, Davies-Colley et al. 1992). Reduced light levels lower photosynthesis and productivity in the benthic zone (Lloyd et al. 1987, Davies-Colley et al. 1992), and reduces food quality (Sloane-Richey et al. 1981, Graham 1990, Ryder 1989). Interstitial spaces in coarser substrates are often filled with fine sediments (Ryder 1989, 1991), which may lead to a reduction in water circulation through the subsurface gravels, lowering oxygen levels in the sediments (Bjerklie & LaPerriere 1985, Ryan 1991).

High silt loads are also responsible for physical abrasion of periphyton communities (e.g. Biggs 1995) which reduces their biomass.

Invertebrate biomass and abundance are often reduced with sedimentation (Quinn et al. 1992, Culp et al. 1986, Wagener & LaPerriere 1985), although Soroka & McKenzie-Grieve (1983) and Hellawell (1986) found that sedimentation caused a change in only invertebrate species composition.

Fish densities are often reduced following sedimentation episodes (Barton 1977, Alabaster & Lloyd 1982, for example).

1.2 New Zealand Setting

Rivers in New Zealand are often highly dynamic environments, characterised by unpredictable high flows interspersed with periods of baseflow.

Sediment levels in many New Zealand rivers are naturally high, because of the combination of high rainfall, mountainous terrain and relatively youthful land forms on easily eroded rocks. The Southern Alps in particular have high sediment yields of c.1000 tonnes per km^2 per year (Duncan 1987), although watersheds such as those of the Hokitika and Haast Rivers have much higher yields of c.8000 t per km^2 per year (Jones & Howie 1970).

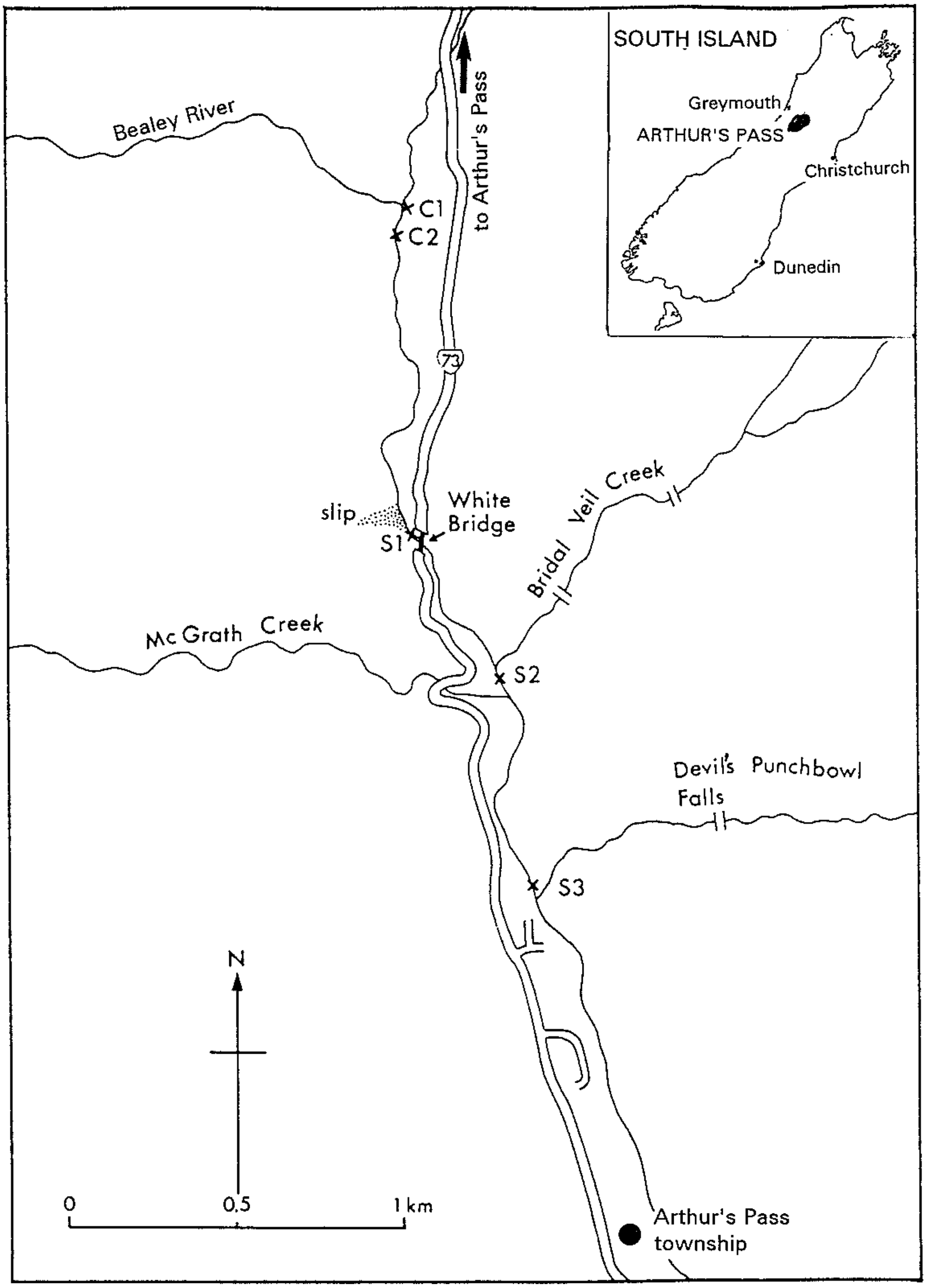

Figure 1.1 Bealey River. Arthur's Pass National Park, and location of the slip just upstream from the White Bridge. Two control sites (C1, C2) were upstream of the slip, near the Bealey Chasm, and three impacted sites (S1, S2, S3) were at increasing distances (10 m, 550 m, and 1.2 km) below the slip.

Sediment often originates from anthropogenic activities such as forestry and agriculture, gold mining, or road construction, and occurs irrespective of high flow events. While activities such as forestry and agriculture result in high sediment inputs to rivers only during rainy weather (Duncan 1987, Doeg & Koehn 1990, for example), sediment from alluvial gold mining and road construction can occur irrespective of river flow. These activities create an unnatural situation because flows are low and dilution is minimal, and mixing of sediments will not occur as easily as during high flow. As well, suspended sediments settle more quickly during low flow when they are more likely to smother biota.

Investigations of the impacts of anthropogenic sediment in New Zealand rivers are limited, and restricted to studies on the effect of placer gold mining (Davies-Colley et al. 1992, Quinn et al. 1992), logging (Graynoth 1979, Rounick & Winterbourn 1982, Winterbourn & Rounick 1985, Winterbourn 1986), and some non-point source sedimentation resulting from changes in land use (Quinn & Hickey 1990, Williamson et al. 1992, Smith et al. 1993).

1.3 Reasons for Study

Road works proposed for State Highway 73 (between Christchurch and Greymouth, New Zealand), alongside the Otira and Bealey Rivers, have the potential to produce significant sediment that will wash into these rivers, and so adversely affect the river biota. The need to minimise adverse biological impacts from the road works has long been acknowledged in the planning procedure (Ministry of Works & Development (MWD) 1987a,b, 1991) as these rivers are not only of great scenic value, but the Otira River also supports significant numbers of the endangered Blue Duck (*Hymenolaimus malacorhynchus*).

Assessments of the ecological impacts of road construction on stream biota in New Zealand are, however, lacking, and only a few international studies have been published (Barton 1977, Tsui & McCart 1981, Cline et al. 1982). These studies have reported a marked increase in suspended sediment yield associated with construction activities, and a subsequent decrease in invertebrate density (Tsui & McCart 1981, Cline et al. 1982), or a change in invertebrate community structure (Barton 1977). Algal biomass (Cline et al. 1982) and fish density (Barton 1977) were also reduced below road construction sites.

1.4 This Study

On 18 June 1994, an earthquake of 6.5 magnitude on the Richter Scale occurred, that was centred near Arthur's Pass. Heavy rain followed the earthquake and caused a number of large slips that partially blocked the Otira and Bealey Rivers. The slip into the mid-reaches of the Bealey River (Figure 1.1) happened during the night of 22-23

June (and was first noticed on the morning of 23 June by road workers in the area, Mark Davies, Department of Conservation, Arthur's Pass National Park, pers.comm.). This natural point-source sedimentation episode thus presented a unique opportunity to study the ecological effects of sudden sediment inputs into a river, similar to those which could occur as a result of road construction works.

A study was commenced soon after the slip occurred to ascertain the effects of this natural slip, and the associated increased sediment inputs, on the ecology of the Bealey River. Baseline data obtained from the study was used to assess the impact of different sedimentation levels on pristine rivers in the Southern Alps of New Zealand.

The results of this study of a natural sedimentation episode contributed to biological monitoring work in progress (in 1994-95) in the Otira and Bealey Rivers as part of road works in Arthur's Pass National Park. They will be used to evaluate the ecological effects of possible sedimentation episodes that could be caused by proposed road works in the Park.

2. STUDY SITES

The study was conducted in the mid reaches of the Bealey River, some 3 km downstream from its headwaters on Mt Rolleston. The slip was approximately 150 m upstream of the White Bridge, 2.2 km west of Arthur's Pass Village, and it had almost completely blocked the Bealey River, creating a lake c.5 m deep, 200–300 m long.

Control Sites

Two control sites were chosen about 1 km above the slip, well above possible slip effects. They were located upstream from the small foot bridge that crosses the Bealey River above the Bealey Chasm. The upper control site (C1) was located 20 m below the confluence with Twin Creek in a short riffle section between turbulent chutes and short falls. The lower control site (C2) was 100 m below the C1 site, in a wider riffle area just above waterfalls. Substrate composition of these sites was assessed. by Wolman sampling of 120 randomly selected particles of bed sediment. Substrates at these sites were dominantly boulders and large cobbles (Figure 2.1).

Impacted Sites

Site S1, situated 10 m below the downstream side of the slip in a shallow riffle section, was the first impacted sampling site. Much of the substrate here had obviously been brought down from the slip because it had jagged edges. Although the percentage of boulders was still high at this site, the percentage of cobbles was higher than at the control sites (Figure 2.1).

