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Small headwater streams of the Auckland Region Volume 4: Natural Values

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Small Headwater Streams of the Auckland Region Volume 4: Natural Values

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Prepared for
Auckland Regional Council

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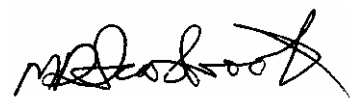
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Executive Summary

Small headwater streams can be highly vulnerable to modification from land use and management changes (e.g., urbanisation, cultivation, deforestation), and re-engineering (e.g., piping and damming). Currently, streams providing year-round habitat for fish, invertebrates or aquatic plants are given greater protection under the Proposed Auckland Regional Plan: Air, Land and Water¹ than streams that dry up for part of the year. The Auckland Regional Council (ARC) requires information on the value of small headwater streams in terms of their function and natural values, to aid development of management options.

The first step in understanding the potential importance of headwater streams is to establish the nature and extent of this habitat resource in the Auckland Region. A companion document (Wilding & Parkyn 2006) describes the spatial extent and seasonal variability of headwater streams in four hydrogeological areas within the Region (Franklin volcanics (FV), sand country (S), Waitemata sandstones (WS), and mudstone (M)) and three land use classes (pasture (P), pasture with riparian protection (PR), and native forest (NF)). 165 tributaries were assessed from 32 catchments in the Auckland Region. The second step is to assign natural values, so a subset of sites was selected to investigate the aquatic invertebrate communities in mud, isolated pools and flowing sections of headwater streams, and compare these with adjacent perennial streams.

Aquatic invertebrates were found in all habitats of the headwater streams, including mud. Taxon richness and EPT taxon richness were generally similar across each of the water habitat types (perennial, flowing, isolated pools), and EPT taxa were even present in mud in native forest and riparian-protected pasture streams.

Additional taxa were found in the temporary headwater habitats that were not present in the perennial stream, and this suggests that these areas contain specialist species that do not occur commonly in perennial streams. If these areas were included in assessments of natural values, overall biodiversity of stream systems would be increased.

The relative abundance and presence/absence of taxa typical of each of the habitat types were similar and differences between these groups were not apparent using multivariate analyses.

The headwater stream habitats, particularly those in pasture, experienced higher water temperatures and lower dissolved oxygen (DO) levels in summer than in winter. In summer, dissolved oxygen was below 5 mg/L on average in pasture headwaters in all habitat types, indicating poor habitat conditions. The isolated pools and flowing habitats experienced similar levels of DO and temperature to that of perennial streams, which may in part explain why there is little difference in aquatic values between those habitats.

¹ These provisions are subject to a number of appeals and may change.

The biggest differences between the invertebrate communities were between the land uses. Pasture streams had generally lower overall richness and EPT richness than native forest and riparian protected sites. Encouragingly, riparian protection of pasture streams offered sufficient habitat to improve the streams natural values towards that of native forest streams.

From this assessment, we conclude that small headwater streams should be given the same status as small perennial streams regarding management for the protection of natural values.

To restore or protect biodiversity in headwater streams, we recommend riparian protection with planted or natural buffers of native trees. While shaded buffers may reduce the nutrient processing capacity of headwaters, they provide multiple ecological benefits.

Based on the water quality and headwater wetland functioning research (McKergow et al. 2006, Sukias & Nagels 2006), we strongly recommend fencing stock out of headwater streams and wetlands for water quality improvements. For wetlands, fencing could take the form of hotwire fences that could be removed for stock grazing if the wetland dried up in summer.

It may not be necessary to protect every headwater tributary to achieve some degree of improved biodiversity and water quality. We recommend further research into catchment-based approaches to assess the cumulative impacts of loss or continued deterioration of pastoral headwater streams, and potential methods to select important or representative reaches.

