Distribution and Dispersal of Aquatic Invertebrates in the Waitomo Stream

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by

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ABSTRACT

A survey of the distribution and dispersal of aquatic macroinvertebrates was carried out in the Waitomo caves catchment, located South of Hamilton, New Zealand. Eight sites were selected along the Waitomo stream. The sites represented a longitudinal gradient that flowed from the native forested, headwaters to pasture, then into native forest remnants, before flowing into pasture and onto the glowworm caves at the bottom of the catchment. It was found that both the benthic and drift fauna underwent a change in community composition along the length of the catchment. Initially, the diversity decreased and invertebrate abundance increased as the stream flowed from forest to pasture. There was also a change in community composition from 'sensitive' taxa e.g. Plecoptera and *Archichauliodes diversus* to more 'enrichment' tolerant eg chironomids and *Austrosimulium* sp. However the biota of the stream was 'restored' upon the stream flowing into a forest remnant, the Aranui reserve. There was also a seasonal reduction in drift of invertebrates from the Waitomo stream over winter. Additionally significant differences were found for many drift taxa between forest and pasture sites. Suggestions as to future research topics and recommendation for restoration of the catchment streams and biota were made.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

1. Introduction

1.1 Thesis Introduction

The Glowworm *Arachnocampa luminosa* (Skuse) is found throughout New Zealand in damp, sheltered and shaded places in bush and caves. The larvae form of the glowworm is predaceous and lives in a mucus tube or galley from which they hang vertical "fishing lines" made from silk and sticky mucus. Glowworms use bioluminescence to attract flying insects, which are captured on these fishing lines and hauled up and eaten by the larvae (Broadley 1998).

Research at Waitomo has focused on the glowworms, due to their value as a tourism resource. This research has centred primarily on the ecology of the glowworms and their diet. For example, Pugsley (1980) established that the food supply is a major factor controlling the overall distribution of the glowworms. The diet of the glowworm larvae has been previously determined to consist of chironomids with some tipulids, mayflies and caddisflies (Pugsley 1980). The emergence from the grotto benthos has been found to be the main food source for the glowworms, however no evidence of chironomid egg laying has been found, indicating that the source of this food supply is elsewhere in the catchment (Pugsley 1980). In order to maintain a cave glowworm population the streams must transport aquatic insects into the cave from outside. The main transportation method for larvae and exuviae to enter the cave is via drift, thus the nature and distribution of the upstream fauna is of relevance to the glowworm population (Pugsley 1980, Oxenham 1985). However, very little is known about food source pathways to glowworms in cave systems, specifically, which sections of the streams in the catchment contribute which invertebrates and how do these invertebrates disperse throughout the catchment.

Accordingly, the purpose of this study was to determine the distribution and dispersal pathways of benthic and aerial aquatic insects along the Waitomo stream from the headwaters to the glowworm cave to resolve any seasonal changes in availability of glowworm food. Specifically I examined three aspects of the aquatic invertebrate fauna: 1) their distribution in benthic habitats; 2) the composition of the drift; and 3) the emergence of adult insects. Additionally a small-scale intensive study above and within the glowworm cave was carried out to elucidate the source pathways to the glowworms.

This thesis consists of 7 chapters. The remainder of chapter 1 introduces some of the aspects of dispersal techniques of aquatic macroinvertebrates (eg drift) as well as the effects of landuse activities on macroinvertebrates distribution and abundance. Chapter 2 provides a general description of the Waitomo Caves catchment and its landuse, and then details the sites used for this study. Chapter 3 presents the results of physical and chemical parameters measured during this study. Chapter 4 provides the benthic distribution of aquatic invertebrates along the Waitomo stream. Chapter 5 contains the dispersal by drift and upstream migration of aquatic invertebrates and relates to the dispersal of potential food supplies to the glowworms. Chapter 6 covers the emergence and aerial trapping of adult aquatic insects. Chapter 7 contains conclusions based on my findings and a discussion of possible effects of the Waitomo

Catchment Control Scheme and recommendations for monitoring. It also contains a summary of future research needs in the Waitomo catchment.

1.2 Dispersal of aquatic macroinvertebrates

Dispersal, or the movement of individuals from one area to another, is an activity exhibited by most species and is of ecological significance (Smock 1996; Rawer-Jost *et al* 1999). In streams, both active and passive dispersal movements are common among benthic macroinvertebrates in response to a number of factors. The continuous flow of water that helps define a lotic environment provides a convenient and energetically efficient mechanism for downstream dispersal, known as 'drift', but it can force unwanted displacement of individuals to downstream areas and make upstream dispersal or 'migration' difficult. Overland dispersal also occurs, primarily by the flight of adult insects that emerge from the streams. Dispersal of aquatic macroinvertebrates also is a key process in the recolonisation of disturbed areas of streams, such as stream scoured and denuded by spates (Smock 1996).

1.2.1 Drift of Aquatic Invertebrates

Invertebrate drift is the downstream transport of organisms in running waters, it is one of the most intriguing phenomenon in stream ecosystem functioning (Waters 1972). With this steady displacement of animals downstream in the drift, the headwaters would become totally devoid of fauna without upstream migration to compensate (Lock and Williams 1981). The upstream movement of invertebrates in running waters was been frequently observed. Unlike drift, upstream movements are always active. Upstream movement has been shown to exhibit a species-specific seasonal as well as diel periodicity (Soderstrom 1987). However studies of the upstream migrations has found they fail to offset the losses caused by drift (Lock and Williams 1981).

It has been proposed that adult insects have a tendency to fly upstream to oviposit and thereby maintain population size. However, in the absence of density dependence the replenishment from downstream must exactly match the depletion. Hershey *et al* 1993 suggested that depletion need only be slight to shift the entire population downstream as depletion would accumulate through successive generations. It is equally true that if upstream flight is greater than drift then the population will accumulate upstream. It is very unlikely that these conditions will be meet in a natural environment as lotic systems are subject to random perturbations such as flooding (Anholt 1995).

Anholt (1995) describes the action of density dependence as the as the best way to explain the long-term persistence of stream invertebrate populations such to drift losses. Differential reproductive success of invertebrates that undertake upstream migration could explain it evolution and maintenance. The upstream biased dispersal would be favoured by natural selection when the upstream areas are relatively depauperate due to drift. The lower initial population size would mean more resources per capita available and result in higher growth and survival rates for offspring of individuals that oviposit into upstream reaches. Offspring of individuals that migrate upstream also tend to have lower mortality rates as they are less likely to begin life in an unsuitable habitat or die by drifting out of the habitable section of the stream (as they have further to go). Thus, all other parameters being equal, individuals with upstream biased dispersal are favoured because of higher birth rates and lower death rates (Anholt 1995).

1.2.2 Emergence of adult insects

Emergence is measured by collecting insects as they leave the aquatic juvenile stages and enter the terrestrial or the aerial adult stage by installing a trap over a defined area of the water surface (Statzner and Resh 1993). Once adult aquatic insects emerge from the stream they live in the nearby riparian zone where they may select streamside vegetation to complete metamorphosis, to rest while awaiting the proper swamming time, to feed in order to produce eggs, or to mate. The provision of suitable habitat for adult insects, both in quantity and quality is a important consideration as the adult life stage can be crucial in regulating the aquatic larvae population and adults can play an important role in terrestrial food webs (Collier and Smith 1998).

Statzner and Resh (1993) analysed data from over 1 million specimens of stream insects collected in mergence traps at 18 sites, for over 32 trap-collection years and concluded that, a significant relationship does exist between annual emergence biomass and annual benthic secondary production.

1.3 Landuse Activity and Invertebrate Distribution and Dispersal

Streams are the products of their catchments (Hynes 1975). Climate, geology, relief, vegetation and land use are thought to be primary factors in determining composition and abundance of invertebrate assemblages in New Zealand streams (Biggs *et al* 1990; Harding *et al* 1997). It is unlikely that climate, geology and relief will alter significantly on a short term scale in Waitomo, thus changes in vegetation and land use are vital factors in the composition and abundance of the glowworms food supply.

Land use effects the physical, chemical and biological aspects of streams. Studies in New Zealand have demonstrated the effects of differing land use on stream hydrology, water chemistry, light and temperature regimes, energy sources and aquatic biota (Scarsbrook and Halliday 1999). Currently in New Zealand, rural landuses are perceived to be the primary cause of degradation of rivers (Storey and Cowley 1997). Studies in New Zealand and Australia comparing the effects of different landuse practises have found consistent reductions in taxonomic richness in streams draining arable land compared with streams in less developed catchments, and the replacement of enrichment-sensitive taxa with more tolerant taxa (Hogg and Norris 1991; Harding and Winterbourn 1995; Quinn *et al 1997*).

Despite widespread catchment development, significant areas of native vegetation remain in many parts of New Zealand and these areas provide streams that can act as local reference sites when studying land use impacts (Quinn and Cooper 1997).

These studies and others have assessed the differences between catchments under different land use conditions, rather than the effects associated with land-use change within a catchment. While these studies have highlighted the effects of pastoral land use on stream ecosystems, resource managers (e.g. regional councils) and resource users (e.g. farmers) require information on the means of mitigating the adverse effects of pastoral land use (Scarsbrook and Halliday 1999).

2. Study Site:

Waitomo Caves Catchment

2.1 Study Area

The Waitomo caves are situated 10 kilometres South West of Otorohanga and 80 kilometres South of Hamilton (Figure 2.1). All sampling for this study was undertaken in the catchment of the Waitomo caves.