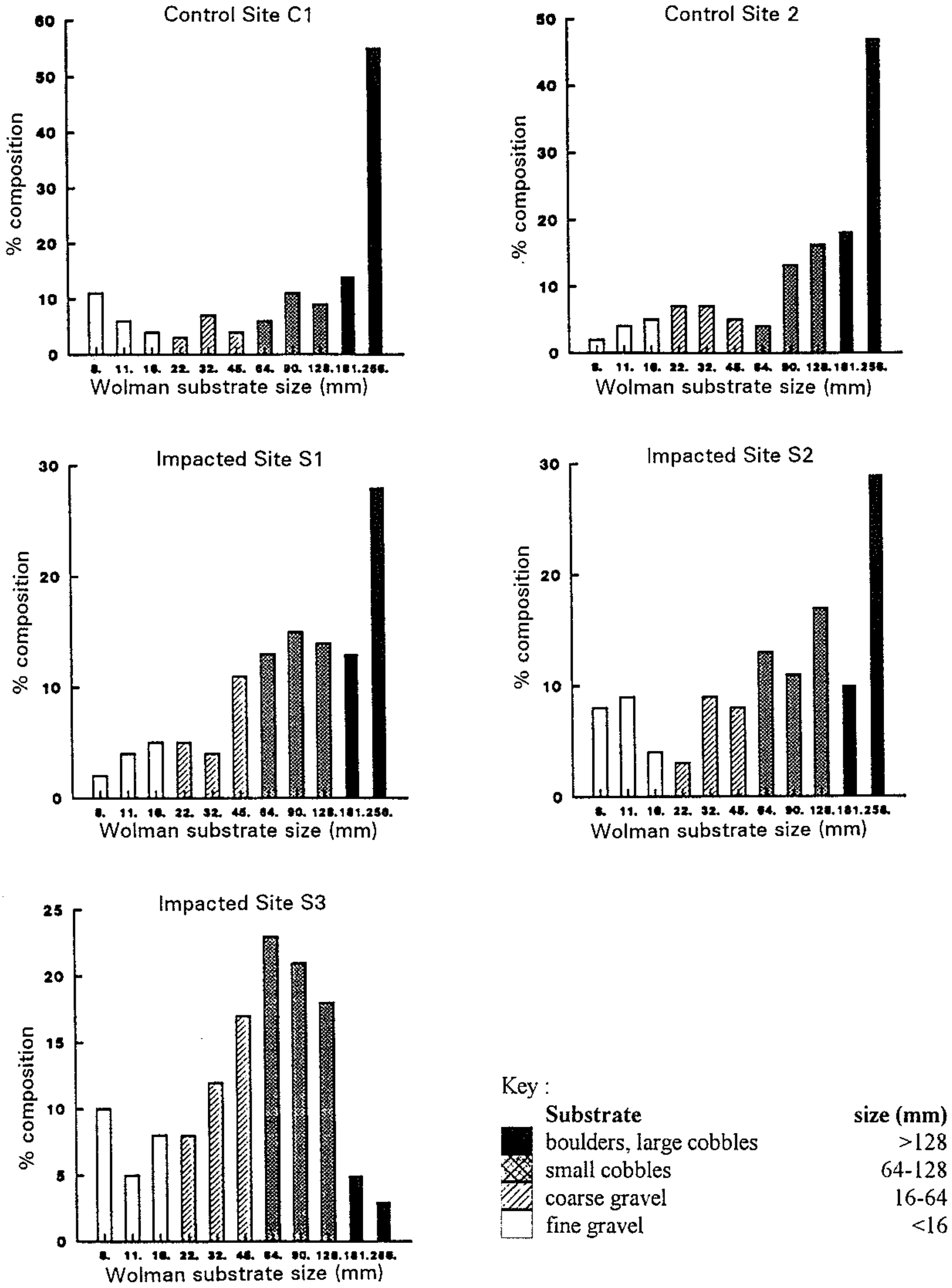

Figure 2.1 Results of Wolman sampling showing substrate composition (% boulders, cobbles, gravel) from the five study sites, based on the collection of 120 randomly selected substrate materials.
(Note changes in scales of % composition.)

Site S2 was 550 m downstream of the slip (Figure 1.1) in a riffle-run section. The particle size distribution at Site S2 was similar to that at Site S1, and consisted of a mixture of boulders and cobbles (Figure 2.1).

The lowest impacted site (S3) was located in the Bealey River 1.2 km below the slip, some 50 m upstream of its confluence with Punchbowl Creek, and about 1 km upstream of Arthur's Pass Village (Figure 1.1). Here the Bealey was very open and flowed along a wide (c.50 m) flood plain. Substrate material at this lowest site was dominated by cobbles, and boulders were rare (Figure 2.1).

3. METHODS

3.1 Timing of Sampling

The first sampling trip was made some 30 h after the slip had occurred (i.e. on 24 June 1994). The exposed face of the slip was covered with fine soil and clay (Figure 3.1). These fine sediments were continually being washed into the Bealey River and transported downstream every time it rained. While much of this sediment remained in suspension and was carried away, some settled out at the river margins and in slow flowing eddies behind boulders.

The sampling programme was planned to assess the effect the slip had on the river, and on its biota, so it was conducted at regular intervals, and after rainfall events when new material would have been washed into the river. The inputs of sediment were expected to be highest during the early phase of the study, with less new sediment being introduced with increasing time since the slip. Therefore, sampling trips were planned weekly for the first month (June-July 1994) following the slip, and then at monthly intervals (Table 3.1). The exact timing and duration of sampling trips was, however, determined largely by the flow of the Bealey, because sampling could not be conducted at times of high flow. Biological sampling for invertebrates and periphyton continued until such time that no statistical differences could be detected between these variables at sites above and below the slip.

Table 3.1 Sampling programme for the five study sites on the Bealey River.

Trip No.	Date	Days after slip	Invertebrates, benthic matter	Periphyton on natural substrates	Periphyton on artificial substrates	Suspended sediment
1	24/6/94	1	x	x		x
2	5/7/94	12	x	x		x
3	13/7/94	20	x	x		x
4	23/7/94	30		x	deployed	x
5	12/8/94	50		x		x
6	31/8/94	70		x	retrieved x	x
7	23/10/94	123			deployed	
8	7/11/94	138			washed away	

Figure 3.1
The exposed face of the slip on 24 June 1994, some 30 h after it had occurred (on the night of 22-23 June).

Until November 1994, when the slip was washed away completely, freshly exposed soils and clays from the slip were being continually washed into the Bealey River during high rainfall events.

3.2 Invertebrate Sampling

Invertebrates were sampled on the first three trips, i.e. on 24/6/94, 5/7/94, 13/7/94. Benthic invertebrates were collected from each site in triplicate drift nets (mesh size 250 µm, aperture of net 55 cm^2, volume 5500 cm^3) that had been positioned below the surface at 0.6 of the water depth. These three drift nets were deployed in line in riffles, and anchored to metal stakes driven into the substratum. They were left overnight and collected the following morning to catch the dusk and dawn peaks of invertebrate drift. Water velocity was measured at the lower entrance of each net using an Ott current meter, at the time that the nets were deployed and retrieved.

All samples were preserved with ethanol and returned to the NIWA[1] laboratory in Christchurch for sorting. Invertebrates and organic matter were elutriated from inorganic material and placed in perspex sorting trays. These trays were scanned under a binocular microscope and all invertebrates were identified and counted to as low a taxonomic level as possible.

3.3 Benthic Organic Matter Sampling

Organic matter collected in the nets was dried (for 24 h at 60°C), weighed and ashed (for 12 h at 550°C) to calculate ash-free dry weight.

3.4 Periphyton Sampling

3.4.1 Sampling of Natural Substrates

Samples of 6 randomly selected cobbles (coarse gravels: 16-64 mm) were taken from each site, placed on ice and transported to the laboratory where they were frozen (-18°C) until analysed. The samples were thawed, then placed in separate glass containers and covered with 90% ethanol. These containers were then sealed with thick PVC film to minimise evaporation and boiled (at 83°C) for 5 minutes to extract photosynthetic pigments from the periphyton adhering to each cobble.

On cooling, samples were filtered and light absorbances read at 664 and 750 nm, before and after acidification with 0.05M HCl. Chlorophyll *a* and phaeopigment values (used to quantify periphyton biomass) were determined using methods of Sartory & Grobbelaar (1984) and Suren (1990). After extraction, each cobble was weighed to determine its surface area from a weight–area regression that has been developed for greywacke cobbles (unpublished data).

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[1] NIWA National Institute of Water and Atmospheric Research

3.4.2 Sampling of Artificial Substrates

An inherent problem that exists with sampling periphyton communities on natural substrates is that the disturbance history of a particular cobble in the substrate is unknown. Thus, one cobble may have recently been violently tumbled along the riverbed, and consequently lost its algal biomass, while another cobble may have remained stationary.

Thus to minimise possible bias in the periphyton sampling programme caused by different pre-sampling disturbance regimes, artificial substrates were also used to investigate periphyton dynamics.

Artificial substrates were constructed of unglazed ceramic tiles (10 cm wide x 10 cm long) covered with grass carpet. This grass was composed of short tufts of nylon strips (1.5 mm wide x 9 mm long) woven into a thick nylon base. Each tuft contained about 20 strips, and there were 4 to 5 tufts per cm^2. These grass carpet-covered tiles not only provided a surface that periphyton could colonise, but also trapped fine sediments between their tufts.

Two of these tiles were jammed into a metal tile holder (size 25 cm x 10 cm) constructed from angle iron. These holders were attached to 5kg lead weights that were buried into the substrate 40 cm upstream from the tile holder. Three sets of these holders (i.e. six replicate tiles) were placed in riffles at each of the five sites and left for 40 days. This period is long enough for algal biomass to peak in these streams (Suren 1990, Suren & Winterbourn 1992).

After 40 days, all the tiles were removed and each was placed in its own plastic bag, put on ice and frozen upon return to the laboratory. Chlorophyll *a* biomass was assessed, using the methods for periphyton sampling referred to in Section 3.4.1. After pigment extraction, organic matter and sediments trapped in the grass carpet were removed from each tile by hosing it with high pressure water and scrubbing it twice with a stiff nylon brush. All water from this procedure was collected and passed through a 60μm sieve to retain the coarse sediments.

The washings was then placed into pre-weighed crucibles. The filtrate was passed through pre-weighed and pre-ashed Whatman GFC filter paper under vacuum to collect the fine sediments (<60 μm). All material retained in the crucibles, or on the filters, was dried (at 60°C for 24 h) and re-weighed to determine weight of sediment that had been trapped in the grass carpet on the tiles.

3.5 Suspended Sediment Sampling

Replicate water samples were collected on each sampling trip (see Table 3.1) using a depth-integrated suspended-sediment sampler at 4 points across a transect placed at each site. Samples were kept chilled (4°C) for up to 4 days before turbidity was measured, using a Haach turbidity meter. Quantification of the relationship and suspended sediment weight was determined next, to predict the weight of sediment (per m^3) on the basis of how turbid a sample was. After measuring turbidity, each sample was then violently shaken for 60 s, and the weights of suspended solids were determined by filtering a known volume of water collected at each site onto pre-weighed pre-ashed filter papers, and re-weighing after drying (for 24 h at 60°C).

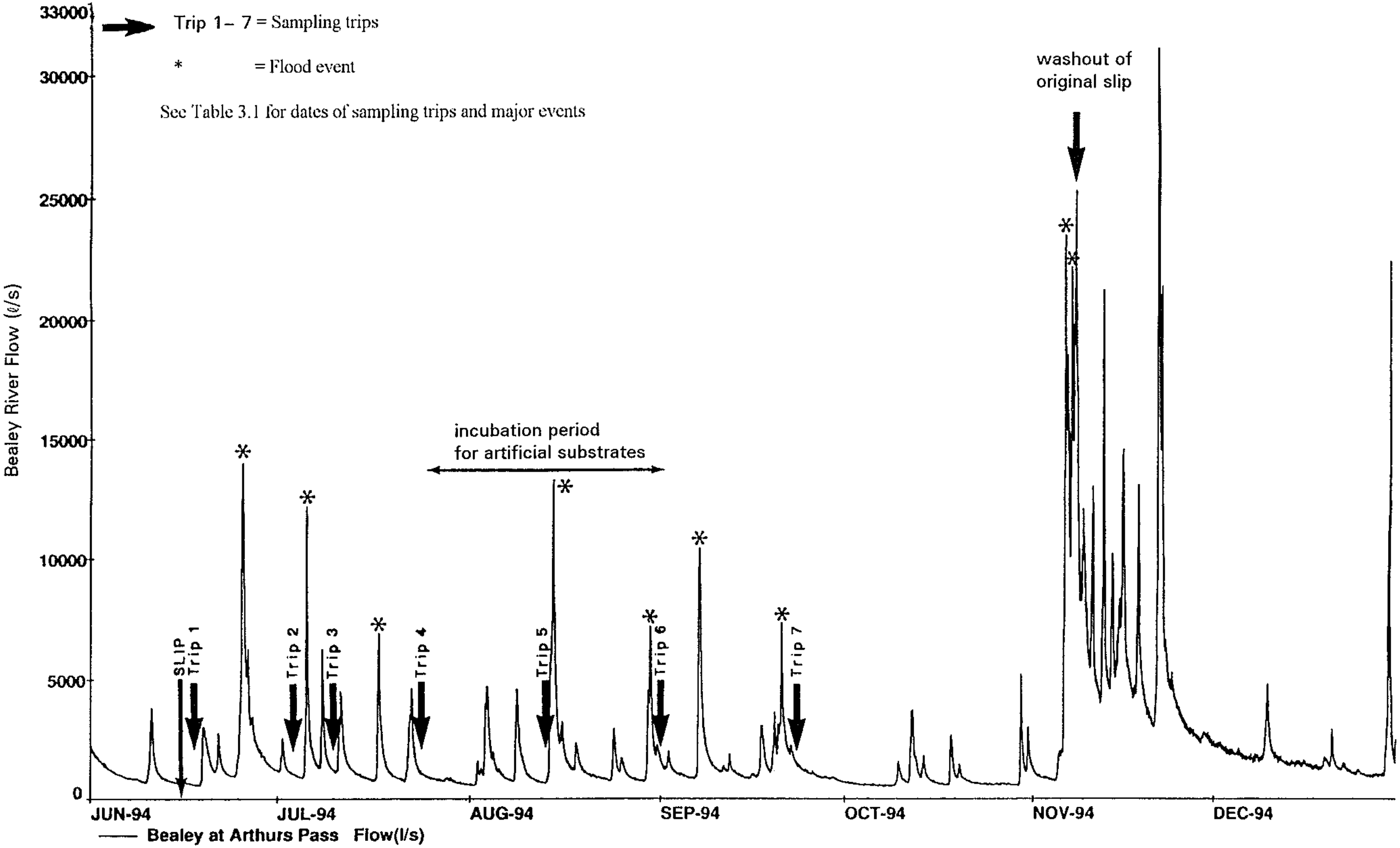
Suspended sediment loads, and resultant turbidity values, are intimately linked with discharge, but it was impractical to collect continuous water samples during a high flow. To overcome this problem, two Greenspan automatic turbidity meters were installed at one site above the slip (site C2) and at one site below the slip (site S2). These meters were programmed to record sediment levels every 15 minutes, and to continuously log the data. These sediment levels could then be related to discharge records from the Bealey River gauging site, situated c.500 m upstream of the lowermost slip site (S3) and operated by the Canterbury Regional Council (CRC).