2 Introduction

2.1 Background

Headwater streams are highly vulnerable to modification from land use and management changes (e.g., urbanisation, cultivation, deforestation), and re-engineering (e.g., piping and damming). In addition, defining where a headwater stream starts can be difficult, as this often depends on hydrological conditions. Many headwater streams are ephemeral (flow only during storm events) or intermittent (flow for only a portion of the year). Streams that do not flow year round have received relatively little specific research in New Zealand or internationally, and there is considerable inconsistency in the terminology describing these streams (Dieterich & Anderson 2000).

The definitions of a stream under the Proposed Auckland Regional Plan: Air, Land and Water are currently based on habitat permanence and ecosystem values (Appendix 1). The terminology used in the Plan (Category 1 and Category 2 streams) is subject to appeals and may change. As it currently stands, continuously-flowing water is not a prerequisite for Category 1 streams provided they maintain perennial pools or aquatic habitat. Streams that dry out completely (Category 2) are presently given less protection than Category 1 streams under the plan (pending results of this research and a consideration of management options).

The Auckland Regional Council (ARC) requires information on the value of headwater streams in terms of their function and natural values, to aid development of management options. There are several components to this project, for which Parkyn et al. (2003) provided an introduction and outline. The first step in understanding the potential importance of headwater streams was to establish the nature and extent of this habitat resource in the Auckland Region. A companion report, Wilding & Parkyn (2006) describes the spatial extent of headwater streams in the Auckland Region, investigating the different habitat types found in headwater streams and the influence of geology and land use. Additional studies on hydrology and water quality functions of headwaters were also undertaken and are detailed in McKergow et al. (2006) and Sukias and Nagels (2006).

2.2 Framework

ARC identified that the research should be focused on the predominant land use within the Auckland Region, dry stock agriculture, with consideration of peri-urban areas (lifestyle blocks) and market gardening. The influence of land use and management options on headwater stream communities and water quality were also important to ARC, so sites were selected in pasture with and without riparian protection, and in native forest catchments.

We delineated the study area into four main hydrogeological areas (HGA), namely Franklin volcanics, Awhitu/Kaipara sand country, Waitemata sandstones, and Dairy Flat/Wellsford mudstone, based on data and knowledge supplied from ARC.

A number of other hydrogeological areas exist in the region, but were not studied. These include the greywackes of the Hunua Ranges, the volcanic and associated sedimentary rocks of the Waitakere Ranges and the volcanics on the Auckland Isthmus. The Hunua and Waitakere ranges are mostly in Regional Parks where development is not an issue. Streams in the foothills of these ranges are not dissimilar to Waitemata sandstone streams. Waitemata sandstone covers a large proportion of the region and was well represented in this study. The Auckland Isthmus is completely urbanized, and most of the smaller headwater streams have been piped, so was not included in this study.

2.3 Aims

The aims of the natural values survey were to (1) determine the biodiversity values of headwater streams relative to perennial streams in summer and winter, and (2) determine whether land use affects the type of aquatic communities found in these headwater habitats. The ARC need to identify the aquatic values of these small headwater streams before they can decide on whether protection is appropriate and what form it should take. We included an assessment of native forest streams to indicate the natural condition and native fauna that could be expected in the Auckland Region, and contrasted this with sites under the dominant land use, pastoral farming. As a potential management tool, we also assessed streams in pasture with riparian fencing and planting in place.

2.4 Definitions and spatial extent

Parkyn et al. (2003) reviewed the definitions of streams for streams that flow for only part of the year and that text was adapted for this report. There is considerable inconsistency in the terminology for streams that only flow for part of the year. Temporary, intermittent, and ephemeral are all terms used to describe streams and ponds with irregular flow. Flow duration is generally used to differentiate the different stream types – but despite this, flow duration is seldom measured or verified to delineate the stream types (Hansen 2001). Under these definitions, perennial and intermittent stream types flow well beyond storm events. Under normal circumstances, perennial streams flow all year. Intermittent streams cease flow for portions of a year. Ephemeral channels may flow during, but typically not for extended periods following, storm events.