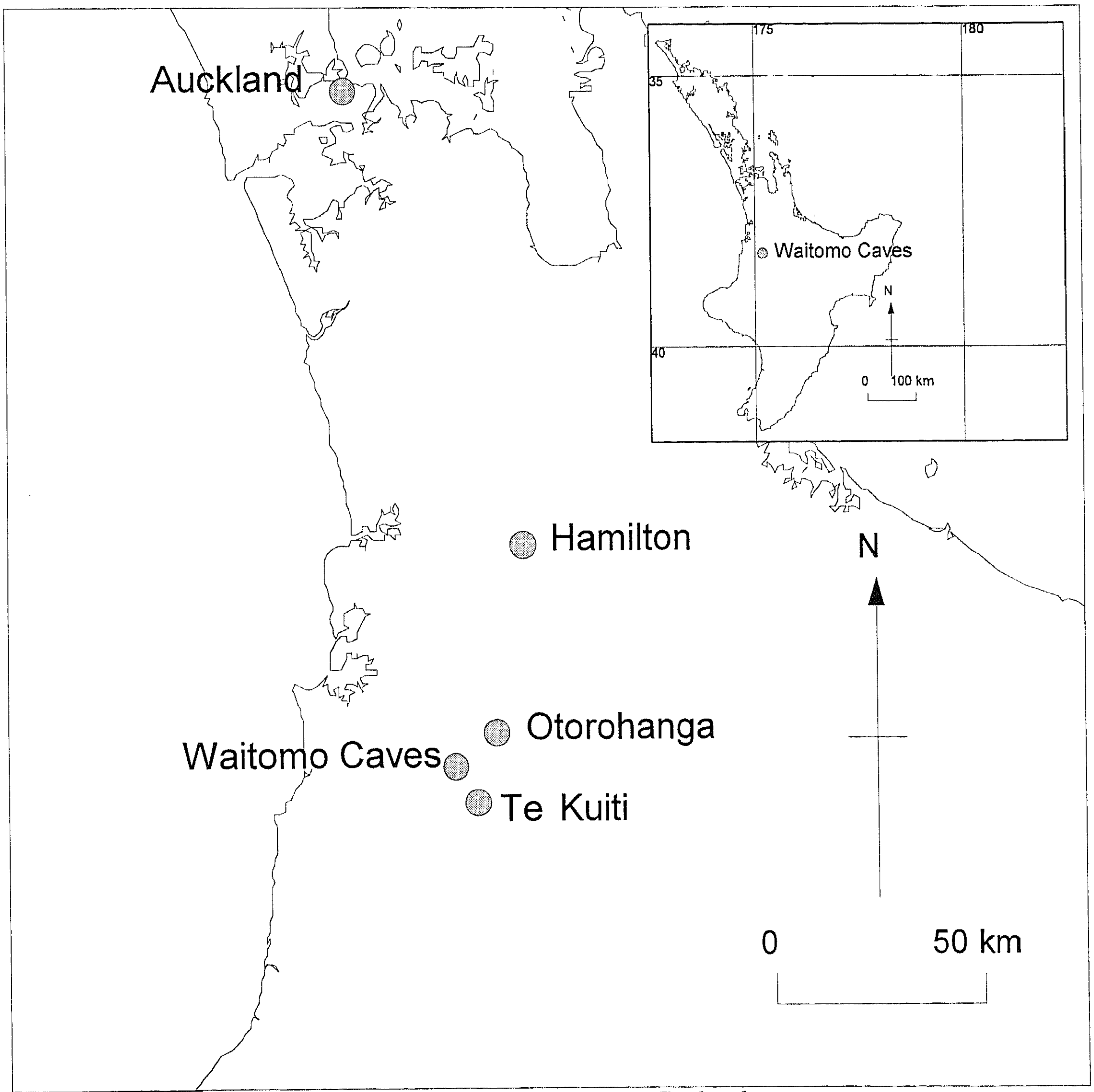

Figure 2.1 Map showing location of Waitomo, New Zealand.

2.1.1 Waitomo Caves catchment

New Zealand is a geologically young landscape with high weathering rates, mostly from sedimentary rock (Mosley 1992) and the Waitomo catchment is no exception.

The Waitomo catchment is characterised by very steep hill slopes. The areas pattern of variable weather systems, combined with the strong orographic influences of the steep King Country hills, results in a rainfall pattern that is marked by intense local instability and short duration high intensity falls (Hawke 1982).

The characteristics of the soils of the Waitomo are generally a function of the tephra layers, which mantle the topography. Resultant soils contain very slippy amorphous clays, which allow free drainage while retaining high moisture content. Soils developed from tephra deposits are considered unsuitable for roading and heavy buildings as they have a low critical limit of stability under pressure, the results of such failure are evident in the numerous slips which occur along the roads of the Waitomo district (Hawke 1982). The sediment from these slips finds it way into the streams of the catchment (Pugsley 1980).

The native vegetation of the district is dominated by podocarp forest. The major species are Rimu *Dacrydium cupressium,* Tawa *Beilschmiedia tawa*, Kahikitea *Podocarpus dacrydiodes* and Totara *Podocarpus totara.* The understorey is dominated by suppplejack *Rhipogonum scandus* and bush lawyer *Rubus cissoides* with frequent occurances of parataniwha *Elatostema rugosum* (Hawke 1982).

Clearing of the catchment began at the turn of the twentieth century, with the large rimu, kahikatea and totara being logged for timber. Next came clearance of the land with the establishment of exotic grassland (Environment Waikato 1997). In New Zealand farming country often forest clearance has been incomplete, with a scattering of small forest fragments left standing (Quinn and Cooper 1997; Storey and Cowley 1997). This was the case in Waitomo where small portions of the basin, notably those with steep slopes or a complex landscape of depressions remaining uncleared. However the grazing of feral goats has modified the understorey and ultimately the composition of these sections. Approximately 10% of the Waitomo catchment remains under the modified natural vegetation, generally having been declared scenic reserves (Hawke 1982). Pasture landuse takes up 78% of the catchment (Environment Waikato 1997).

As a consequence of the steep slopes, soil, rainfall patterns and land use patterns, the valley floor, the Waitomo stream and the world renown Glowworm Grotto have all accumulated over three metres of sediment since 1889 (New Zealand Speleological Society Inc. 1974). Following roadworks in 1975 up to 100cm of sediment was deposited as a result of floods and the remaining life of the glowworm grotto was estimated at less than fifty years (Pugsley 1980). Such erosion and sedimentation has the potential to detrimentally effect the water quality, including the cave systems, and lead to loss of productive potential from the land (Environment Waikato 1997).

It was with this background that the Waitomo Catchment Control Scheme (WCCS) was initiated in 1984 (Fig 2.2). The scheme covers the physical watershed of the

Upper Waitomo stream catchment, an area of 5000 hectares. The Upper Waitomo stream flows through the Waitomo caves before heading north and entering the Waipa river at Otorohanga (Environment Waikato 1997). The primary objective of the scheme is to protect the water quality in the Waitomo catchment, and to encourage appropriate and sustainable land management practises.

Scheme components consist of:

- Fencing and stock retirement of waterways, tomos and erosion prone land.
- Planting of tree species for erosion control.
- Provision of stock crossings and alternative water supplies.
- Minor engineering works (sedimentation dams)

The present day statistics about the catchment control scheme can be seen in table 2.1 While a catchment map showing the spatial layout of these features is found in figure 2.2

Table 2.1 Waitomo Catchment Control Scheme Facts (from Environment Waikato 1999).

Properties involved	14
Replacement value of Scheme	$600 000
Fences	55km
Protected indigenous bush	624ha
Protected/production forestry	350ha
Sediment dams	3
Water supplies	3

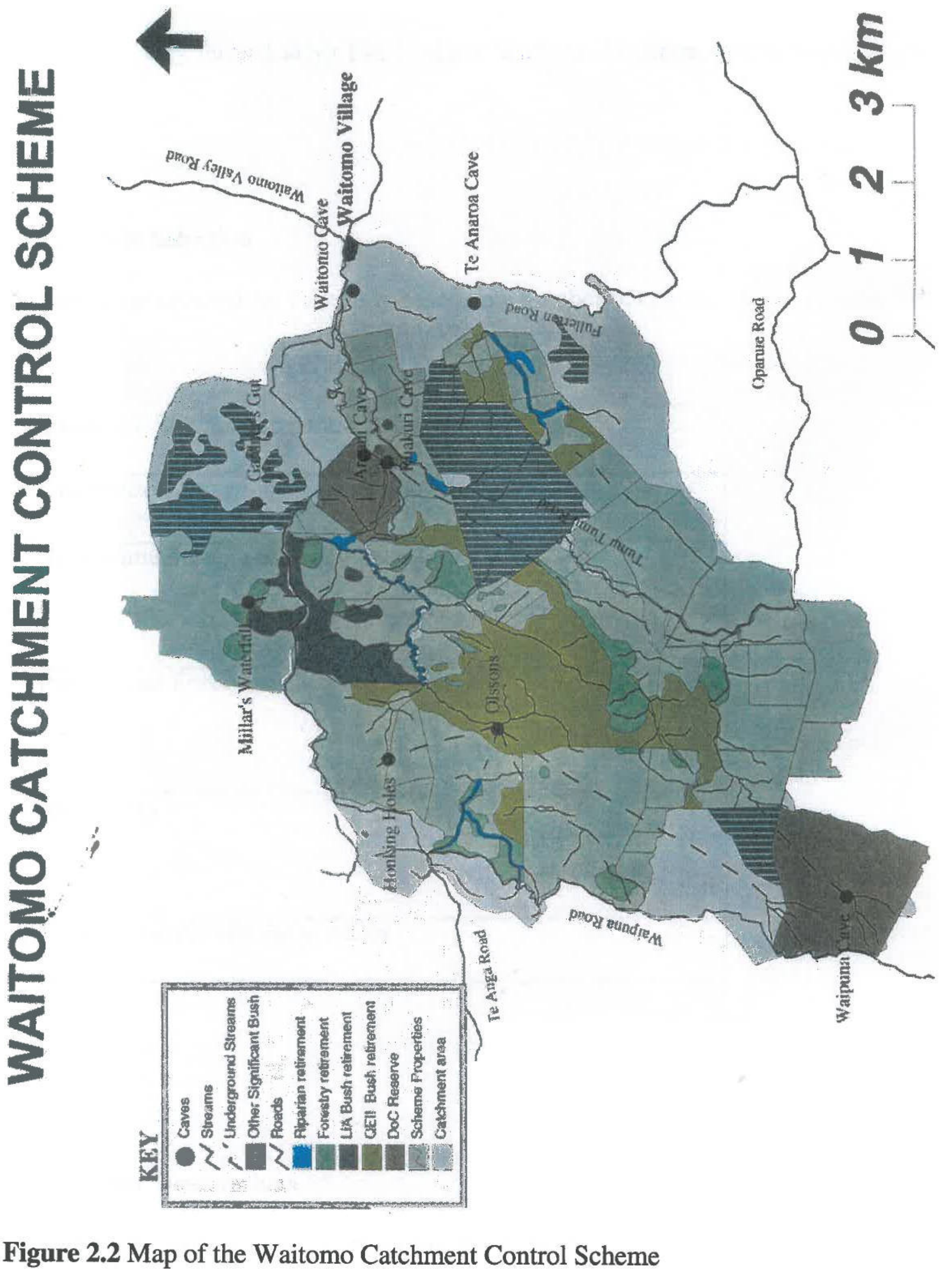

Figure 2.2 Map of the Waitomo Catchment Control Scheme

The Waitomo catchment does not have intensive dairy farming and so a high use of fertiliser in the catchment is not expected, so nutrient addition will not be as great as in intensively farmed areas like lowland Waikato. Sediment conversely is a greater issue.

2.1.2 Site Selection

Sites were selected for this study based on a number of criteria, shown in table 2.2.

Table 2.2 Site Selection Criteria.

Distribution along length of catchment
Sites immediately above and below main tourist cave
Pasture and Forest sites
Site access –
Sites physically similar ie riffles

2.1.3 Site Descriptions

Eight sites were selected from within the Waitomo Caves catchment (Figure 2.3) and sampled over a period of eleven months from February 1999 to December 1999. All sites except site 4 are located on the Waitomo stream. Numerous small first and second order streams drain into the Waitomo stream along the length studied. This is in part due to the highly dendritic nature of karst drainage patterns (Hawke 1982).

Table 2.3 Study Site Details

Site	Site Number	Map reference NZMS 260	Site name
Stream in headwaters – originating in forest	1	R16 886230	"headwaters"
Stream in headwaters pasture	2	S16 907244	"pasture"
Stream junction right 2nd"	3	S16 920243	"aranui
Stream junction left 1st	4	S16 921243	"blackwater"
Stream in pasture	5	S16 932249	"valley"
Upstream of Glowworm cave	6	S16 942248	"submergence"
Glowworm caves.	7	S16 943248	"glowworm grotto"
Downstream of Glowworm cave	8	S16 944249?	"emergence"

Site 1: Headwaters. This site is located on the Haggis farm, in an area of native bush although it is patchy in places with grass growing. The stream emerges from under ground approximately 50m upstream of this site.