3.6 Characterisation of River Hydrology

Data from the CRC's water-level recorder were used to obtain information about the number, and magnitude, of high flows that occurred during the study. Frequent river-bed movement, coupled with the failure of some water level recorders, has resulted in only limited data of flows in the Bealey River over the study period.

The next closest water-level recorder was at the Taipo River, a tributary of the Taramakau River, 40 km west of Arthur's Pass Village. It has been maintained by NIWA staff since 1978. Correlation analysis of specific yield flows (i.e. Q/A) between the flows of the Taipo and Bealey Rivers showed a significant relationship between flows ($r = 0.781, P < 0.01$). Estimated flows for the Bealey River from 9 September 1994 onwards could thus be computed using the software program TIDEDA (Rogers & Thompson 1992), based on data gleaned from the Taipo record. The resultant hydrograph (Figure 3.2) was used to assess not only how often the Bealey flooded during the study, but also to calculate the likely return intervals of particular spates. These were calculated using NIWA's software EVAN (Event Analysis) for the 12-year data from the CRC Bealey record.

Figure 3.2 Hydrograph of the Bealey River showing the number of flood events that occurred during the study period.



Trip 1– 7 = Sampling trips

* = Flood event

See Table 3.1 for dates of sampling trips and major events

3.7 Analysis of Sample Data

Data from the invertebrate sampling programme were first examined using Cochran's Q test which examines community structure (i.e. presence or absence of species) between sites. This test compares the observed variance in total numbers of taxa among sites with the variances expected if taxa are randomly distributed among the sites (Pridmore 1985). The analysis was performed separately on data gleaned from each invertebrate sampling trip to see if community structure at the five sites changed over time.

Following this, samples from each site were classified by TWINSPAN. This is a clustering technique that classifies samples on the basis of their species composition and abundance so that samples which have similar faunas are placed in the same sample groupings. This classification technique was performed on the quantitative data after log $(x+1)$ transformation to normalise the data.

Total invertebrate drift density, taxonomic richness, and densities of selected taxa were analysed by a nested ANOVA program to assess differences between sample locations and within sites at each location. This type of statistical test determined first whether invertebrate drift densities etc. differed between the two locations (i.e. control sites and impacted sites). It then assessed whether drift densities differed between samples within each location (i.e. whether there were differences in drift densities between C1 and C2, and between S1, S2, and S3).

All data were checked for normality and log $(x+1)$ transformed before analysis if data were not normally distributed. Data for the biomass of organic matter trapped in drift nets, periphyton chlorophyll *a* from natural and artificial substrates, and inorganic matter trapped within the artificial substrates, were also analysed by nested ANOVA. Where significant differences were observed between locations, a *post hoc* Tukey's Test was done to determine where these differences occurred.

4. RESULTS

4.1 Description of the Invertebrate Fauna

A total of 67 invertebrate taxa were identified during the study (Appendix). Of these, 12 taxa were terrestrial in origin, and most likely had been swept into the river from vegetation that had fallen into the river. Of the 55 aquatic taxa collected, the Diptera and the Trichoptera were the most diverse (14 and 13 taxa respectively). The stonefly *Zelandobius confusus* and the mayflies, *Deleatidium* spp. and *Nesameletus* spp., were the most numerically abundant taxa encountered.

The fauna in this study was similar to that reported by Suren (1991) for a small tributary that flows into the Bealey River just downstream of the White Bridge, and again by Suren (1993) in his survey of 20 first-order streams throughout Arthur's Pass National Park. All these taxa are indicative of clean, high quality water, and none are known to be rare or endangered.

4.2 Description of Invertebrate Communities

4.2.1 Community Structure

Invertebrate drift was successfully sampled at all sites on the first and third trips. During the second sampling trip, however, the drift nets deployed at the lower two impacted sites (sites S2 and S3) were lost. Drifting invertebrates were successfully collected from the upper sites (C1 and C2) and the impacted site immediately below the slip (S1), and so some limited comparisons could still be made.

The invertebrate community structure between control and impacted sites were significantly different on the first and second sampling trips ($\chi^2 = 38.21, 15.51$ respectively, $P < 0.01$). By the third trip (20 days), no significant differences in invertebrate community structure between any of the sites were observed ($\chi^2 = 9.25$, $P > 0.05$).

TWINSPAN analysis corroborated this result, in that invertebrate communities differed between sites on the first (1 day after the slip had occurred) and second (12 days after) sampling trips, but appeared similar by the third trip (20 days after). TWINSPAN analysis of the samples collected on the first and second trips showed clear demarcation between the control samples and those collected from below the slip (Sites S1-S3) (Figures 4.1,4.2). By the third trip, however, this shift in community structure appeared weaker. TWINSPAN clusters were not as clear cut, and indeed some of the control samples clustered in the same groups as samples from the impacted sites (Figure 4.3). This suggests that the original differences in community structure that were evident in the first sampling trip were not as evident 20 days later.

Figures 4.1-4.3 TWINSPAN classification of invertebrate drift samples collected in the triplicate drift nets deployed at each of the five study sites, collected on sampling trips 1 (24/6/94), 2 (5/7/95), and 3 (13/7/94).

Key :

S1, S2, S3	Impacted sites below slip
C1, C2	Control sites above slip
R1, R2, R3	Replicate samples

Figure 4.1 Classification dendrogram of samples from Trip 1, 24/6/94.

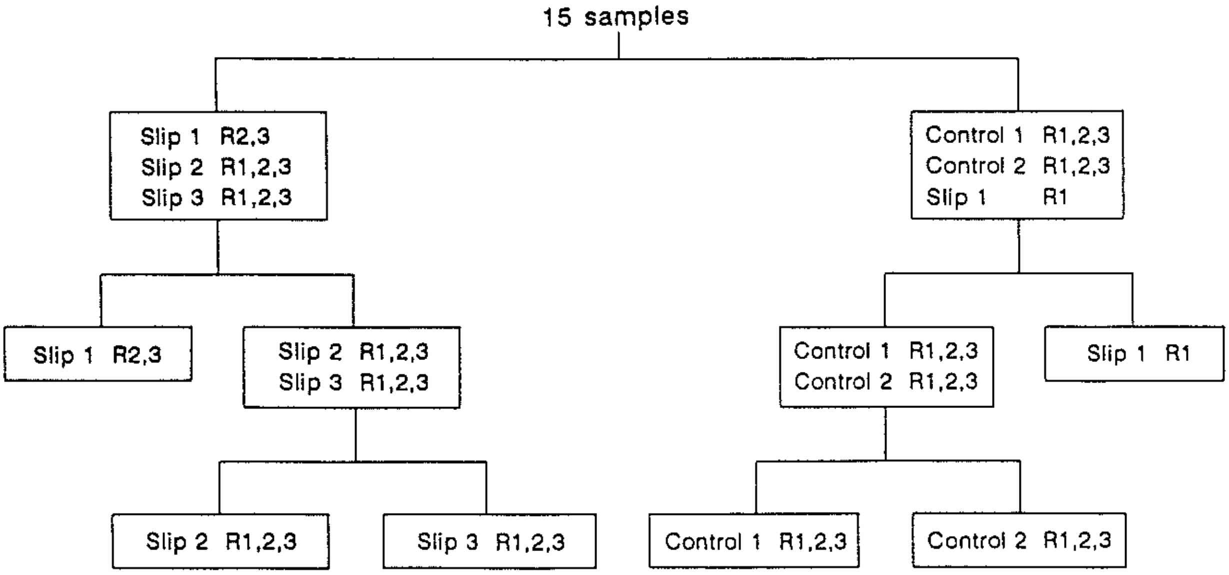


Figure 4.2 Classification dendrogram of samples from Trip 2, 5/7/94.

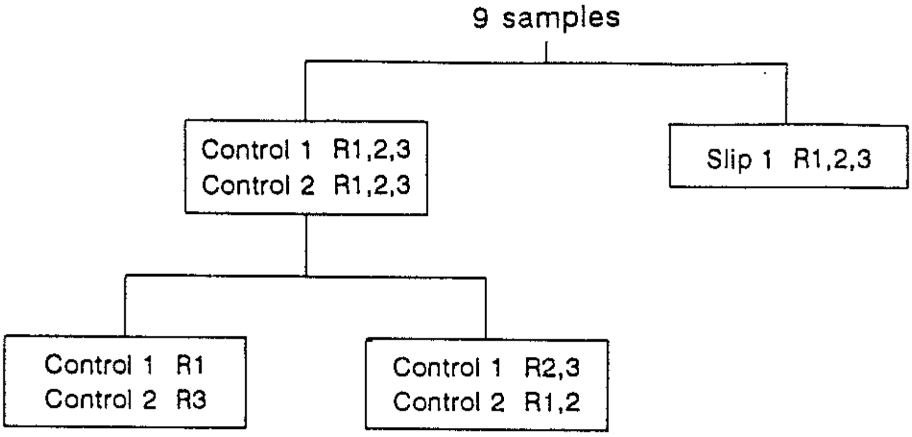
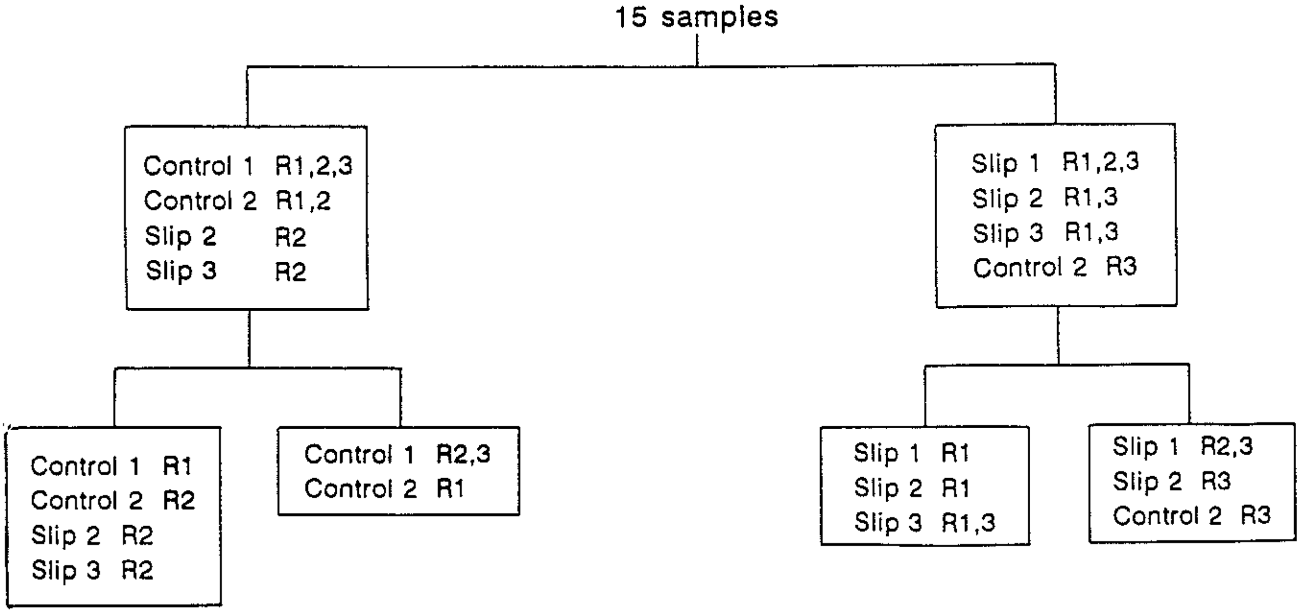


Figure 4.3 Classification dendrogram of samples from Trip 3, 13/7/94.