It is estimated that ephemeral streams drain over one-third of the earth's land surface (Donath & Robinson 2001), but the hydrological regime of small, ephemeral and/or isolated waters is poorly understood (Brooks & Hayashi 2002). In most

catchments, downstream floods are preceded by a longitudinal expansion of the channel network. Soils become saturated and formerly dry channels become an integral part of the drainage system. The length of formerly dry channels may well exceed that of permanent streams, and function to modify water quality as well as to provide habitat (Dieterich & Anderson 2000).

Because it is often difficult to monitor flow duration at a large number of sites, it is helpful to use field indicators of flow duration and of channel responses to flow (Hansen 2001). Field criteria that Hansen (2001) used to determine stream type are listed in Table 2.1 below.

Table 2.1:

Field criteria used by Hansen (2001) to determine stream type.

Criteria	Stream type		
	Perennial	Intermittent	Ephemeral
Channel	Defined	Defined	Not defined
Flow duration (estimated)	Almost always	Extended, but interrupted	Stormflow only
Bed water level	Above channel	Near channel surface	Below channel
Aquatic insects	Present	Few, if any	None
Material movement	Present	Present, less obvious	Lacking or limited
Channel materials	No organic buildup	Lacks organic buildup	Mostly soil materials Organic buildup

Streams that only flow for part of the year may also be termed wetlands in some instances, especially where the channel is poorly defined or spread out. Emergent wetland vegetation can be expected to develop where water velocities during floods are not high enough to scour the channel. Of the wetland types described by Johnson & Gerbeaux (2004), seepages (including flushes) are the type most likely to also be termed headwater streams. A seepage is an area of slope with surface and groundwater flow that is “less than that which would be considered as a stream or spring” and which receives periodic flushes of water from rainfall.

This project looks at a wider spectrum of small headwater streams in the Auckland Region, including streams that may be termed ephemeral, intermittent or perennial in various texts. We have categorised these small headwater streams according to both channel form and flow characteristics and for the purposes of this report the term ‘headwater stream’ is used to cover a range of water states from slow flowing, standing, pools and muddy or dry channels. Sometimes the term temporary headwater habitat is used to help distinguish these samples from the perennial stream samples, or the headwater streams may be referred to as intermittently flowing. The perennial stream sites were also small streams.

3 Methods

3.1 Site Selection

The research focused on the predominant land use within the Auckland Region, dry stock agriculture, with consideration of peri-urban areas and market gardening. We selected sites within the four main HGAs (hydrogeological areas): Franklin volcanics (Pukekohe), sand country (Awhitu/Kaipara), mudstone (Dairy Flat/Wellsford) and Waitemata sandstones. Sites were selected to fall into three land use categories: pasture (P), pasture with riparian protection (PR), and native forest (NF). Descriptions of these sites and the characteristics of their headwater spatial extent are included in Wilding & Parkyn (2006).

A subset of 12 sites from the 32 catchments surveyed in the spatial extent study (Wilding & Parkyn 2006) was chosen for natural values assessment (Table 3.1). A map and photo of each site is provided in Appendix 2. The focus of site selection was on land use types and we aimed to include representatives of all HGAs in each of the land use types. We also required sites with consistent land use within the catchment upstream of, and including, the permanently flowing section. Locating sufficient numbers of sites with riparian protection was difficult, particularly in the smaller HGAs, e.g., sand country where no pasture-riparian sites were found. Thus, in the pasture with riparian protection (PR) category, we replicated the PR sites in the most extensive HGA, Waitemata sandstones.

Table 3.1:

Site code, locations and dates of catchment surveys for each land use and hydrogeological area. Abbreviations represent: Pasture (P), native forest (NF), pasture with riparian protection (PR), Franklin volcanics (FV), mudstone (M), sand (S), Waitemata sandstone (WS).