Site 2: Pasture. This site was fenced off from stock during the present study in the spring. Prior to this time stock could enter the waterway to drink with detrimental effects on the stream. The site was used as occasional crossing, drinking spot.

Site 3: Aranui. Aranui reserve contains mature native bush with the vegetation types being described in section 2.1.1. The stream flows through over 1 kilometre of reserve before reaching site 3.

Site 4: Blackwater. The site is located 20m downstream of an emergence of the Okahua stream. The Okahua stream flows into the Waitomo downstream of this site. Commercial "blackwater" tubing occurs along the stream inside the cave.

Site 5: Valley. This site is located in pasture The stream channel at this section of the stream has steep banks and pronounced channelisation, while the surrounding paddocks are very flat and used for haymaking.

Site 6: Submergence. The site is immediately upstream of glowworm cave and it vegetation is a mixture of native bush and grass. This vegetation does provide some shade and inputs of allothonous material to the stream.

Site 7: Glowworm grotto. Located within the tourist cave, water velocity is slow leading to sediment deposition. After floods sediment has to be washed from the jetty to resume tourist operations (Pers. Obs.). The glowworm cave is the best known of the tourist caves at Waitomo. The cave takes the Waitomo stream through a low limestone ridge that forms a barrier across the Waitomo valley.

Site 8: Emergence. This site is located immediately downstream of the glowworm cave. On one side of the stream is verged by mown grass and then a carpark, while the other side has blackberry and then long grass.

Initial sampling was carried out at the end of December 1998. Sampling was carried out along the length of the catchment for a further 11 months.

Plate 2.3 Site 3, representative forest site.

Plate 2.4 Site 5, flood conditions. Taken approximately 24 hours after plate 2.3

3. Physical and Chemical Variables

3.1 Methods

3.1.1 Substrate composition

Visual estimates of substrate composition (%) were made using the following particle size scale (From Jowett and Richardson 1990):

Sand (0.06-2 mm nominal diameter)
Fine gravel (2-10 mm)
Gravel (10-64 mm)
Cobble (64-256mm)
Boulder (>256mm)
Bedrock (solid rock surfaces)

3.1.2 Channel Width and Depth

Measurements of the channel width were made at three cross-sections perpendicular to the channel direction in each 20 m length. Channel width was measured by tape measure from the point of maximum rate of change in stream-bank slope (i.e., the point at which the stream bank was most strongly convex). Channel depth was measured at each of the three transects, from the stream bed up to the transept line, with this value representing the depth of water until bank overflow. The width of the stream channel was measured at all sites. The wetted stream width and channel depth was also measured at all eight sites.

3.1.3 Stream Temperature

Three spot measurements were taken for Temperature each month at all eight sites. These measurements were initially taken with a YSI 6000 probe. However this probe was found to be faulty during the year and a YSI 30 and YSI 55 were used for the remainder of the sampling. Initially it was planned to take spot measurements of percent dissolved oxygen and conductivity, however the early measurements made with the YSI 6000 probe proved to wildly inaccurate, so this was discontinued.

3.1.4 Continuous Environmental Data

Environmental data from an Environment Waikato monitoring station in the Aranui reserve was analysed for seasonal trends and extreme events. The site (NZMS 260 S16 939249) is approximately 100m downstream of the confluence of the Waitomo stream and Okahua stream. Sites 3 and 4 are 20m up each respective stream from the confluence. The data set covers the period from January 1993 to July 1999, with automatic monthly samples being taken. Data for percentage dissolved oxygen, turbidity and stream temperature was analysed.

3.2 Results

3.2.1 Substrate Composition

The results of the substrate analysis are found in table 3.1

Table 3.1 Substrate composition of all 8 sites.

Site	Sand (0.06-2 mm)	Fine gravel (2-10 mm)	Gravel (10-64 mm)	Cobble (64-256mm)	Boulder (>256mm)	Bedrock (solid rock surfaces)
1	5	10	5	10	30	40
2	30	20	20	30		
3	5	10	10	15	20	40
4	10	10				20
5	100	-	-	-	-	-
6	100	-	-	-	-	-
7	100	-	-	-	-	-
8	30			10	60	

Site 1 in the forested headwaters, substrate was comprised of mainly bedrock and cobbles. Sites 5,6,7 were totally dominated by a fine sand silty substrate. This is the result of the high levels of suspended solids deposition in the stream. Sites 3 and 4 in Aranui reserve had a very similar substrate to that of the headwaters. Site 2 in pasture had a lot of sand and silt but also cobbles, which provide a more diverse habitat for aquatic life. Site 2 could be considered an intermediate in between the other pasture sites and the forest sites but closer in composition to the pasture. Boulders dominated site 8, this seems unusual given the composition immediately upstream of this site was completely sand/silt dominated. Additionally the valley floor, which this site is in, has been in filled by over three metres of sediment since 1889. The boulders at this site are the remnants of an engineering project designed to slow the stream flow and reduce sedimentation. The result was increased sedimentation due to reduced stream flow and consequently most of the boulders were removed (New Zealand Speleological Society Inc. 1974).

3.2.2 Channel Width and Depth

Table 3.2 Wetted channel width and depth and channel width and depth for all sites.

Site	Channel Width (m)	Channel Depth (m)	Wetted Width (m)	Depth (m)
1	6.5	1.2	5.35	0.3
2	7.00	4.00	4.15	0.6
3	9.00	3.00	5.45	0.4
4	-	-	4.05	0.35
5	9.00	5.00	2.90	1.10
6	6.00	3.00	4.50	1.0
7	-	-	-	3.00-4.00
8	6.50	3.40	4.50	0.50

During the winter months and the flow at site 4 increases, the stream fills an adjacent dry streambed, thus complicating the hydrology. Site 7 is inside the cave, the stream flow slows and a mini 'lake' forms, known as the "glowworm grotto".

3.2.3 Stream Temperature

The temporal pattern of temperature at all sites was found to follow a seasonal pattern, with lowest temperatures in winter and increase in spring through to the highest temperatures in summer (fig 3.1)

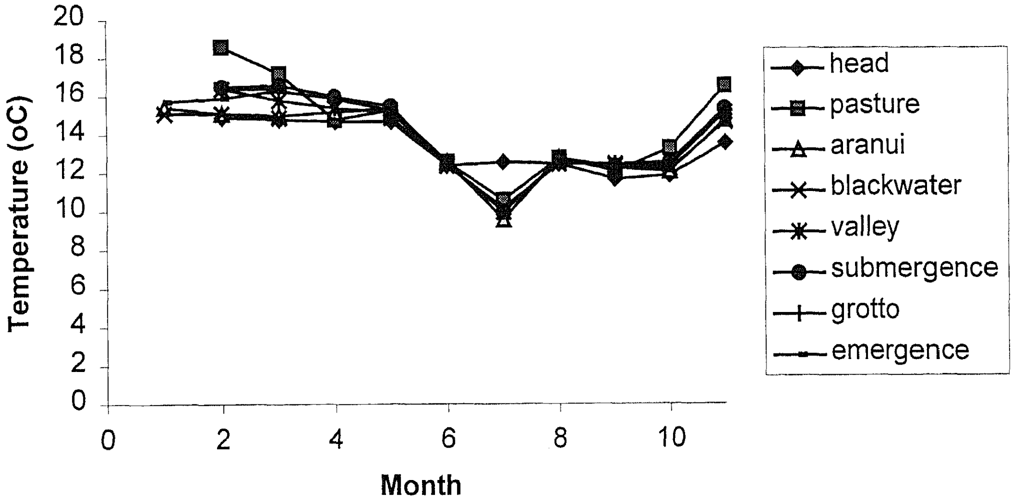

Fig 3.1 Temporal temperature pattern for all sites.

Temperature variation throughout the study period was highest in December (3.8°C) and lowest in June (0.2°C). The maximum temperature recorded was at site 2 in March (18.6°C), while the minimum was recorded at site 6 in July (9.6°C).

The spatial pattern of stream temperature for the study is shown in figure 3.2

Month

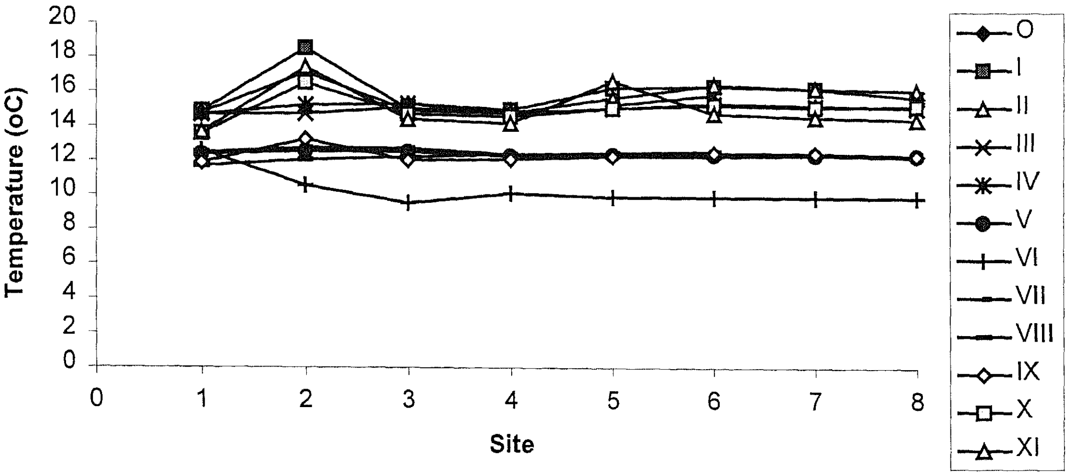

Fig 3.2 Spatial trends in temperature

Within site variation in temperature over the study period was found to be greatest at site 2 (8°C). The least variation within a site over the study was site 1 (3.2°C). This lack of variation is likely to be due to the length of time the water spends underground before emerging.

3.2.4 Continuous Environmental data

Over the six and a half years of years of sampling (n=79) the average stream temperature was 13.9 °C, while the average %DO (percent dissolve oxygen) was 102.9%. The average turbidity measured was 256 NTUs, however this figure is skewed by several large values. The temperature range was 9.7-18.1°C, with the minimum of 9.7°C occurring in July 1997. The maximum, 18.1°C was recorded in February 1997, January 1999 and February 1999. The minimum %DO was recorded in November 1998 (92%), one month after the maximum turbidity reading (421 NTUs October 1998). The maximum percent dissolved oxygen was also correlated with turbidity, with both occurring in February 1994 (126.5 %DO, 1.2 NTUs).

3.3 Discussion

3.3.1 Substrate composition

Site 8 is very different in substrate composition from all the other sites, with the substrate being primarily boulders and sand. This difference is likely to due to anthropogenic disturbances, as rocky rubble was dumped just below the stream emergence. The substrate at Sites 5,6 and 7 completely sandy, this is not surprising as they are located in a low gradient area and therefore experience deposition of sediment. It is this area of the catchment that has accumulated over 3m of sediment in the period 1889 to 1974 (New Zealand Speleological Society Inc. 1974). Pool areas are sediment deposition areas due to their slower flow; therefore they may be more sensitive and quicker to respond to sediment addition than riffles (Hogg and Norris 1991).

3.3.2 Temperature trends

Over the summer months there was a general trend for increases in temperatures from site 1 to site 2, as the stream flows from underground and forest to pasture. The temperature then decreases at site 3 in forest before increasing again as it flows onto pasture at site 5 and a further increase to site 6. Once in the cave at site 7 there was a very slight decrease and further decrease at the emergence from underground at site 8. Site 4 is not included in this analysis as it is a separate stream, however its temperature was consistently similar to that of site 3.