4.2.2 Drift Densities

Invertebrate drift density was significantly higher at sites below the slip on the first sampling trip (24/6/94) ($F = 17.25$, $P < 0.001$). In site S1, closest to the slip, drift densities were at least three times higher than in upstream control sites (C1, C2, Figure 4.4). Drift densities at the lowest impacted sites (S2, S3), however, were similar to those at control sites.

No differences in drift densities between control and impacted sites were evident on the second sampling trip (5/7/94) ($F = 1.38$, $P > 0.05$) , although more invertebrates were collected from the upper control site (C1) ($F = 14.32$, $P < 0.01$; Figure 4.4).

Drift densities on the third trip (13/7/94, 20 days after the slip occurred), were significantly lower at impacted sites S1-S3 than at the control sites ($F = 10.63$, $P < 0.001$; Figure 4.4).

4.2.3 Taxonomic Richness

Taxonomic richness was significantly lower at the control sites ($F = 7.39$, $P < 0.01$) and progressively increased at the impact sites below the slip at the first sampling (24/6/94) (Figure 4.5). Taxonomic richness at all five sampling sites was similar however, after both the second and third sampling trips ($F = 0.970$, 0.581 respectively, $P > 0.05$; Figure 4.5). Drift densities of the ten most common taxa collected in the samples were assessed for responses of individual taxa to sedimentation from the slip.

Immediately after the slip, drift densities of seven taxa were significantly higher at all sites below the slip (Table 4.1), with most drift occurring at the impacted site closest to the slip. By the third trip, however, drift densities of six of these taxa were lower in the downstream impacted sites than at the control sites, suggesting that the factors responsible for enhanced drift densities in the impacted sites were no longer operating.

Drift densities of the mayfly *Nesameletus* and the cascade fly *Neocurupira hudsoni* were also very high at site S1, although drift densities below the slip were not significantly different to densities at the control sites. On the third trip, however, drift densities at impacted sites were much lower again suggesting that environmental conditions at sites below the slip were no longer causing enhanced drift density rates (Table 4.1).

Table 4.1 Drift densities (numbers/m^3 of water filtered) of the ten most common invertebrate taxa (listed in Appendix), collected from drift nets placed at control sites C1, C2 upstream of the slip and at impacted sites S1, S2, S3.

Taxa	**Sampling Trip 1** 24/6/94	**Sampling Trip 3** 13/7/94
Acarina	Slip > Control 7.295**	Slip = Control 0.138
Chironomidae	Slip > Control 26.85**	Slip > Control 6.261**
Collembola	Slip > Control 10.196**	Slip = Control 7.000
Deleatidium	Slip > Control 7.304**	Control > Slip 49.590**
Hydrobiosis charadraea	Slip = Control 1.618	Control > Slip 5.558**
Neocurupira hudsoni	Slip = Control 1.446	Control > Slip 11.364**
Nesameletus	Slip = Control 0.345	Slip = Control 2.548
Zelandobius confusus	Slip > Control 12.280**	Control > Slip 28.976**
Zelandobius unicolor	Slip > Control 55.896**	Control > Slip 69.692**
Zelandoperla decorata	Slip > Control 7.717**	Slip = Control 2.010

** Densities were significantly different between sites($P < 0.05$).

* Sampling trip 2 data are not presented as a flood event had destroyed the lower two sites.

Figure 4.4 Invertebrate drift densities (numbers/ m^3 of water filtered) collected in triplicate drift nets placed at the five study sites on the three invertebrate sampling trips ($x \pm 1SE$, $n=3$). (Note changes in scales.)

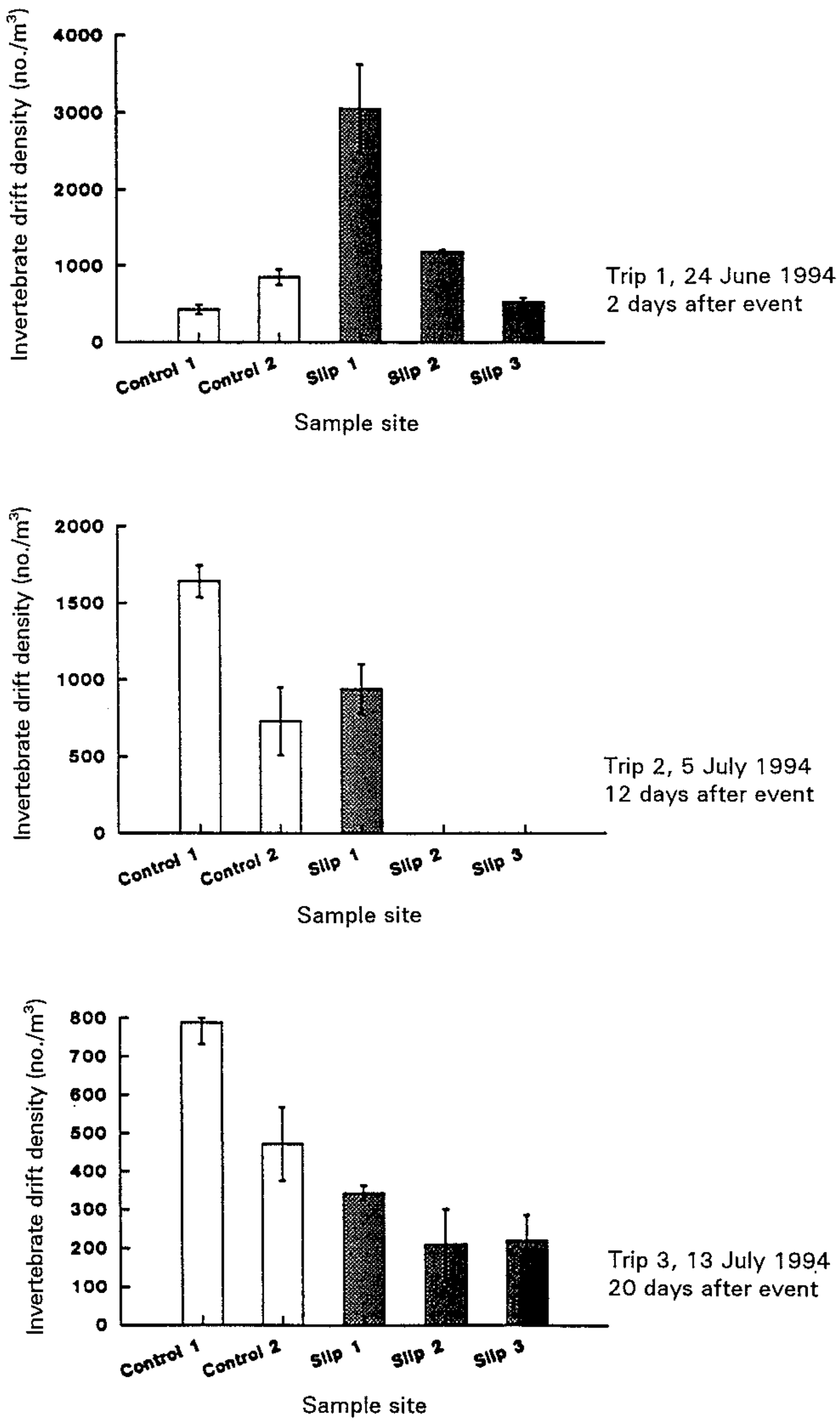
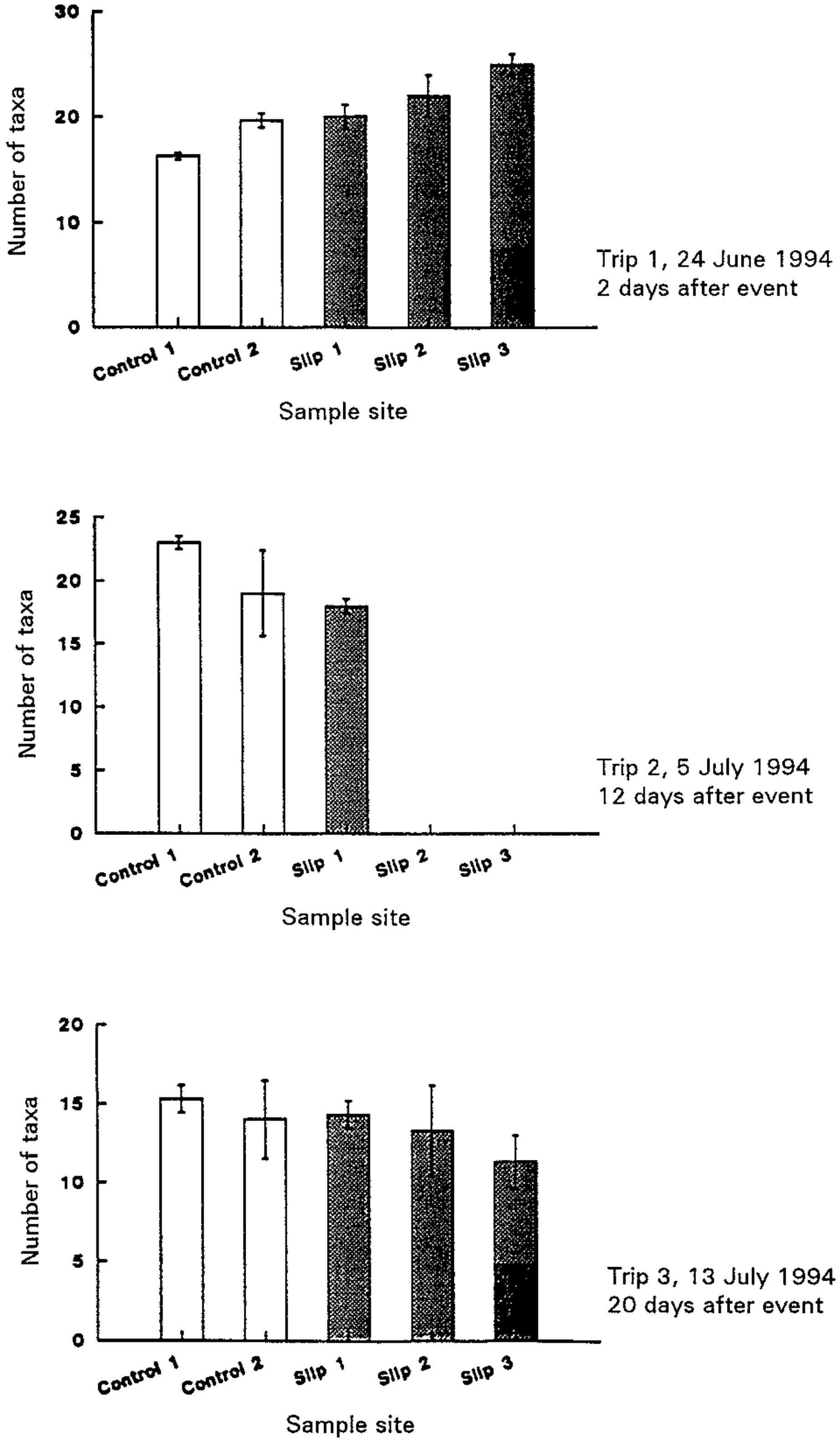


Figure 4.5 Number of invertebrate taxa collected in triplicate drift nets placed at the five study sites on the three invertebrate sampling trips ($x \pm 1SE$, $n = 3$). (Note changes in scales. Conventions as in Figure 4.4.)