Site Code	Area	Easting	Northing	HGA	Land use	Catchment area (ha)	Winter survey	Late summer survey
FV6	Waiuku`	2669313	6438487	FV	NF	12.37	17/9/2004	
FV7	Waiuku	2669367	6439160	FV	P	24.58	17/9/2004	
M2	Wellsford	2636039	6541445	M	NF	15.43	23/9/2004	
M5	Wellsford	2637185	6541505	M	P	24.53	23/9/2004	
S3	Awhitu	2653018	6454675	S	NF	18.87	16/9/2004	
S5	Waiuku	2658518	6436534	S	P	68.76	16/9/2004	
WS1 (D)	Totara Park	2680504	6465189	WS	PR	11.08	24/9/2004	
WS2 (A)	Shakespear	2673612	6509242	WS	PR	9.08	25/8/2004	
WS6	Orewa	2658772	6512364	WS	NF	27.06	25/8/2004	
WS7 (A)	Long Bay	2666556	6501471	WS	PR	5.05	24/8/2004	
WS8	Long Bay	2666030	6500716	WS	P	20.37	24/8/2004	
WS9 (A)	Orewa	2662694	6514837	WS	P	5.99	24/9/2004	

3.2 Survey Methods

The habitat characteristics of each of the headwater streams were mapped according to both channel form and surface water, as indicated in Table 3.2 and described fully in Wilding & Parkyn (2006). The invertebrate sampling was undertaken in four habitat categories that were defined largely by surface water and flow characteristics: mud, isolated pools, obvious flow, and perennial.

Table 3.2:

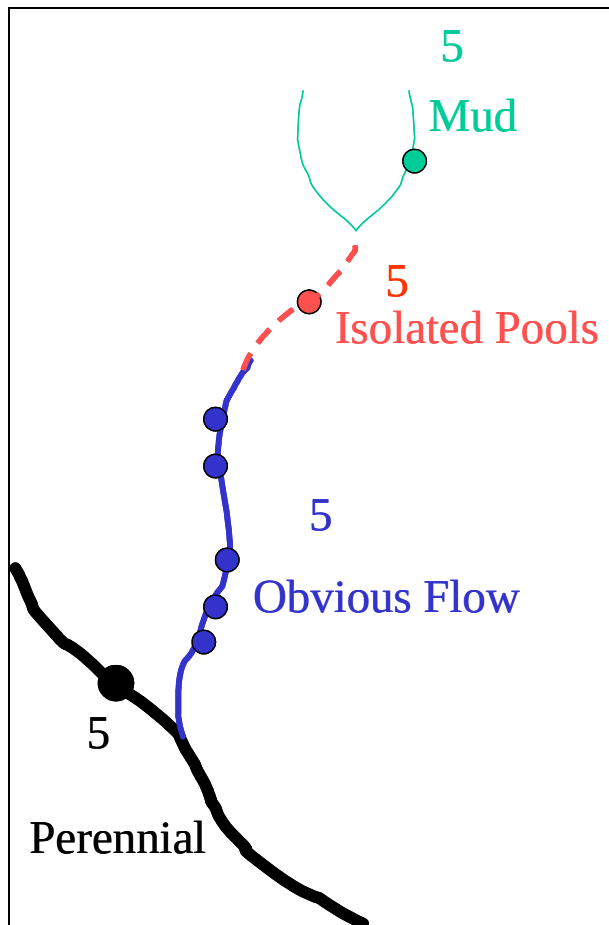
The coding system used to describe channel form (rows) and amount of surface water (columns). Each section of stream was described using this system.

		Water				
		1. Obvious flow	2. Slow flow or standing	3. Isolated pools	4. No open water, muddy	5. Dry
Channel	A. Channel incised, no terrestrial vegetation	1A	2A	3A	4A	5A
	B. Stream bed substrate, no banks, no terrestrial vegetation	1B	2B	3B	4B	5B
	C. No banks, bed vegetated	1C	2C	3C	4C	5C
	D. Wetland	1D	2D	3D	4D	5D

We took up to 5 samples in each of the four categories, depending on the availability of habitat types. Kick net (mesh size 500µm) samples were taken at 5 different locations within the habitat type, usually as we moved upstream, and the area sampled was measured. We composited the samples for each habitat type, which gave about 1m² sample for each of the perennial, obvious flow, and isolated pool habitats. Mud was sampled in a different way; we used a circular bucket to define an area and 2-3 cm of the surface mud layer and leaf litter was scraped and collected. The radius of the circle was 7.5 cm, giving an area of 0.017 m² per sample and a combined area of 0.085 m².