3.3.3. Suspended sediment effects

The extreme suspended solid events in the Waitomo catchment are likely to be detrimentally effecting the biota of the streams. Hogg and Norris (1991) demonstrated a negative effect of runoff from land clearance and development, on benthic macroinvertebrate numbers and species richness in pool areas of a river. They concluded that the deposition of fine inorganic sediment following storm events, and the resulting change in composition of the substratum, was the major cause of low numbers of invertebrates. Following the cessation of incoming sediment and the subsequent flushing of fine deposited sediment from the substratum during high flow events, recovery of benthic invertebrates in pool and shifting sands areas should be rapid. Suspended sediments create a threat to aquatic environments only when they are present over extended periods in unusually large amounts, thereby changing the character of the habitat (Hogg and Norris 1991).

4. Distribution of Benthic Invertebrates

4.1 Benthic Sampling Methods

Freshwater macroinvertebrates are ubiquitous, they are found in even the most environmentally extreme lotic environments. By convention, the term 'macroinvertebrate' refers to invertebrate fauna retained by a 500µm net. However, the early stages of many macroinvertebrate species pass through this mesh size. Because these early stages are important to the understanding of ecological relationships, there has been a trend to use finer mesh (e.g. 125 to 250µm) (Hauer and Resh 1996). It was for these reasons that I used 250µm mesh in the collection of drift and benthic samples. The number of samples collected were based upon the number of replicates required, in order to estimate benthic density with a desired degree of precision and risk of error. A pilot test was carried out in December 1998 to determine this.

For this study, a light collapsible 0.9m^2 Surber sampler was constructed (see plate 4.1). The light construction of this Surber sampler made it easier to handle when in use and especially in transport by foot to the sites. The Surber sampler net was fabricated so that sample containers could be screwed on to it whilst sampling was taking place. A sample container lid with its top cut out was fastened onto the end of the net. This enabled the containers to be screwed on while the sampler was in use and then after all the detritus and organisms were washed down, easily removed.

According to the sampling design, benthic sampling was to been done on 4 occasions, however due to flooding this was not achieved. Analysis of samples was completed on two dates, April and December. On each sampling occasion, 5 samples were taken within a ten-metre reach, at sites1,2,3,4,5 and 8. Site 6 and 7 were not sampled as they were consistently too deep. The order of sampling and the actual sampling positions were determined by the use of random numbers. Labels were added to the samples and they were preserved immediately with 5% formalin. Prior to analysis the samples were rinsed with water in a small hand held dip net with 250 μm netting.

Plate 4.1 Surber Sampler Aparatus.

4.1.1 Statistical analysis

Variances of drift and benthic invertebrates increased with the mean with all taxa indicating the need for data transformation before statistical analysis could be performed. Data was transformed using log transformation.

4.2 Results

During April and December 1999, a total of 12,701 macroinvertebrates were collected from five replicate Surber samples ($0.9m^2$). A total number of 60 benthic samples were collected from sites 1,2,3,4,5

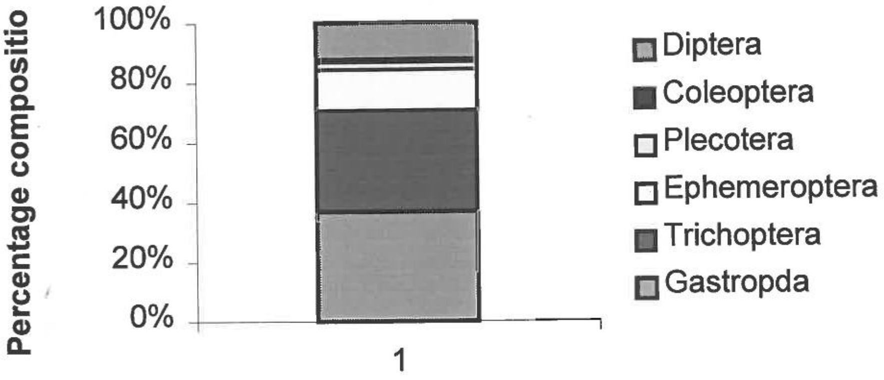

Fig 4.1 Percentage composition of the main taxonomic groups to the total benthic density(number. m^{-2}) at all sites.

The six most numerically abundant orders in the benthos were: Gastropoda (31%), Trichoptera (28.4%), Ephemeroptera (11.5%), Diptera (10.4%), Plecoptera, and Coleoptera (0.9%).

Spatial trends in benthic invertebrates are shown in figures 4.2-4.7

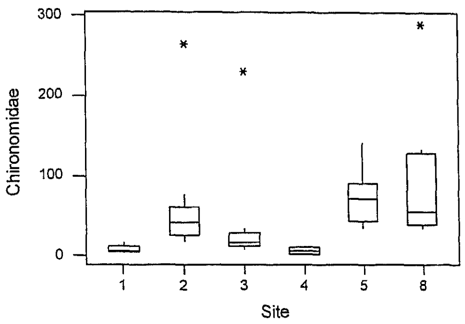

Fig 4.2 Spatial abundance of chironomid spp. in the benthos

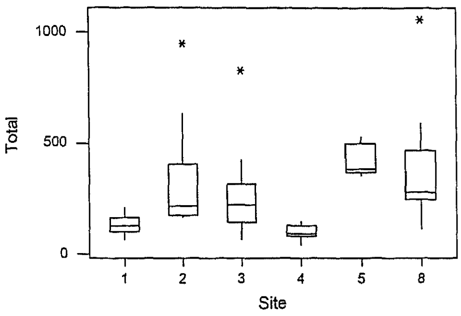

Fig 4.3 Spatial abundance of Total invertebrates in the benthos

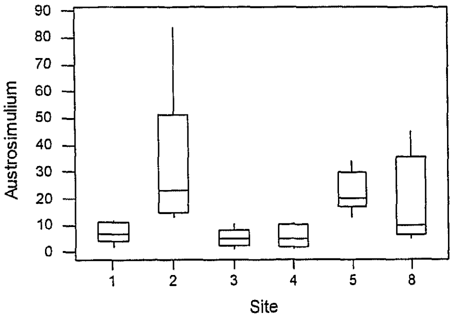

Fig 4.4 Spatial abundance of *Austrosimulium* sp. in the benthos

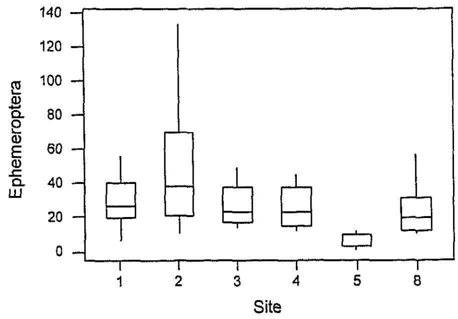

Fig 4.5 Spatial abundance of Ephemeroptera in the benthos

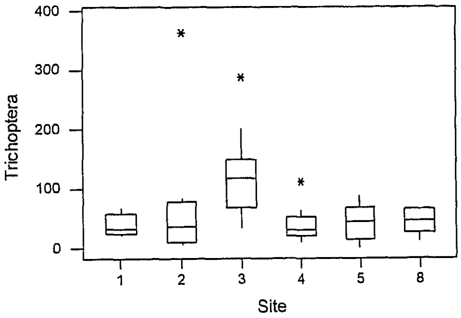

Fig 4.6 Spatial abundance of Trichoptera in the benthos

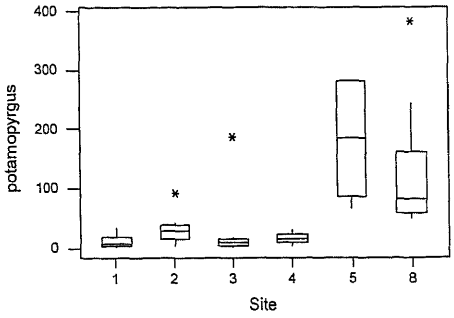

Fig 4.7 Spatial abundance of *Potamopyrgus antipodarum*

The Chironomids and *Austrosimulium* sp. were found to be most abundant in the benthos at the downstream and pasture sites, 2,5,8 (fig4.2 and fig4.4). *Potamopyrgus antipodarum* was numerically dominant at the pasture and downstream sites (fig 4.7). While Trichoptera was most abundant in the benthos of Aranui reserve at site 3(fig4.6). Total invertebrate densities were highest at the pasture sites 2 and 5 and downstream at site 8 (fig4.3). This is shows a general trend for increasing invertebrate density from the headwaters (site 1) to the pastures site 2, Next is a reduction in numbers to site 4 and then another increase to pasture site 5.

Archichauliodes diversus was only found in the benthos at the three forest sites, as was the mayfly, *Coloburiscus humeralis* and the Tipulid, *Aphrophila neozelandica.*

4.3 Discussion

Mayflies, stoneflies and caddisflies dominated the forested sections of the stream, while *Potamopyrgus antipodarum, austrosimulium* sp. and chironomids dominated the pasture and downstream sites. This change in community composition occurred along the length of the catchment and involved a deterioration and restoration of invertebrates associated with better water quality. Additionally there were several taxa that only occurred within the forested sites, indicating a greater species diversity within these regions.

Environment Waikato has been monitoring the stream since 1990 and during this time there has been a significant reduction in suspended sediment (Environment

Waikato 1999). As sediment input to stream has a major effect on the biota, this will have had an effect on the composition of the benthic macroinvertebrates of Waitomo. In conjunction with increasing riparian zones, this could lead to a restoration of aquatic biota that is found in the headwaters. Pugsley (1980) suggested that on basis of evidence of past sediment deposition, that the streambed consisted of fine sediments even before the felling of indigenous forest in the early 1900's. Therefore, even before pasture conversion, chironomids and oligochaetes dominated the macroinvertebrates of the stream. The present study's results indicate that this is unlikely as the forested sites community composition is dominated by caddisflies, mayflies and stoneflies rather than chironomids and oligochaetes.

Attempts to restore streams previously degraded have led to renewed interest in the process by which invertebrates colonise such systems. Rapid recolonisation has often been expected, but some streams still have an improvished insect fauna years after improvements are implemented. The reason for this may lie with the methods of recolonisation. Where remnant populations occur in the same catchment, colonisation may be fast through larval drift, upstream migration and local oviposition. However, if colonisation requires overland flight by egg-bearing females from neighbouring catchment, recovery may be much slower (Peterson *et al* 1999). This study has shown that remnant populations of "undisturbed" invertebrates occur in the headwaters and forested sections of the Waitomo stream, it is from here that potential repopulation of newly restored stream sections can occur.

5. Dispersal by Drift and Upstream Migration

5.1 Introduction

5.1.1 Drift of Aquatic Invertebrates

One of the most studied aspects of drift is its diel periodicity. Numerous studies have shown that drift displays distinct circadian patterns with maximum drift occurring at night (fig 5.1). Many macroinvertebrates display a peak in drift soon after nightfall as the light intensity falls, while others are crepuscular, displaying both dusk and dawn drift peaks (Elliott 1969; Williams 1981; Brewin and Ormerod 1994;Kiffney *et al* 1997).