Trip 1, 24 June 1994
2 days after event

Trip 2, 5 July 1994
12 days after event

Trip 3, 13 July 1994
20 days after event

4.3 Benthic Organic Matter

Biomass of organic matter collected in drift nets was considerably higher in the impacted sites than the control sites ($F = 6.66, P < 0.05$; Figure 4.6). Nets at impacted site S1 trapped at least 20 times more organic matter than control sites (i.e. 35.23 g v 1.52 g). Drift nets at impacted site S2 trapped approximately half the amount of organic matter as the upper site (14.34 g), while nets at lower impacted site S3 collected a similar amount of organic matter as nets in the control sections C1 and C2. By the second trip, organic material trapped by drift nets was similar at the control sites and the impacted site S1 ($F = 1.53, P > 0.05$; Figure 4.6).

Considerably less organic matter was collected from all sites on the third trip, when more organic material was collected by the nets at the control sites than at the impacted sites ($F = 10.35, P < 0.01$; Figure 4.6). This finding suggests that the large inputs of terrestrial organic matter from the slip were only relatively transitory, and that after 20 days the amount of material entering the impacted section of the river below the slip was similar to the quantities entering the control sites.

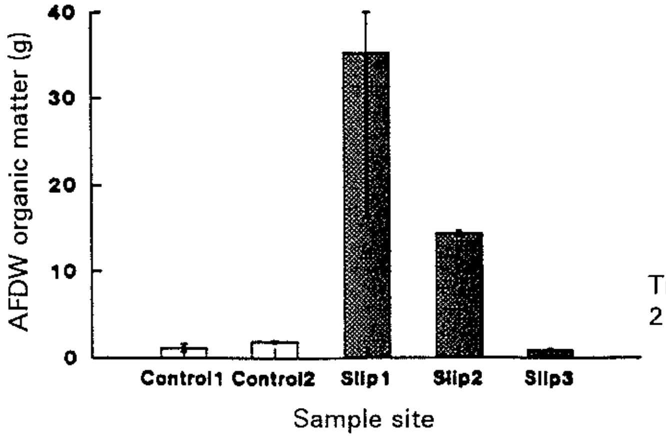
4.4 Periphyton Biomass

4.4.1 Periphyton on Natural Substrates

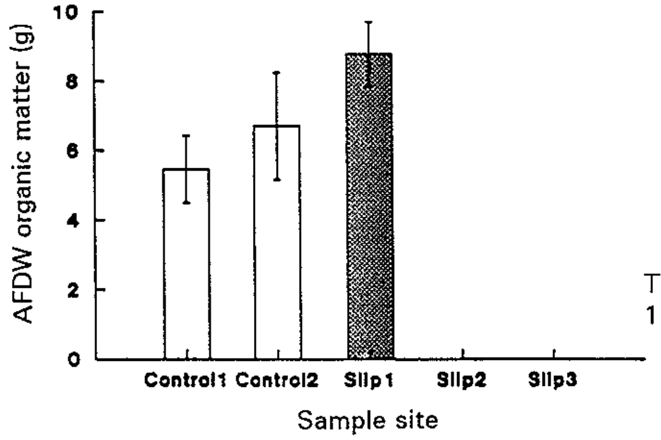
Periphyton biomass on cobbles collected on trip 1 immediately after the slip was similar at all sites ($F = 1.09, P > 0.05$; Table 4.2). A high flow event occurred 4 days after the slip, on 27 June (Figure 3.2) and this flood reduced periphyton biomass at all sites by the second sampling trip (5/7/94). This reduction was, however, more noticeable at the sites below the slip, where algal biomass was much less than at the control sites ($F = 32.55, P < 0.001$; Table 4.2). This greater reduction in biomass at sites below the slips suggests that the high amount of silt that would have been washed away from the slip during heavy rainfall also scoured away algal populations below the slip.

Total algal pigment was still significantly lower on cobbles collected at all impacted sites by trip 3, 20 days after the slip ($F = 13.07, P < 0.001$; Table 4.2), but biomass at all sites was higher than on trip 2. Three smaller high flow events had occurred between the second and third sampling trips, but these were not of sufficient magnitude to remove algal biomass from control sites. Rainfall associated with these events was, however, still releasing some sediment from the slip into the Bealey River, and this sediment kept algal biomass to a low level at the impacted sites.

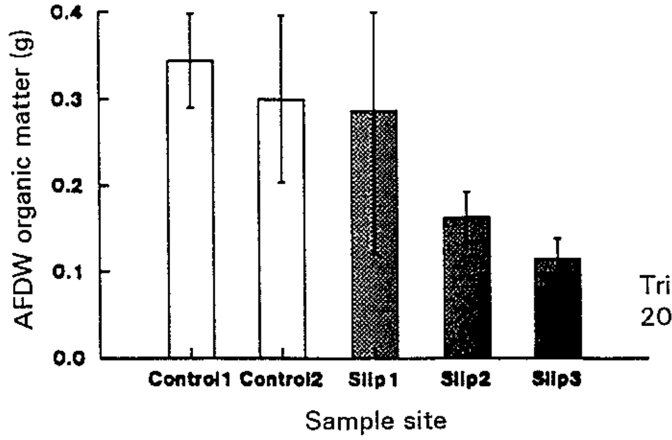
Figure 4.6 Ash-free dry-weight (AFDW g) of organic matter collected in triplicate drift nets placed at the five study sites on the three invertebrate sampling trips ($x \pm 1$SE, $n = 3$). (Note changes in scales. Conventions as in Figure 4.4.)



Trip 1, 24 June 1994
2 days after event



Trip 2, 5 July 1994
12 days after event



Trip 3, 13 July 1994
20 days after event

Table 4.2 Periphyton biomass (as μg/cm^2 of chlorophyll *a*; $x \pm 1$SE, $n = 6$) on natural cobbles collected from control sites C1, C2, above the slip in the Bealey River, and from impacted sites S1, S2, S3, at increasing distances downstream from the slip. The table shows the *F*-ratio result given by the nested ANOVA test, showing when chlorophyll *a* biomass differed between the control and the impact sites (the "Location" column), and when the biomass differed between samples at each location (the "Site" column).

Sampling Trip (Date)	**Days after Event**	**Control Sites**		**Impacted Sites**			***F*-ratio**	
		Site C1	Site C2	Site S1	Site S2	Site S3	Location	Site
1 (24/6/94)	1	0.547±0.109	0.498±0.175	0.341±0.009	0.519±0.021	0.432±0.056	1.095	0.612
2 (5/7/94)	12	0.212±0.059	0.221±0.042	0.026±0.020	0.076±0.002	0.032±0.022	32.553**	0.466
3 (13/7/94)	20	0.293±0.004	0.352±0.019	0.168±0.028	0.248±0.074	0.113±0.015	13.072**	2.266
4 (23/7/94)	30	no samples taken						
5 (12/8/94)	50	0.300±0.081	0.682±0.044	0.310±0.048	0.859±0.149	0.358±0.038	0.069	13.794**
6 (31/8/94)	70	0.765±0.047	0.627±0.129	0.544±0.055	0.718±0.034	0.413±0.043	2.202	3.747*

* = $P < 0.05$; ** = $P < 0.001$

No significant difference was recorded in periphyton biomass between the impacted and control sites sampled on trip 5 (12/8/94), 50 days after the slip ($F = 0.07$. $P > 0.05$; Table 4.2). Considerable variation was however recorded in biomass at both the control and impacted sites. Cobbles collected from the lower control site (C2) and the middle impacted site (S2) supported a similar periphyton biomass (mean of 0.771 μg/cm^2), which was much higher than that on cobbles at the other sites (mean of 0.322 μg/cm^2).

Periphyton biomass on cobbles collected 70 days after the slip (trip 6, 31/8/94) were not significantly different between samples collected from the impacted or control sites ($F = 2.20$, $P > 0.05$; Table 4.2). Another high flow event had occurred some 15 days before collecting these samples (Figure 3.2), but this event had no apparent detrimental effect on algal populations below the slip.

4.4.2 Periphyton on Artificial Substrates

The first set of artificial substrates were deployed on 23 July, 1994, approximately 30 days after the initial slip. They were left in place for 40 days, and retrieved on 31 August. During the time the artificial substrates were deployed, four high flow events occurred, with a relatively large flow (12 m^3/s) occurring half way through the deployment period, about 13 August (Figure 3.2).

Chlorophyll *a* biomass extracted from periphyton colonising the grass carpet tiles was similar between the control and impacted locations ($F = 0.683$, $P > 0.05$; Figure 4.7a). Significant differences in phaeopigments, however, occurred between locations, with substrates placed at the control sites having almost eight times more phaeopigments than substrates at the impacted sites ($F = 24.28$, $P < 0.001$; Figure 4.7b).

The differences in phaeopigment biomass may reflect the impact of the high flow event on 13 August, which may have released large amounts of abrasive material from the slip into the Bealey River. This material would have physically scoured the algae from downstream substrates.

The age of an algal community can be ascertained by the biomass of phaeopigments, as it is higher in older communities. The higher phaeopigment levels of the algal communities colonising substrates at the control sites indicate that these communities were older than those at the impacted sites, which had been abraded after the slip event.

The physical scouring of algal communities at the impacted sites is further substantiated by the significantly higher quantities of both coarse and fine inorganic material trapped on tiles placed below the slip ($F = 7.87$, 16.13 for coarse and fine material respectively, $P < 0.05$; Figure 4.8a,b).

A second set of artificial substrates was deployed in the river on 23 October, 1994, and it was planned to retrieve them a month later (in November). A large spate on 7 November, however, washed all the artificial substrates away.

Figure 4.7a Biomass (expressed as chlorophyll *a* (μg/cm^2)) of periphyton colonising artificial substrates placed at the five study sites for a 40-day exposure period ($x \pm 1SE$, $n = 6$). (Conventions as in Figure 4.4.)

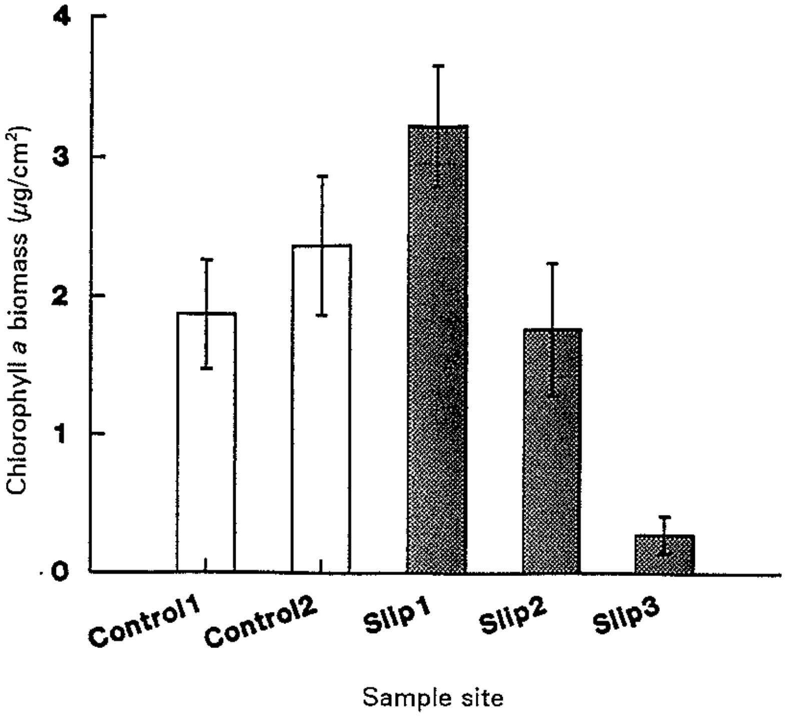


Figure 4.7b Biomass (expressed as phaeopigments (μg/cm^2)) of periphyton colonising artificial substrates placed at the five study sites for a 40-day exposure period ($x \pm 1SE$, $n = 6$). (Conventions as in Figure 4.4.)

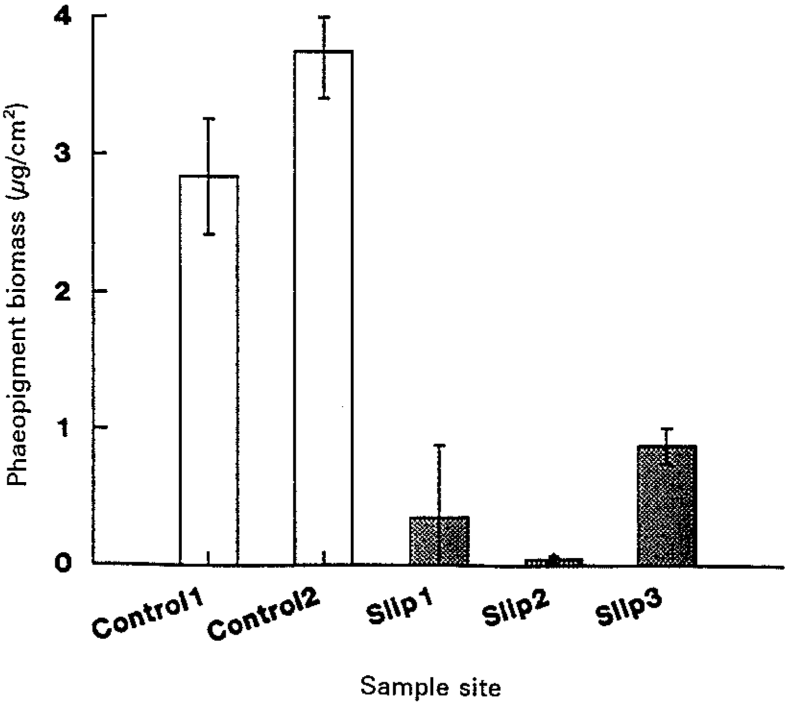


Figure 4.8a Weight (g/100 cm^2) of coarse silt (>60 μm) trapped between tufts of grass carpet on the artificial substrates placed at the five study sites for a 40-day exposure period ($x \pm 1SE$, $n = 6$). (Conventions as in Figure 4.4.)

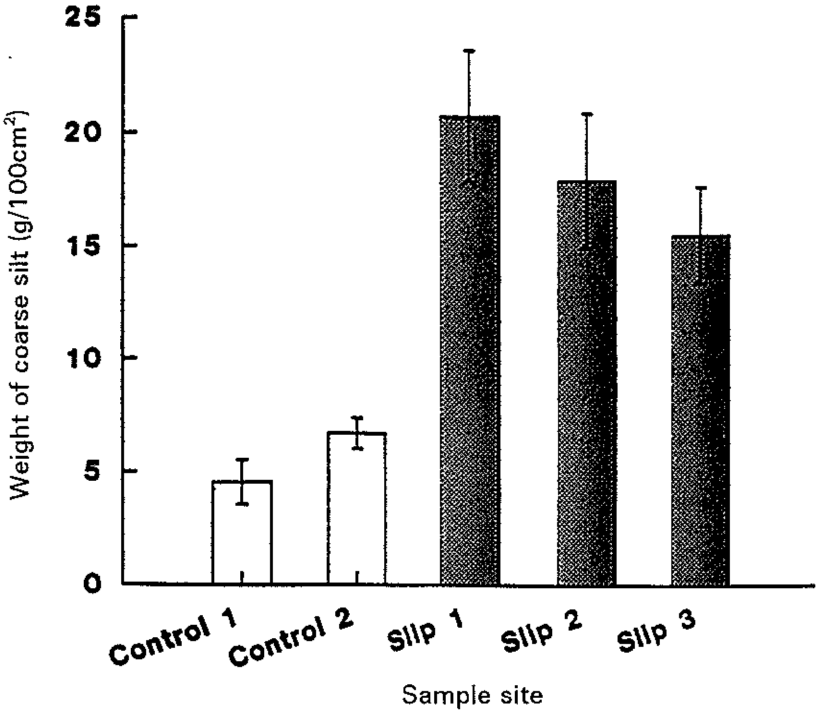
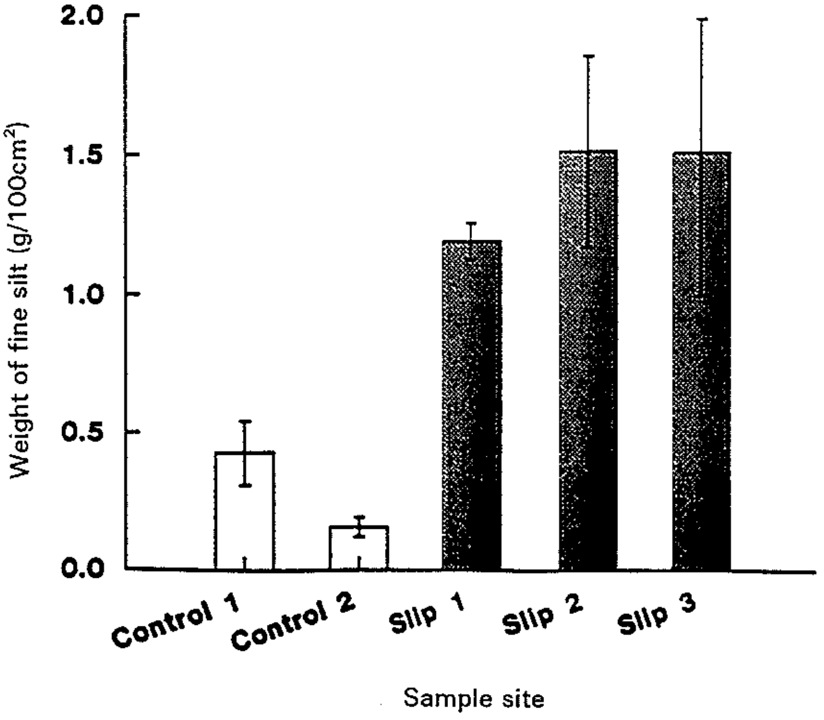


Figure 4.8b Weight (g/100 cm^2) of fine silt (<60 μm) trapped between tufts of grass carpet on the artificial substrates placed at the five study sites for a 40-day exposure period ($x \pm 1SE$, $n = 6$). (Conventions as in Figure 4.4.)

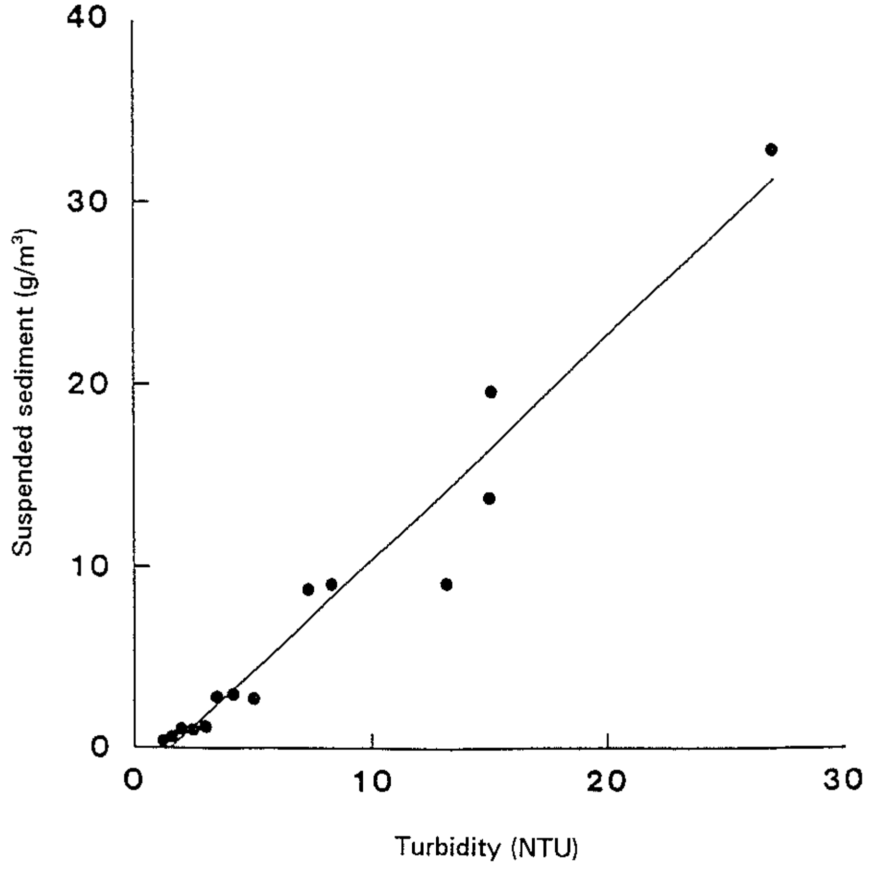


4.5 Suspended Sediments

A significant relationship existed between water turbidity and weight of suspended solids (Figure 4.9). This enabled the weight of suspended material to be predicted from measurements of turbidity alone. Spot turbidity readings taken during routine sampling showed that turbidity was often higher below the slip than above, with the highest readings (32 NTU; 37 g/m^3) found immediately below the slip on the first sampling trip.

Technical problems with the two turbidity meters meant that continuous readings were not available. The highest turbidity reading (32 NTU) was observed on 24 June, immediately after the slip. The many high flow events that occurred following this recording would almost certainly have washed more material into the river. Turbidity values of >32 NTU were thus likely, especially during the early stages of a heavy rain period, while the river was rising.

Figure 4.9 Relationships between suspended sediment (g/m^3) and turbidity values (NTU) based on water samples collected on the first three sampling trips ($r^2 = 0.955$, $F = 16.69$, $P < 0.001$, $n = 15$).



5. DISCUSSION

5.1 Impact of Floods on Aquatic Biota

New Zealand's Southern Alps are areas of high, unpredictable rainfall. Rivers in this environment are exposed to frequent high flows interspersed with periods of low base flow. Alpine rivers represent a harsh environment for river biota, which must contend with not only frequent unpredictable flows but also often extensive substrate movement and high silt levels. During floods, biota are exposed to three discrete stresses: fast turbulent water; substrate movement; increased sediment load.

The biota of alpine rivers is well adapted to such harsh environmental conditions. Invertebrate communities are generally thought to be highly resilient to disturbances (Winterbourn et al. 1981, Death 1991), and are dominated by a "core assemblage" of animals that are renowned for their ability to quickly recover their populations to pre-flood levels (Scrimgeour et al. 1988, Winterbourn et al. 1981, Scarsbrook & Townsend 1993, for example). During high flow events, invertebrate drift densities are often very high, reflecting habitat disruption and the subsequent entrainment of animals into the water column. Although absolute numbers of drifting invertebrates often increase during floods, drift densities (the number of invertebrates per m^3 per hour) actually decrease (Graesser 1988). This suggests that during floods, fewer invertebrates per unit volume of water passing a given area of riverbed are being washed downstream because the invertebrates have moved deeper into the underlying undisturbed substratum to avoid faster currents. Animals which seek shelter deep in the riverbed during high flows can quickly re-colonise other areas of the river during the lower flow periods after floods.