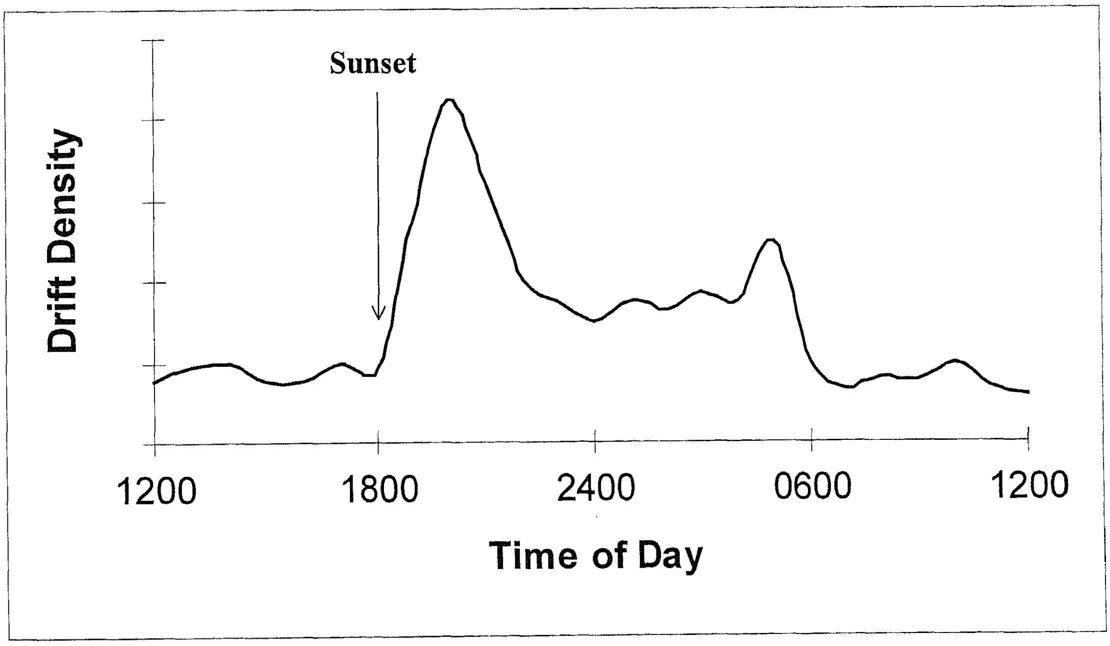

FIG 5.1. Typical macroinvertebrate diel drift pattern. (redrawn from Smock 1996).

These diel cycles in invertebrate densities must be taken into account in research designs and sampling protocols in order to identify and interpret correctly results of studies (Donahue and Schindler 1998).

While the choice of sampling method is dependent upon the question(s) being addressed, several aspects of drift sampling enhance its value as a complementary tool to benthic sampling. Firstly, while drift samplers are biased towards collection of organisms that enter the water column and don't provide a quantitative estimate of the benthic invertebrates per area of stream bottom, they do represent an integrated sample of invertebrates from a variety of habitats. However drift sampling alone may not provide information representative of some systems (e.g. those characterised by oligochaetes, molluscs and heavy cased Trichoptera) it can serve as an effective complimentary tool to direct sampling. Secondly, drift samples are fairly 'clean', with invertebrates not being mixed with substrate from the stream bottom. Thirdly, drift sampling is non-destructive, as it does not disturb the bottom substrate (Pringle and Ramirez 1998). Additionally variation between drift samples is smaller than between benthic samples (Matthaei *et al* 1998).

Drift samplings potential value in assessing species composition and monitoring water quality has been illustrated in studies of larval Chironomidae (e.g. Wilson and Bright 1973; Wilson and McGill 1977; McGill *et al* 1979).

The understanding of benthic communities in stream is complicated by the fact that sampling techniques do not always indicate actual community composition and structure. Most techniques are insect based and sample only streambed substrate, for eg Surber and Hess samplers. Techniques to assess stream communities in less direct ways have not been widely used, for e.g. while drift samplers have often been employed to study insect behaviour (Waters 1972), only a few studies have used this method to assess benthic community composition (Pringle and Ramirez 1998).

5.1.2 Upstream Migration of invertebrates

The upstream movements and migration of benthic macroinvertebrates are also an important component of running water systems. Upstream migration is movement against the stream flow and therefore clearly non-random (Rawer-Jost *et al* 1999). Benthic invertebrates have been found to migrate over considerable distances (Rawer-Jost *et al* 1999).

5.2 Methods

5.2.1 Drift sampling

For the drift sampling, a sampler was constructed with an opening of 0.3m by $0.2m^2$ (plate 5.1). Two pieces of tubular aluminium were attached to each side of the frame, allowing the nets to be placed in the stream with the use of metal stakes. The net was made of 250 μm mesh and was 0.8m long, funnelling down from the frame to a point. The apex of the net was left open for the attachment of sampling vessels, this was achieved by attaching the lid of a container with a hole cut in the top. This enabled the sample containers to be screwed onto the net for sampling and then removed with the sample.

Sampling was carried out once a month at all sites except 7, for a twelve-hour period starting approximately 1/2 hour before dusk. Sample duration was chosen as the sample unit rather than sample volume as per Culp and Srimgeour (1994). This choice was made based on the fact it is easier to standardise sample duration under field conditions. Although some variation occurred in sampling volume among replicate nets, this was reduced by sampling areas with a uniform current.

Three nets were used at each site to provide three replicate samples. Site 7 inside the glowworm cave was not sampled as the water was too deep for the deployment of this type of drift net. The net was anchored to the substrate with two electric fence standards with the foot removed, except at sites where the substrate did not allow this, at these sites the nets were attached to concrete anchor with a rope cradle (plate 5.2). The nets were placed approximately 20m off the stream bed. When the net was emptied, it was lifted out of the stream and all organisms and debris was washed down into the sample bottle by splashing the net with stream water. Sample labels were added and the invertebrates preserved in 5% formalin before transportation back to the laboratory. In the laboratory, samples were washed through a 250μm dip net and then identified. For data transformation see section 4.2.1.

Plate 5.1 Drift Sampler Aparatus

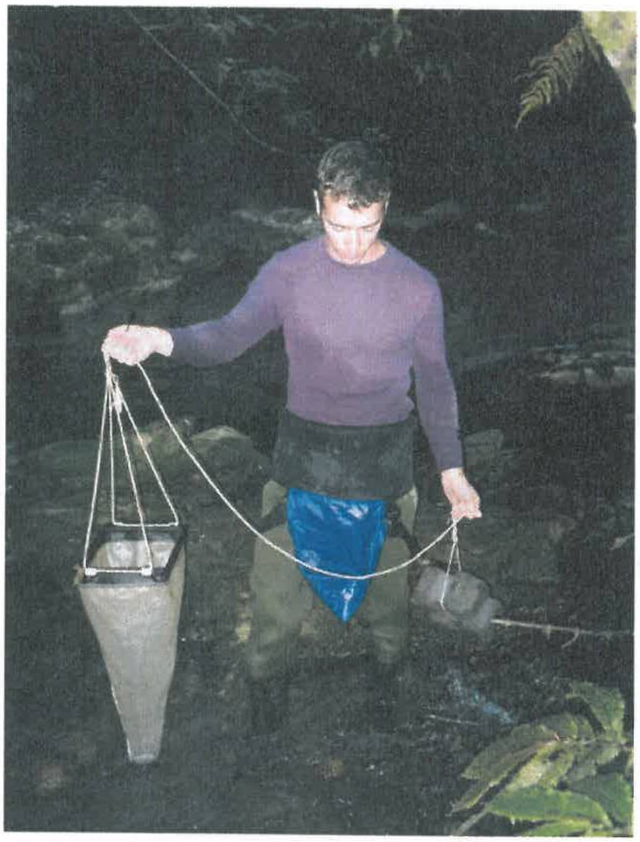

Plate 5.2 Drift Sampler in Use

5.2.2.Migration

Drift and upstream movement of benthic macroinvertebrates were measured using a combination drift-upstream movement sampler (plate 5.3) (Hobbs and Butler 1981). However it was constructed out of sheet metal instead of plywood. The drift opening was 0.3m by 0.2m^2, the same as the other drift nets used. While the two migration entrances were 0.15m by 0.3m^2 each. The nets used were 250µm mesh with the same vessel attachment as the drift and Surber sampler. 250µm mesh was also used on the front of the trap to stop organisms entering the sample from the drift. This sampler was utilised for a 12-hour period at sites 6 and 8 every month commencing in March, once the sampler was constructed. The upstream migration was sampled in an attempt to determine whether any invertebrate migration is occurring into the glowworm cave from downstream, or occurring upstream from site 6.

5.2.3 Water velocity

Water velocity was measured at the start of the sampling period for both drift and migration using a Marsh McBirney flow meter. Measuring the velocity of the water that flows through a known space (drift and migration samplers) over a known time (12 hour sampling period) means the invertebrates trapped can be calculated as a number per metre square of water. This was discontinued after the meter developed a fault, however the initial measurements were used to determine if any clogging of the nets was occurring and causing back eddies in the entrance to the nets. There were no significant differences between the before and after measurements. However this was under low flow conditions and there was no measurements of the velocity during peak flow and increased suspended solids.

Plate 5.3 Hobbs and Butler (1981) Combination upstream migration/drift sampler, with lid removed to show internal design.

5.3 Results

5.3.1 Drift

A total of 13,005 individual organisms were collected from the drift at the 7 drift sites from February to December 1999. June, August and September sampling could not be completed due to flooding.

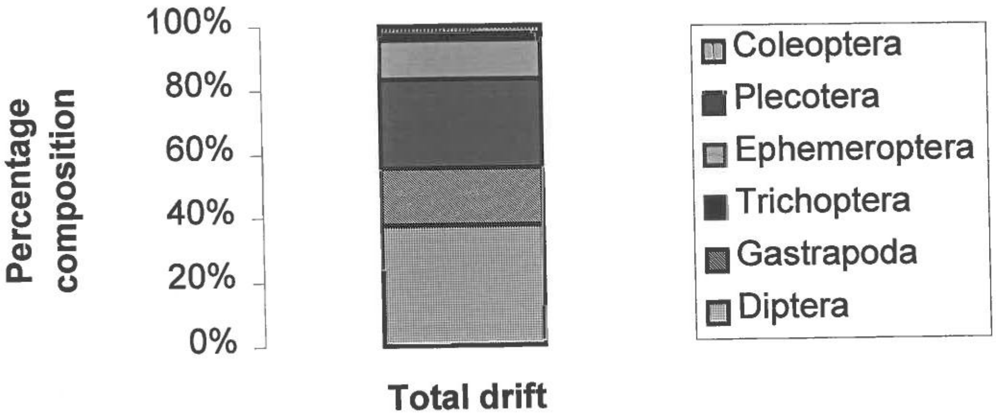

Figure 5.2 Percentage composition of the invertebrate orders in the total drift.

Diptera was the most numerically dominant order within the drift, contributing 37.4% of the total drift observed (Figure 5.2). This was followed by Trichoptera (27.9%), Gastropoda (17.8%), Ephemeroptera (12.3%), Plecoptera (2%), and Coleoptera (2.6%). The Diptera was comprised of two main groups, the blackfly *Austrosimulium* sp. and Chironomid spp. The Gastropoda was almost entirely comprised of the hydrobiid snail *Potamopyrgus antipodarum.*

The spatial trends in drift abundance of Invertebrates were calculated for the entire study period from February 1999 to December 1999, excluding 3 flood interrupted sampling events.