Periphyton biomass is also reduced during high flow events. This reduction reflects removal of these communities from the riverbed, either by the physical force of water scouring communities from the rocks (e.g. Biggs 1995, Biggs & Thomsen 1995), or by physical abrasion caused by water-borne sediments or by movement of larger substrates that crush the communities (e.g. Horner et al. 1990). Despite these reductions in biomass during high flows, periphyton communities in alpine streams are highly resilient, and can quickly re-colonise denuded riverbed areas following high flows.

5.2 Impact of the Slip

5.2.1 Sediment Levels

The slip into the Bealey River introduced large quantities of sediment into the river without an accompanying high discharge. The biota below the slip was thus exposed to increased sediment levels only, without the compounding influence of high discharge. This provided an ideal opportunity to assess the impacts of sedimentation alone, a situation that may occur during road construction in Arthur's Pass National Park.

Spot turbidity levels were higher below the slip than above, suggesting that fine sediments were being washed into the river from the recently exposed face of the slip. Fine sediment accumulations, often observed along the river margins, were expected to affect the biota.

5.2.2 Organic Matter Inputs

The initial effects of the slip were dramatic. Within 30 hours, organic matter inputs into the Bealey River were greatly increased (up to twenty times) below the slip as terrestrial vegetation was washed downstream. Organic matter inputs below the slip quickly returned to levels similar to those found above so that by the third trip, 20 days after the slip, more organic matter had been collected in drift nets at the control sites above the slip than at impacted sites below the slip. This rapid loss of introduced organic material highlights the lack of retentiveness in these alpine rivers, and the constant substrate movement that causes loss of organic material from the riverbed (Winterbourn et al. 1981).

5.2.3 Invertebrate Communities

Following the slip, invertebrate drift densities were considerably higher below the slip than above it. This difference suggests that animals were actively drifting to avoid heavily silted substrates, because no difference in velocity was evident between the impact and control sites. Similar responses of invertebrates to sedimentation have been reported in both overseas studies (for example Campbell & Doeg 1989; Rosenberg & Wiens 1975; Ciborowski et al. 1977; Gammon 1970) and New Zealand, in West Coast streams (Graesser 1988; Quinn et al 1992) and Otago rivers (Ryder 1989).

Invertebrate avoidance of heavily silted areas, as seen in this study, reflects an active mechanism whereby animals actively enter the drift to escape water carrying high silt loads. Normally, drift from areas upstream of the slip (the control sites) would replenish the populations in the impacted areas below the slip, but animals drifting into silted areas may continue to drift further downstream and so actively avoid resetting on the riverbed (Ryan 1991). Thus benthic invertebrate densities are usually reduced in riverbed areas where turbidity levels are high (e.g. Quinn, et al. 1992) as a result of increased drift rates.

Suspended sediments block interstitial spaces between substrate particles, and reduce the interchange of subsurface water, metabolites and oxygen with surface waters. Periphyton communities also become contaminated with fine sediments as they settle from the water column (Graham 1990), and this also was observed by Davies-Colley et al. (1992) in streams subject to placer gold-mining effluent on the West Coast of New Zealand. Such sediment-contaminated periphyton represents a low quality food source, and is not selected by invertebrates when they have a choice. Also, growth of the caddisfly *Pycnocentroides* is slower on silt-contaminated periphyton than on clean periphyton (Ryder 1989).

Many invertebrates actively move from areas with such poor quality food, and will drift in search of more favourable habitats. Indeed, observed drift densities of the mayfly *Deleatidium*, the stoneflies *Zelandobius confusus*, *Z.unicolor* and *Zelandoperla decorata*, and of chironomids, were much higher after the slip. These animals are known to consume periphyton, and so may have drifted from heavily silt-contaminated areas to avoid consuming what may have been a poor quality food source.

By the third trip, invertebrate drift levels below the slip were more similar to those of the control sites above, suggesting that recovery had occurred after 20 days. Community structure was also more similar between sites after the third sampling trip, as shown from Cochran's Q-test and the TWINSPAN classification. Both these tests did not accurately separate samples on the basis of their location above or below the slip after this time. Moreover, accumulations of fine sediments along river margins and in eddies behind boulders were not as evident on the third trip, as much of this material had been washed downstream with successive rainfall events. This reduction in accumulated sediment most likely improved the physical habitat of areas below the slip, and resulted in a lower invertebrate drift rate.

5.2.4 Periphyton Communities

Periphyton biomass at impacted sites was unaffected by the slip in the first 30 h. Heavy rain four days later (23 June 1994, Figure 3.2) introduced much fine sediment into the river, which would have abraded periphyton on substrates below the slip. This abrasion caused a reduction in periphyton biomass below the slip which persisted for at least 7 weeks. Similar adverse effects of suspended sediments on periphyton have been postulated by Ball et al. (1969) and Horner & Welch (1981), who both recorded a greater reduction of periphyton biomass during spates than was expected from velocity alone. This postulation was further substantiated by Horner et al. (1990) who found experimentally that adding sediment to laboratory channels produced instantaneous loss rates of periphyton that were almost double the loss rates caused by velocity increases alone.

Intermittent sediment pulses into the Bealey River during the study would have scoured periphyton off substrate material, and suppressed its biomass. This effect was also evident in algae colonising the artificial substrates, because high rainfall on 13 August released more sediment from the slip into the river and reduced algal biomass on substrates placed in impacted sites below the slip. These substrates also trapped more sediment material than similar substrates placed in control sites above the slip. This highlights the higher concentration of suspended sediment at the impacted sites.

Higher suspended sediment concentrations below the slip were further substantiated by spot sampling of turbidity at the impacted sites. Readings of up to 32 NTU (37 g/m^3) were observed on occasions, and higher levels would possibly have been recorded if continuous measurements could have been taken during flood events. Even at these low sediment levels, periphyton can accumulate up to 50% of its dry weight as silt (Graham 1990). Studies by Gammon (1970) have also shown that invertebrate drift increased by 25% at suspended sediment concentrations of 40 g/m^3, and by 90% when suspended sediment concentrations reach 90 g/m^3. On the first sampling trip in this study, values of c.40 g/m^3 were observed in water samples collected at impacted sites below the slip, and invertebrate drift densities were over 300% times those in control areas.

5.3 Temporal Aspects of the Slip

Although algal and invertebrate populations were affected by increased sedimentation below the slip, these changes were short-lived. During the study, nine high flow events (arbitrarily defined as five times the long-term discharge, according to Biggs & Close 1989 and Suren 1996) occurred in the Bealey River (Figure 3.2), and this frequent flushing of the river appeared to ameliorate the effects of the slip. With each rainfall episode, new sediment material would have washed from the slip into the river, but the quantity of this material would presumably decline over time as the slip stabilised. Material deposited below the slip would have been washed away from its source and the riverbed would become free of any fine sediment accumulation. Over time, the effects of the slip would diminish and, indeed, invertebrate communities appeared to be recovering 3 weeks after the slip, and periphyton after 7 weeks.

This relatively rapid biological recovery reflects both the naturally high rainfall and associated high disturbance regime in this alpine area, and the fact that the biota has adapted to these physical processes. A similar conclusion of a short-lived effect of sedimentation episodes on the biota in alpine rivers was observed by Cline et al. (1982). They found only short-lived changes in invertebrate densities following construction of a highway over a mountain pass in Northern Colorado, USA. They attributed the rapid recovery as reflecting the highly variable hydrologic regime, and the steep gradient of their study site, which helped ensure the rapid removal of detrimental fine sediments from the streams.

The importance of meteorological and hydrological conditions in minimising effects that the slip may have had on the river were also clearly evident by the washout of the slip following heavy rain, and the subsequent high flows on 7 November 1994. This event removed much debris and washed much of the slip away. Using data extrapolated from the Taipo River, this flood had a discharge of 25.4 m^3/s. A larger flood, on 17 November, had a estimated discharge of 31.1 m^3/s. Even these relatively large floods, however, have an annual return probability of greater than 90%, and so are considered a natural part of the ecosystem. This again highlights the dominant effect that hydrology has on the ecosystem of a river, and how the effects of even a relatively large disturbance such as a slip could be minimised by the more intense effects of flooding.

6. CONCLUSIONS

A natural landslip can have a dramatic, but short-lived, impact on the biota of a river such as the Bealey, as this study has shown. The effects of increased sediment input were quickly ameliorated by the frequent rainfall and high stream flows so that diminishing amounts of fine sediments were washed into, and accumulated in, the river below the slip.

The slip was a one-off event, the effects of which lasted about 100 days. Road construction works may, however, result in a continual input of fine sediments into a river over a longer period (up to months). These long-term effects may have more noticeable effects on the biota. Also, the slip was a single source of sediment into the river, whereas road works may result in several sources, the cumulative effects of which may have a more demonstrable impact on the biota.

Even low suspended sediment levels (37 g/m^3, or 32 NTU) caused significant short-term changes to the biota. Thus, any construction work should preferably keep levels of suspended sediment below this level of turbidity, especially during times of low river flow. Long periods of low flow are, however, unlikely in the Southern Alps, and any introduced sediments will quickly be washed downstream with each successive rainfall event.

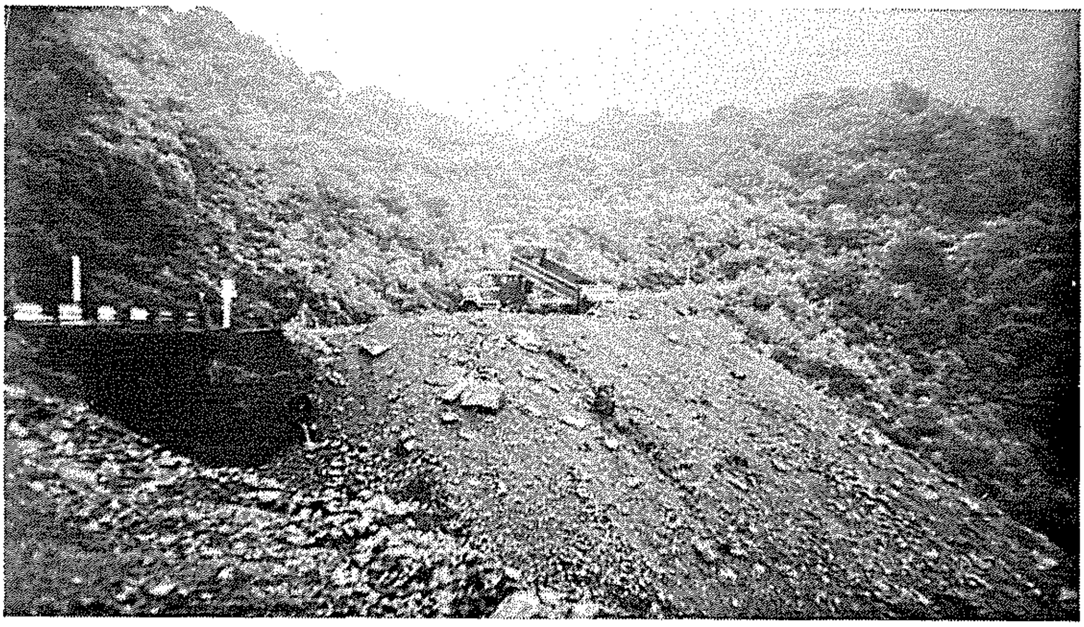
Current road work practices in Arthur's Pass National Park involve much clearing of gravel from roads and dumping it directly into rivers (Figure 6.1) as it is obviously a quick, convenient way of disposing of the gravel. While this activity is likely to have some localised impact on small areas of a river, these impacts are unlikely to be severe or long term.