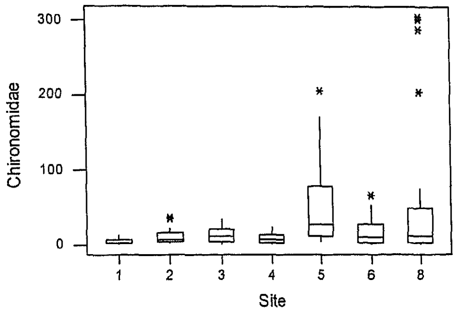

Fig 5.3 Spatial abundance of chironomids in the drift.

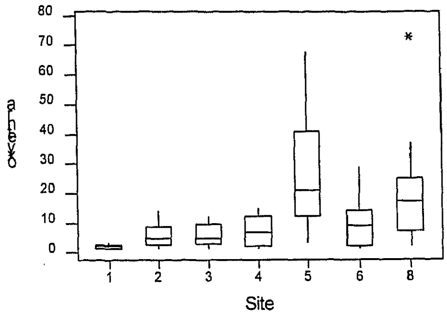

Fig 5.4 Spatial abundance of *Oxyethira albiceps* in the drift.

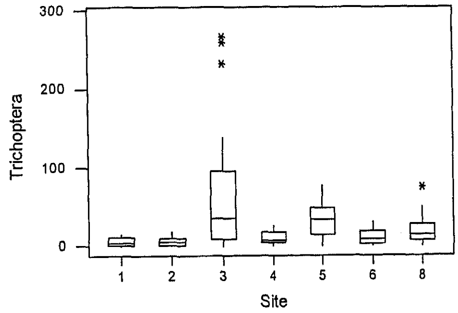

Fig 5.5 Spatial abundance of Trichoptera in the drift.

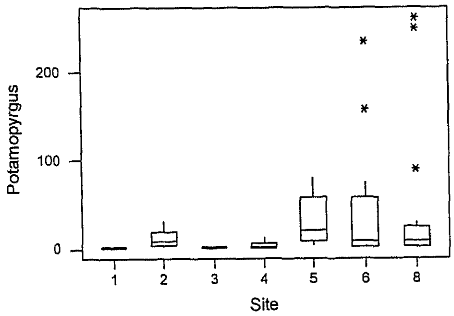

Fig 5.6 Spatial abundance of *Potamopyrgus antipodarum* in drift.

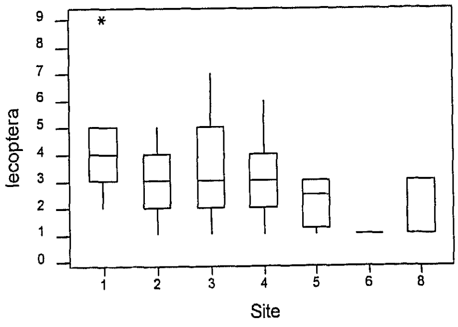

Fig 5.7 Spatial abundance of Plecoptera.

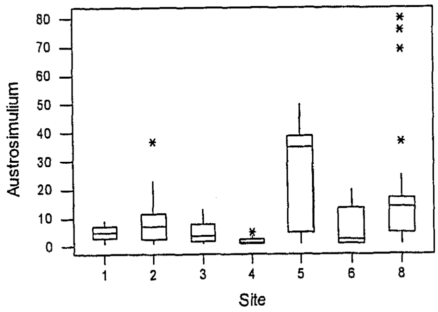

Fig 5.8 Spatial abundance of *Austrosimulium* sp. in the drift.

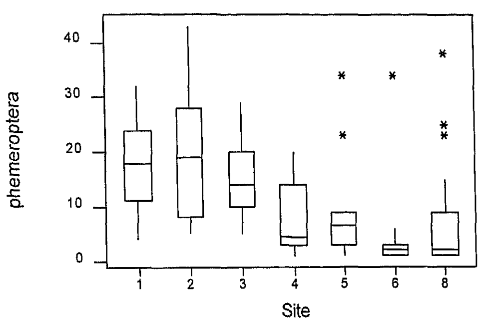

Fig 5.9 Spatial abundance of Ephemeroptera

in the drift.

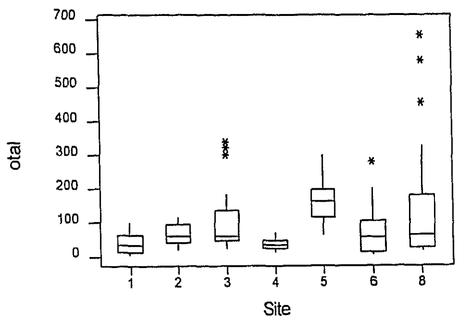

Fig 5.10 Spatial abundance of all invertebrates in the drift.

Chironomid species were found to occur in their highest abundance in pasture at site 5 and downstream sites 6 and 8 (figure 5.3). Relatively lower numbers were found at the upstream sites including the pasture site 2. The algal piercing *Oxyethira albiceps* was found to be most abundant the three downstream sites especially the pasture site 5 (figure 5.4). While total Trichoptera numbers in the drift were highest at site 3 in the Aranui reserve, the effect of the *Oxyethira albiceps* can be seen as an increase in numbers at sites 6 and 8 (figure 5.5). *Potamopyrgus antipodarum* followed a similar trend of increasing at the downstream sites (figure 5.6). The low numbers of *Potamopyrgus antipodarum* at site 1 increased downstream to the pasture site 2 and then decreased again at site 3. The spatial abundance of Plecoptera (figure 5.7) in the drift showed a gradual trend of decreasing from the headwaters, to the bottom of the catchment. *Austrosimulium* sp. were by far were found in their greatest numbers in the drift at the three downstream sites of 5,6 and 8 (figure 5.8). This increase in numbers from the upstream sites is likely due to landuse change. Ephemeroptera increased from the headwaters site 1 to the pasture site 2 (figure 5.9). This is a similar trend to the benthos. Then they decreased in drift abundance along the longitudinal gradient to the bottom of the catchment.

Sites 1 and 3 were combined to indicate the composition of the forested sites (n= 39) and compared with the composition of the pasture sites 2 and 5 (n=36) (Figure 5.3)

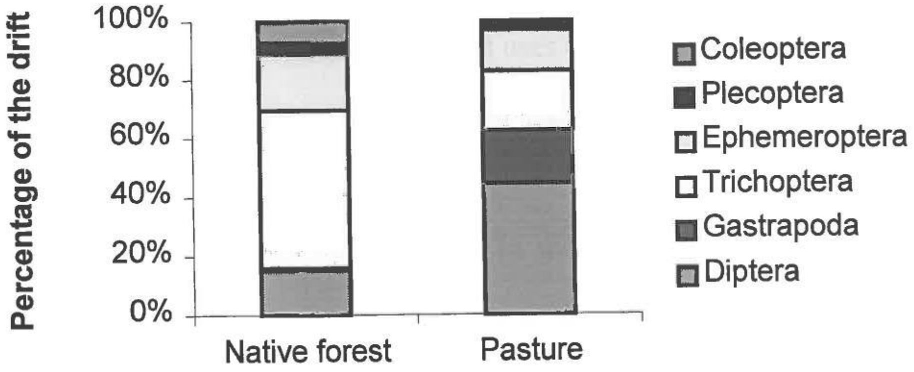

Figure 5.11 Mean percentage contributions of the main invertebrate orders to the total aquatic drift between native forest (sites 1 and 3) and pasture sites (sites 2 and 5)

It was found that Diptera increased in composition of the drift at the pasture sites from that found at the native forest sites, as did the Gastropoda (figure 5.11). While Trichoptera, Ephemeroptera, Plecoptera, and Coleoptera decreased. This is similar to the pattern observed in the benthic samples and other New Zealand land use studies (Harding and Winterbourn 1995; Scott *et al* 1994; Quinn and Hickey 1990).

One way ANNOVA were performed on the log transformed data to indicate differences in drift between different land uses (table 5.1).

Table 5.1 Effects of land use on invertebrate drift. n.s., not significant;*P<0.05.pasture n =36, forest n=39

Taxa	Forest to pasture effect on invertebrate drift	P
Potamopyrgus antipodarum	Increase	*
Trichoptera	Decrease	*
Ephemeroptera	Decrease	n.s.
Plecoptera	Decrease	n.s.
Coleoptera	Decrease	*
Chironomids	Increase	*
Austrosimulium sp.	Increase	*
Total Invertebrates	Increase	*

There was a significant difference ($p<0.05$) between native forest and pasture sites for total drift abundance.

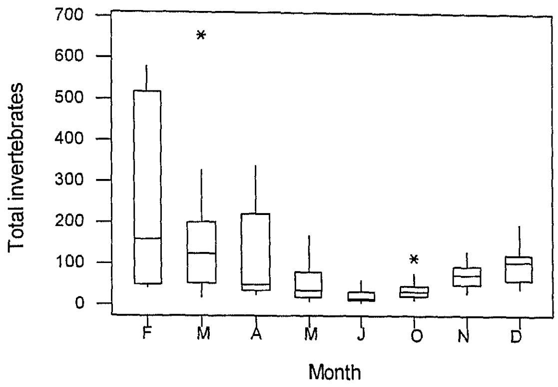

Fig 5.12 Temporal abundance of all drift invertebrates sampled.

The total drift abundance was highest over the summer months and then decreased through winter before experiencing an increase in spring.

5.3.2 Upstream Migration

A total of 28 migration samples were taken over the study period, samples were not obtained from June, August, or September, as the stream was flooded at these times. The samples from May at site 6 were invalidated as the trap was tipped on its side. A total of 357 upstream migration individuals were obtained. A total of 168 individuals were obtained from site 6, while 189 individuals were obtained from site 8. The composition of the sites was compared and found to similar (Figure 5.13).

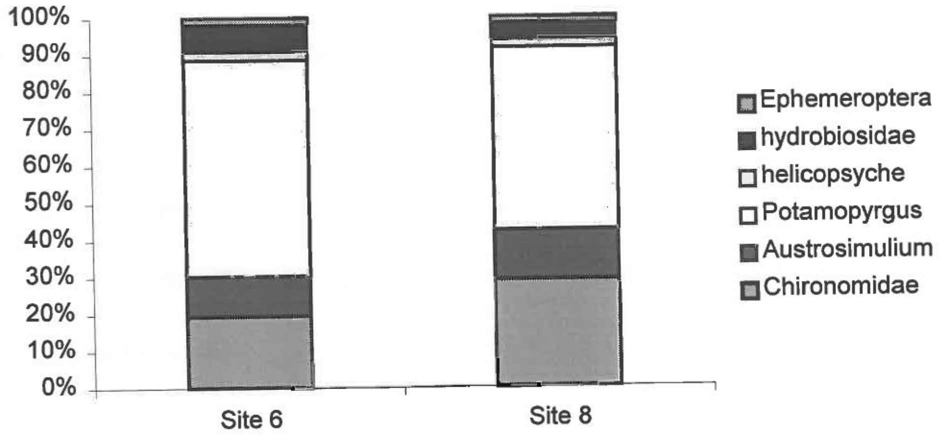

Fig 5.13 Composition of the main groups of upstream migration

Potamopyrgus was most the most numerically dominant group, contributing 53% of the upstream migration observed. This was followed by chironomidae (24%), then Austrosimulium sp.12%, and then Trichoptera 8%

Temporal patterns in upstream migration are shown in figure x

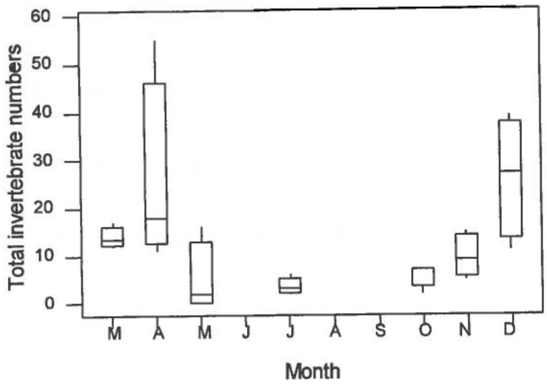

Figure 5.14 Temporal pattern of invertebrate upstream migration.