However, the practice of dumping rubble and gravel directly down roadsides into a river through stands of beech trees is also common, and in places appears to effectively ring-bark the trees, eventually killing them. This practice could lead to bank destabilisation, and may possibly make the area more susceptible to future slipping. Where possible, roadside gravels should be deposited down gullies that are already bare of vegetation. Ideally, areas above rivers with high water velocities that would ensure quick removal of fines from the system, even at low flows, would be a better choice for this practice.

While the biota of these rivers appear sensitive to only small increases of turbidity, these effects appear short-lived and are quickly masked by the natural variability of river flow. This study was, however, unable to quantify the amount of sediment that caused the observed changes to the biota. More work is needed to accurately quantify biological responses to increased sedimentation loads, and simple in situ experiments using flumes would be extremely useful to achieve this goal.

Such experiments would provide quantitative relationships between suspended sediments and instream biota. Then monitoring during a road construction phase would comprise measuring only the turbidity levels. This would make sure that the levels remained lower than the critical value at which biological effects become apparent.

Figure 6.1 Dumping large quantities of road construction waste down steep valleys and into rivers may have only minimal long-term impact on river ecosystems. But waste gravels indiscriminantly dumped down banks covered with trees will kill the trees, cause bank erosion, and so affect the biotic integrity of the rivers.



7. RECOMMENDATIONS

Two recommendations are made:

1. Research is needed to provide quantitative relationships between suspended sediment levels and in-stream biota. This needs to be done for a variety of different locations, as not all rivers will respond to sediments in a consistent manner.

   Such research will allow further monitoring of road construction activities to be made by measuring turbidity levels alone, and ensuring that the levels remain below established critical values where biological effects become apparent. Monitoring of turbidity would also be cheaper than conducting more labour-intensive biological monitoring programmes.

2. Further research about road construction techniques, possibly using filter fabrics, is needed so that the amount of sediment entering streams during road construction is reduced.

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APPENDIX.
LIST OF INVERTEBRATE TAXA COLLECTED FROM BEALEY RIVER

Invertebrate taxa collected in drift nets placed in the Bealey River for 24 h periods on three separate occasions are listed. While most of these taxa are in the larval aquatic phase, some of the taxa encountered were terrestrial, and were especially common in drift samples taken 30 h after the slip had occurred. These were most likely to have been swept from the vegetation that had fallen into the river after the slip. Taxa were identified to as low a taxonomic level as possible, but identification of some animals at species level was uncertain. The numbers in parentheses indicate the animal groups that are being treated as "taxa" (e.g. larvae, pupae and adults of the same group are treated as separate "taxa" because, from a functional point of view, they behave differently in the ecosystem).

Phylum NEMATODA (1)

Phylum NEMATOMORPHA
Class Gordiidae (2)

Phylum PLATYHELMINTHES
Class Turbellaria
Order Tricladida
Neppia montana (3)

Phylum ANNELIDA
Class Oligochaeta
Order Haplotaxida (4)

Phylum MOLLUSCA
Class Gastropoda
Subclass Prosobranchia
Family Hydrobiidae
Potamopyrgus antipodarum (5)
Subclass Pulmonata
Family Planorbidae
Gyraulus corinna (6)

Phylum ARTHROPODA
Class Insecta
Order Collembola (7)

Order Ephemeroptera
Family Leptophlebiidae
Deleatidium spp. (8)
Family Siphlonuridae
Nesameletus spp. (9)

Order Plecoptera	
Family Gripopterygidae	
Acroperla spiniger	(10)
Zelandobius confusus	(11)
Zelandobius unicolor	(12)
Zelandoperla agnetis	(13)
Zelandoperla decorata	(14)
Family Notonemouridae	
Spaniocerca minor	(15)
Spaniocerca zelandica	(16)
Spaniocerca sp.	(17)
Spaniocercoides hudsoni	(18)
Order Trichoptera	
Family Conoesucidae	
Olinga feredayi	(19)
Family Helicopsychidae	
Helicopysche sp.	(20)
Family Hydrobiosidae	
Costachorema callista	(21)
Edpercivalia maxima	(22)
Hydrobiosis charadraeae	(23)
Hydrobiosis silvicola	(24)
Hydrochorema tenuicaudatum	(25)
Hydrobiosis sp.	(26)
Psilochorema nemorale	(27)
Tiphobiosis montana	(28)
Family Hydroptilidae	
Oxyethira albiceps	(29)
Family Oeconesidae	
Oeconesus maori	(30)
Family Philopotamidae	
Hydrobiosella sp.	(31)
Order Lepidoptera - moth/butterfly larvae (terrestrial)	(32)
Order Coleoptera	
Family Elmidae	(33)
Family Scirtidae	(34)
Family Hydrophilidae	(35)
Family Ptilodactylidae	(36)
Family Dytiscidae	
Rhantus pulverosus	(37)
Copelatus australis	(38)
Adult beetles: terrestrial	(39)
Larval beetles: terrestrial	(40)
Order Neuroptera	
Family Osmylidae	
Kempynus sp.	(41)

Order Diptera	
Family Blephariceridae	
Neocurupira hudsoni	(42)
Family Chironomidae	
larvae	(43)
pupae	(44)
adults	(45)
Family Dixidae	
Nothodixa sp.	(46)
Family Empididae	(47)
Family Muscidae	
sp. A	(48)
sp. B	(49)
adult	(50)
Family Simuliidae	
Austrosimulium ungulatum	(51)
Family Tabanidae	(52)
Family Tipulidae	
Eriopterini	(53)
Hexatomini	
Limonia hudsoni	
larvae	(54)
adult	(55)
Order Isoptera - termites: terrestrial	(56)
Order Hymenoptera - wasps: terrestrial	(57)
Order Hemiptera - bugs: terrestrial	(58)
Order Orthoptera - wetas: terrestrial	(59)
Class Crustacea	
Subclass Amphipoda	(60)
Subclass Copepoda	
Order Harpacticoida	(61)
Subclass Malacostraca	
Order Isopoda - wood lice: terrestrial	(62)
Order Amphipoda	(63)
Class Arachnida	
Order Araneae - spiders: terrestrial	(64)
Order Acarina - mites: terrestrial and aquatic	(65)
Class Chilipoda - centipedes: terrestrial	(66)
Class Diplopoda - millipedes: terrestrial	(67)

GLOSSARY

Anthropogenic	Referring to environmental alterations resulting from the presence or activities of humans.
Baseflow	Volume of water flowing down a river, which represents the ground-water contribution. After a spate, rivers will return to their baseflow as run-off from the surrounding land decreases: the length of time that this takes is dependent on surrounding catchment variables such as soil depth, vegetation, geology. Rivers which quickly return to baseflow are termed "flashy" and are characteristic of alpine rivers, whereas lowland rivers have a more "sluggish" response to rainfall and return to baseflow over a longer period.
Benthic	Bottom dwelling.
Biomass	The quantity of living plant and animal material in a given area.
Chlorophyll *a*	The green pigment in plants that is important in photosynthesis. It is found in special membrane-bounded compartments within plant cells. Measuring chlorophyll *a* concentration of periphyton indicates how much live algae is present.
Diatoms	An important and diverse group of algae found in both fresh and sea waters. Characterised by large amounts of silica in their cell walls. Most are unicellular although some are colonial. They form brownish, sometimes slippery, films on surfaces of stones and plants, and are an important food for grazing snails and insects.
Elutriation	The process of washing away the lighter or finer particles in a sample by washing the sample with water, and pouring the fines away from the coarser material.
***F*-ratio**	A statistical value obtained from an ANOVA test: the higher the value the more significant the result is.
Flood	A time of high discharge when a river flows over its banks, i.e. times of bankfull discharge. Floods of this size occur with a return interval of approximately 1.6 times each year. See also *Spate*.
Green algae	A group of important freshwater algae that often form long filamentous mats.
High flow	See *Spate*.
Hydrograph	A graph of the water discharge or depth over time. It can refer to the pattern of streamflow over a season or a year, or to the pattern of daily flows (see Figure 3.2 in this report). This is a "spate hydrograph" and is the result of a single rainfall event. It consists of the **rising limb** where the flow (or depth) is increasing, and the **falling limb** (or recession curve) where the graph falls as the flow (or depth) decreases.

Invertebrates	Any group of animals which lack backbones. In river ecosystems, the most common invertebrates are aquatic insects (e.g. mayflies and stoneflies), snails, worms and crustaceans (e.g. koura, shrimps). Many of these animals feed on periphyton and other organic matter in rivers, and in turn are eaten by fish and birds.
Invertebrate drift	The downstream movement of benthic invertebrates by water currents. Drift can be **active**, whereby animals choose to enter the drift in search of habitats with more food or less crowding. This type of **behavioural drift** often displays strong diurnal variations, with peaks in drift rates just after dusk, and just before dawn. Drift also occurs during high flows, when animals are swept from the riverbed by fast water velocities, or are dislodged from cobbles that start to roll downstream. This is sometimes known as **catastrophic drift**.
Magnitude (earthquake)	A measure of the actual amount of energy released by an earthquake, expressed in terms of the (logarithmic) Richter scale (of Magnitude 1 etc.).
NTU (Nephelometric Turbidity Unit)	A unit of measurement, applied to measurements of the amount of light-scattering particles that are suspended in a fluid (i.e. the degree of **turbidity** in a fluid).
Particle size	Categories of particle sizes used in sediment analysis are:

Boulders		>256 mm
Cobbles,	large	128-256 mm
	small	64-128 mm
Gravel,	coarse	16-64 mm
	medium	8-16 mm
	fine	2-8 mm
Sand		0.06 - 2 mm
Silt		0.004 - 0.06 mm
Clay		<0.004 mm

Periphyton	The organisms growing on substrates in aquatic habitats. Although composed mostly of algae, other organisms such as fungi and bacteria are usually present. Organic debris and sand are also commonly intermixed with periphyton, particularly when the community is thick enough to form a mat. Periphyton is visible as green or brown coatings on rocks, or as filamentous mats.
Phaeopigment	The chemical breakdown product of a chlorophyll *a* molecule. When plant cells die, enzymes enter and break down the chlorophyll *a* molecules.
Retentiveness	The degree to which a river retains organic material that falls into it and becomes lodged in the riverbed or on debris in the riverbed. Many northern hemisphere rivers are "highly retentive" and much autumnal leaf fall is retained during winter. This leaf material is important food for aquatic invertebrates.

Retentiveness (continued)	New Zealand's alpine rivers generally do not retain organic matter to the same extent, reflecting the unpredictable rainfall in alpine regions, and the more unstable substrate. Organic matter is not therefore consumed directly by most invertebrates in New Zealand rivers, many of which feed off periphyton, or prey on other animals.
Riffle	Shallow stretch of a river where water flow is super-critical, i.e. where the water is turbulent.
Riparian	Referring to a river bank.
Spate	Any increase in flow from what it was previously. A spate can be **scouring** where the streambed starts to move, or **subscouring** where there is an increase in discharge but substrate movement does not occur.
Substrate	Any object or material upon or within which a plant or animal organism lives.
Taxon (Taxa pl.)	A general description for a set of organisms, generally referring to varieties, species or genera.
Taxonomic richness	The number of taxa in a particular sample.
Turbidity	The cloudy or hazy appearance in an otherwise naturally clear liquid caused by the suspension of colloidal liquid droplets or fine solids.
Wolman sampling	A method of quantifying riverbed sediments. The observer paces randomly up the river with their eyes closed. At each step, they extend their finger vertically to the ground surface, and the first particle touched is selected. Its size is estimated by comparing it with square holes cut in an aluminium plate. The holes have the same dimensions as the mesh of a set of sieves used by geologists (from 8 mm^2 to 256 mm^2; or -3 to -8 phi, in 0.5 phi increments).