The largest numbers of migration occurred in April with another peak in December, 1999. The lowest numbers of upstream migration were recorded during July.

While the migration/ drift sampler supplies 2 upstream migration samples for every drift sample, the design of the sampler is such that the drift opening is twice that of the migration opening. In other words a single drift sample is equivalent to 2 migration samples. The replacement of invertebrates by upstream migration was calculated to be 54.4%

5.4 Discussion

Variation in estimates of drift density for stream invertebrates is composed of temporal and spatial factors. For example, temporal changes in the densities of most species occur throughout a diel cycle, among seasons or with catastrophic changes in discharge. Spatial components include, the variation due to the placement of the sampler across the stream and vertically within the water column, as well as variations due to site (Culp *et al* 1994).

The drift results showed a "restoration" of species that would be expected if the physical-chemical parameters are "restored" by entering the native forest, for eg an increase in stoneflies. The results also indicate that invertebrate drift would be a key element in restoration of biota following landuse changes like the control scheme.

The dispersal by drift at the down stream sites of 6 and 8 while not in pasture reflected that of site 5 but to a slightly lesser degree, for e.g. chironomid species and the caddisfly, *Oxyethira albiceps* and the *Austrosimulium* species. Kerby (1995) found that the presence of chironomid and simuliid larvae in the drift may have been a direct response to hunger, as indicated by the higher proportion of individuals with empty or partially empty gust compared with those remaining in the benthos. It has also been found that some taxa of stream invertebrates responded to artificial UVB radiation by entering the drift. Insects that inhabit the tops or sides of rock surfaces e.g. mayflies, caddisflies and blackflies were more vulnerable to UVB than insects that inhabit areas not usually exposed e.g. stoneflies (Kiffney *et al* 1997). In the summer of 1998 at Lauder, Central Otago, New Zealand, peak erythemal UV was about 12% more than 10 years ago when measurements began. Larger increases were seen for DNA-damaging and plant damaging UV, whereas UV-A radiation, which is not affected by ozone, showed no change (McKenzie *et al* 1999). The stream in the pasture sites is likely to be exposed to more UV radiation than forested sites due to the lack of riparian shading. There are very few drivers of land use change that operate over very short time scales or narrow spatial scale, with the almost instantaneous reduction in stream shade from forest clearance as one exception (Quinn and Cooper 1997).

Townsend and Hildrew (1976) noted that certain species are intrinsically highly mobile and colonise new substrate quickly, whereas others are highly mobile only because of their susceptibility to flow perturbations.

There was a decrease in the numbers of invertebrate drift over the winter months. Samples were not taken in flood events due to the magnitude of these events and so it is not known if drift increased during these events. Chironomidae were found to be most susceptible to changes in flow by Winterbottom *et al* (1997). It is hard to elucidate the trend more than this, due to flood events that potentially increase the drift were impossible to sample. Rosenberg and Wiens (1975) reported increased drift when the sediment load of a small river was artificially added to. Pugsley (1980) noted that this effect would tend to increase the drift in the Waitomo stream during floods, when the sediment load increases dramatically.

Recolonisation studies have shown that normal carrying capacity can be replenished by drift alone in as little as 10 to 14 days, in some instances (Waters 1964), however four weeks seems to be the average (Williams 1981). Townsend and Hildrew (1976) found that drift was responsible for 82% of the colonisation of denuded areas of streambed in Broadstone Stream, whereas Williams and Hynes (1976) found that 42% of colonisation was due to drift in a Canadian stream.

The glowworm life cycle is not well synchronised, however the overall trend is one of greatest numbers hatching over 2-3 months of spring and early summer (Pugsley 1980). The food supply fluctuated on a broad seasonal basis, however there was a marked increase in spring. Pugsley considered an increase in spring could provide the impetus for the pupation of fifth instar larvae (Pugsley 1980).

Storey and Cowley 1997 found that, existing forest remnants around streams can act as effective refuges for aquatic invertebrates by altering habitat characteristics of a stream over short distances. Such refuges may be able to prevent the loss of aquatic species, and may act as sources of invertebrates for colonisation of other restored stream sections (Storey and Cowley 1997). Drift is a vital link between these source areas and the glowworms.

Upstream migration was found to be much less than downstream drift, similar trends have been found in other studies e.g. Elliott (1971). In the same study it was shown that most of the invertebrates moved upstream near the banks (Elliott 1971), in this study, the sampler was positioned midstream as it was unable to be settled properly near the edges. In part this may be due to the fact that the upstream migration sampler was put in place and removed on each sampling occasion. It would have been better to leave the sampler *in situ* and just attach the nets for sampling on each occasion. However this was not possible due to the possibility of human disturbances.

The high numbers of upstream migrating *Potamopyrgus antipodarum* is likely to a compensation mechanism as they do not posses a flying adult form to offset the downstream displacement caused by drift. The greater a species tendency to drift, the more important is the development of a compensation upstream migration (Lock and Williams 1981).

6. Aerial and Emergence Sampling

6.1 Introduction

The purpose of the aerial entrance net was to measure the number of insects entering the cave as adults. These adults would have emerged from diverse sources such as the Waitomo stream, swamp or bush. However this aspect of the study was not attempting to determine the sources of these flying insects, rather, it aimed to determine if the food supply to the glowworms was entering the cave via the air.

6.2 Methods

6.2.1 Emergence

Emergence nets were constructed for this study (see plate 6.1). Other options were considered, Pugsley (1980) used light traps inside the glowworm cave, with the intention of providing continuous quantitative emergence data, but due to possible detrimental effects on the glowworms this was discontinued. The emergence nets were floated on the surface of the water on polystyrene, attached to the bottom frame of the net. The traps had a 0.5 m square base and were constructed out PVC pipe.

These nets were used at all eight sites for a period of 14 days. This period was determined by a pilot study as long enough to obtain a reasonable number of individuals.

The emergence nets proved prone to damage from both natural and anthropogenic origins. Flood events were the main problem, the nets themselves were often undamaged but the sample containers dislodged. Also increases in water velocity and height led to the traps being tipped upside down and beached. Sampling was carried out from February until June 1999, when sampling was abandoned due to loss of traps.

Plate 6.1 Adult aquatic insect emergence sampler.

6.2.2 Aerial entrance trap

Pugsley (1980) attempted to trap the insects flying into the glowworm cave from the upstream or submergence entrance. However it was found that the insects were setting on the fabric and not entering the funnel shaped section of his trap. The aerial entrance trap used in this study (see plate 6.2) was designed with this problem in mind. The front of the net was rectangular in shape, with dimensions of 1m high by 2m wide. From this rectangle there were essentially two, The inner one had a 280mm opening to allow the insects into it. The second, outer net tapered to a point 2.3m back, where a collecting vessel was attached. This lid of this vessel was cut out and screwed onto the net, an inverted funnel was also attached. This meant that the vessel could be unscrewed from the net to collect any insects caught. The aim was for the insects to be funnelled through the larger aperture near the front. It would not matter if they didn't fly to the collection vessel at the back as any insects settling on the material would be captured when the large entrance was closed in the morning prior to removal.

6.2.3 Intensive sampling – Food Pathways

At the stream submergence the large aerial entrance net was set up (see section 6.2.2). Twenty "Rentokil" flypapers or 'sticky strips' were suspended from a string near the upstream entrance to the glowworm cave, or submergence (plate 6.2 and 6.3).
Rentokil Ltd., Felcourt, East Grinstead, West Sussex RH19 2JY. Tel(01342) 833022.

Ten floating emergence traps (see section 6.2.1) were placed in the glowworm cave. These traps were situated by the viewing platform in the demonstration chamber. This area was chosen as it was out of the immediate view of the public but also by a large population of glowworms. Twenty sticky traps were suspended on string and hung from the viewing platform. All traps were left in place for ten days.

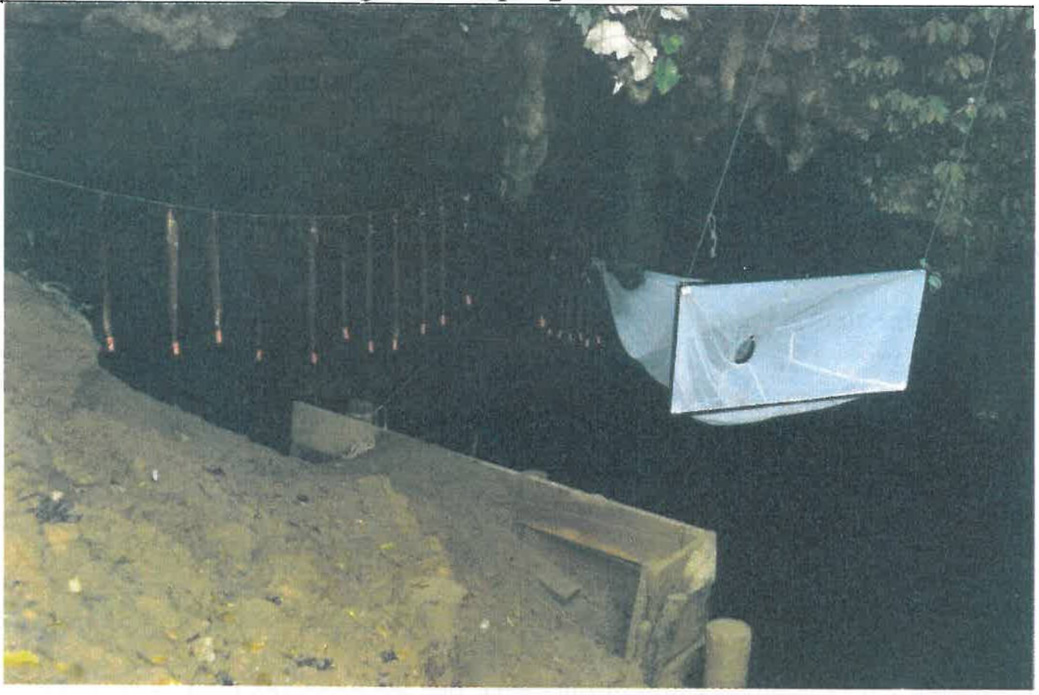

Plate 6.2 Aerial entrance trap and sticky traps out side submergence entrance. Photo Kate Banbury.

Plate 6.3 Sticky traps hanging outside the entrance to the glowworm cave/submergence.

Photo Kate Banbury.

6.3 Results

6.3.1 Emergence

Emergence sampling was carried out at all eight sites for the months of February, March, April and May, before flooding in June caused a halt in sampling. It was planned to start sampling again in spring however the damage to traps meant this was not achieved. The sampling period (14 days) to meant it was too likely that the replacement traps (borrowed from another study) would be damaged. In the 4 sampling occasions only 2 individuals were trapped at site 7 in the glowworm cave. They were both chironomids and were captured in February. Other sites had very low numbers of capture as well. As the numbers were so low (in many cases only one representative of each taxa) the results were not analysed statistically.

Sites 1,3,4 had caddisflies, chironomids and occasionally mayflies. Sites 5,6,and 8 captured chironomids, *Austrosimulium* sp. Additionally site 5 had the largest emergence of a single species, 5 individual *Oxyethira albiceps* in March. Site 2 in pasture had chironomids, *Austrosimulium* sp and mayfly emergence. This again reinforces the benthic and drift results that site 2 is intermediate between pasture and forest

6.3.2 Aerial entrance trap

Due to the lateness in construction of the aerial entrance trap it was first trialed in July, 1999 and used right through to December 1999. However it was not successful in catching any flying insects.

6.3.3 Intensive method

During the 10 day intensive study period a total of 725 individual insects were captured on the sticky traps at the entrance to the cave, compared with 34 individuals inside the cave. This indicates over that 21 times as many insects were flying around the cave entrance as inside.

The ten emergence traps inside the glowworm cave only captured one individual, this was a chironomid and it was found dead on top of the sample container. Therefore it is not known if it emerged from the stream or flew into the cave. The aerial entrance trap did not catch any insects during the intensive study period.

6.4 Discussion

6.4.1 Emergence

Low numbers of emerged aquatic invertebrates were captured during sampling, especially inside the glowworm cave. As a comparison, Pugsley (1980) used two floating emergence traps in the Glowworm grotto but met with little success. Oxenham (1985) also used two emergence traps on three occasions, for a period of 24 hours. After only capturing one chironomid, emergence sampling was abandoned.

It was found that the ethanol used in the sampling containers was gone after the sampling period. This leakage was caused by the ethanol dissolving the original sealant. Selleys wet seal – co-polymer sealant was used to overcome this problem. The loss of the ethanol was not the problem *per se*, as samples were recovered in 'dry' conditions. However in the absence of ethanol, spiders entered the containers and set up home where they had a ready supply of invertebrates. It was impossible to estimate the effect they had on invertebrate capture numbers.

A reduction in channel width in streams converted to pasture will lead to a reduced water width and therefore the habitat useable by aquatic organisms. To compensate for the reduced width, Davies-Colley (1997) predicted a corresponding increase in average stream depth. This will have negative ecological implications, in particular, sites for emergence of adult stream insects (eg emergent cobbles, boulders and woody debris) may be more frequently inundated (Davis-Colley 1997).

6.4.2 Aerial entrance trap

This trap did not catch any flying insect during the study

6.4.3 Intensive method

There were significantly more insects trapped on the sticky traps at the entrance to the cave than inside it. Pugsley (1980) believed that most of the midges the glowworms ate were coming from the grotto benthos itself. However this result indicates that there is a more potential food outside the glowworm cave, than within

It must be remembered that terrestrial invertebrates do provide a food supply to glowworms especially in areas like the Aranui reserve (Broadley 1998) and the presence of terrestrial invertebrates could account for some of the large variation in numbers between in the inside and outside sticky traps.

Pugsley (1980) considered it unlikely that insects would fly to the demonstration chamber from outside. This means that the invertebrates trapped by the viewing platform are likely to have emerged from the stream benthos. However the lack of insects in the emergence nets does not back this up. One possible explanation for this is the patchiness of benthic fauna in the cave (Pugsley 1980).

In the monthly emergence sampling that was carried out, on every occasion, every site had more emergence than the viewing platform. So the extremely low numbers of emergence from the demonstration platform area has been shown on 5 separate sampling periods. Yet there is a healthy population of glowworms at this site. Additionally the presence of flying invertebrates is further backed up by the results from the sticky traps at the platform. Thus

Despite the lower numbers of adult invertebrates found at the viewing platform, this site has sufficient invertebrates to supply the large number of glowworm larvae found here. Indeed glowworms appear to be able to go long periods without food, Broadley (1998) found that they survived on little or no food for 78 days.

Glowworms have been found to inhabit areas where aerial access by adult insects is not possible. The New Cave Chamber is sumped (filled to the roof with water) and accessed only via diving (Pugsley 1980). This means that glowworms living in these caverns are supplied by insects that emerge out of the stream within the cavern, rather than adults flying in. Drift must play an important part in this system as Pugsley (1980) found no evidence of invertebrates laying eggs with the cave.

7. Summary and Recommendations

7.1 Summary

In conclusion, the use of benthic, drift and emergence sampling techniques provided important and often complementary information on stream invertebrate communities along alongitudinal gradient extending from the headwaters to the Glowworm cave in the Waitomo catchment. The importance of this study relates to the food supply that adult aquatic invertebrates potentially provide for the Waitomo glowworms and the distribution and dispersal of these organisms along the length of a karst catchment.

The benthic, drift and emergence results all indicate a decrease in water quality as the stream flows from the headwaters to pasture, however the 'restoration' of the aquatic biota within the Aranui reserve indicates a potential source habitat for the restoration of lower reaches of the stream. It also indicates some of the possible results.

There were several taxa that only occurred within the benthic samples of the forested sites, for example: the dobsonfly, *Archichauliodes diversus* , the mayfly, *Coloburiscus humeralis* and the Tipulid, *Aphrophila neozelandica.*

From the forested headwaters site 1 to site 2 as the stream moved to pasture, there is a decrease in water quality as indicated by the taxa present. This is reversed upon entering the forested region of the Aranui reserve. Next an even larger reduction in invertebrate diversity and an increase in the abundance of invertebrates occurs as the stream flows into pasture once again.

Site 2 is almost an intermediate between the quality of sites 1 and 5 but tends more towards pasture.

That lotic communities respond to changing environmental conditions along the longitudinal gradient of a river system is a fundamental paradigm of stream ecology (Vannote *et al* 1980). A fundamental assumption of stream pollution studies is that the downstream reaches are influenced by upstream disturbances, but have the capacity to recover by processing materials. Therefore when degraded streams draining pasture catchments enter remnants of native forest they might be expected to experience a gradual shift in their physical, chemical and biological characteristics towards those of an undisturbed forest stream (Storey and Cowley 1997). However Stark 1985 cautioned that invertebrate communities can change in a downstream direction, independently of catchment inputs, in such a way as to resemble degradation, and sampling design is important since there is an inverse correlation between land development and altitude. The present study did find a general trend of decreasing water quality and community composition but also localised "restoration" from upstream to downstream sites.

One of the most effective ways of protecting rivers and streams is through the provision of riparian forest margins (Storey and Cowley 1997). Benefits to the stream and downstream waters include, provision of shade, increased food in the form of leaf litter, woody debris to increase habitat diversity, and improved water quality, with reduced sediment, nutrient, and faecal bacterial concentrations and increased diversity of flora and fauna in the otherwise monoculture landscape (Collier *et al* 1995; Vought *et al* 1995; Parkyn and Winterbourn 1997; Storey and Cowley 1997).

However as a *caveat* to stream restoration efforts, Davies-Colley (1997) observed that stream restoration might increase sediment yields for a period of years to decades as the stream channel attempts to restabilise forest morphology. However in Waitomo, the sediment loads carried by the streams are already high, but potential reafforestation of the stream surrounds could lead to an increase in this sediment with corresponding detrimental effects on the stream biota.

As prior to human habitation (c AD) most of New Zealands land area was covered in native forest (Collier *et al* 1995). This suggests that to restore in-stream conditions towards a more “natural” sate, reforestation of riparian zones is required (Scarsbrook and Halliday 1999). Although there will be changes in community composition with restoration of water quality and reafforestation, it must be remembered that this is a return towards the natural state under which the glowworms previously lived.

Riparian vegetation will lead to increased terrestrial invertebrates within the catchment, providing the glowworms with more potential food and suppling the emergent aquatic invertebrates with increased habitat (Collier and Smith 1998). Glowworms in bush attract both greater numbers and species of invertebrates than glowworms in caves (Broadley 1998). This may be due to the increased diversity of aquatic invertebrates found within the benthos, drift and emerging from the stream flowing through the bush. Thus it is likely that under the reafforestation of riparian zones, there will be an increase in the diversity and numbers of potential food for the glowworms. Pugsley 1980 considered that the bigger midges, mayflies, and tipulids although not so abundant, would provide a good food source for the late instars because of their comparative bulk. This could lead to a possible 5th instar for the glowworm larvae. With revegetation of the catchment and riparian strips changing the community composition of the stream, there is likely to a trend towards larger species like mayflies, caddisflies and stoneflies. This poses the question of food values of different invertebrates to the glowworms, how many chironomids equate to one mayfly? This is a possible future field of research in the ecology of Waitomo and the food supply to the glowworms.

7.2 Future research

Research into the food requirements for complete glowworm development. Additionally, researching the total food available to the glowworms, in conjunction with the food values of different species would provide value information. This research could be tied in the ongoing monitoring of the food supply.

Further study into aquatic invertebrate drift during flood events especially into cave could be tied in with monitoring of the food supply. Suspended sediment is potentially the biggest threat to the water quality, life of the glowworm cave and the aquatic biota within the catchment, thus monitoring of suspended solids is vital. Hogg and Norris (1991) noted that high concentrations of suspended solids were determined during storm events that were not detected by regular two-monthly sampling. Therefore if any suspended solids monitoring is to be carried to provide a baseline for indicate that change is occurring, it should be continuous during the flood events.

7.3 Recommendations

The Waitomo catchment is located in a high rainfall area where sound management practises are needed to achieve stability of land and alleviate runoff and sedimentation effects. A combination of riparian plant species that provide detrital inputs to the stream system over an extended period would mean different leaf composition rates. The heterogeneity of this supply is likely to be a better strategy for maintaining food resources for aquatic detritivores, faunal diversity and productivity (Parkyn and Winterbourn 1997). At present 99% of the plantings are *Pinus radiata* and it is unknown what effect this will have on invertebrate community composition. In Waitomo, the area between Aranui reserve and the glowworm cave is very important, as the findings of this study indicate that the drift into the glowworm cave comes from this area. Riparian zones along the stream would provide a corridor of native forest from Aranui reserve to the glowworm cave.

Planting of native trees around the glowworm cave will increase the terrestrial invertebrate input to the ecosystem, additionally, it will provide more habitat for emergent stream insect to complete their life cycle. There is a possibility of some species drifting into an area and emerging with no habitat for the adult stage. If this occurs the life cycle can not be completed and the area in question will remain dependent on the drift from up stream.

The invertebrates of the Waitomo stream live there permanently, thus integrating the effects of geology, vegetation and climate in space and time, they can potentially provide an additional and accurate index of water quality. Furthermore in this case the invertebrates are the main food source of the glowworms, so sampling them will provide information on water quality and the state of the food supply. Thus biological monitoring is recommended in the Waitomo catchment to assess any land use effects including the catchment control on the stream.

Catchment manipulations are aimed at improving stream health, while still allowing an acceptable flow of land based goods and services. Continued monitoring and research of the effects of these catchment manipulations will provide important information on predictions of large scale ecosystem change and provide a crucial feedback loop for adaptive catchment management (Quinn and Cooper 1997).

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