Figure 3.1:

Example layout of sampling locations in the headwater habitat and adjacent perennial stream section.



Sites were surveyed twice to document the change between wet and dry seasons. We sampled in March/April 2004 to represent a late summer dry season and August/September 2004 to represent a winter wet season (see Table 3.1 for survey dates). Our sampling locations were based on the channel/flow categories so if the spatial length of each type of habitat changed, the position of our samples shifted accordingly, rather than remaining at the same geographical points. This is an important distinction as we are not describing what happens to the invertebrate community at a particular location with wetting and drying, but have instead chosen to sample the same type of habitat in winter and summer. In this way, we can describe the seasonal characteristics of the fauna of a particular habitat type (e.g., isolated pools) and link to the spatial extent survey to estimate the amount of habitat available for a particular community type.

Point measures of dissolved oxygen and temperature were also taken, using a YSI 55 probe, at each point prior to invertebrate sampling, and habitat substrate, water depth, pool area, and other habitat descriptors were measured or noted.

3.2.1 Laboratory methods

We preserved the samples in the field with isopropyl alcohol (c. 70-90%) and sorted the invertebrates from the organic matter in the laboratory. Large samples were split to make quantitative counts, but the whole sample was scanned for rare taxa. We identified the invertebrates to species where possible, or the lowest practical taxonomic level, using the keys of Winterbourn & Gregson (1989), Winterbourn (1973), Towns & Peters (1996), Smith & Ward (unpubl.).

3.2.2 Data Analysis

Taxon richness, log-transformed densities, and $\log(x+1)$ transformed EPT taxon richness were analysed with 2-way ANOVA for differences between habitats and season within each land use. Overall differences between land uses were analysed with 3-way ANOVA of land use, season, and habitat. All statistical analyses were performed in Systat 11.

Multi-dimensional scaling plots were produced in Primer 5.0 with additional ANOSIM and SIMPER analysis.

4 Results and Discussion

4.1 Biological values

We focused primarily on the macroinvertebrate community to assess the biological values of the Auckland Region headwater streams. Macroinvertebrates fill a large range of ecological roles and are sensitive to environmental change. Consequently, they have been widely used as indicators of disturbance. Presence of sensitive taxa such as those known to occur in clean, clear, native forest streams and the biodiversity of invertebrate communities can also be used as measures of ecosystem health.

4.1.1 Density

Aquatic invertebrates were found in all habitats of the headwater streams, including mud. There were no significant land use differences in invertebrate densities averaged over all habitat types.

Comparisons of habitat types within each land use showed that densities of aquatic invertebrates were greatest in the mud habitats of native forest ($P < 0.05$, $F = 2.9_{(3,24)}$) and riparian protected pasture ($P < 0.01$, $F = 6.5_{(3,15)}$) streams, particularly in summer where numbers reached 3000-4000 per m^2 (Fig. 4.1). This suggests that invertebrates became concentrated in the mud habitats as the water receded in the dry season. In pasture streams, the mud habitat supported lower densities than those found in NF and PR land use categories, presumably as the lack of riparian vegetation and shading exposed the habitat to desiccation and high temperature.

Pools supported the highest density of invertebrates in the headwater pasture streams ($P < 0.05$, $F = 3.35_{(3,33)}$) across the habitat types, particularly in winter, and the lowest densities were recorded in the perennial stream. In native forest stream pools, high numbers occurred in summer. However, in both land uses, the variation between sites was high, influenced in part by the differences between HGAs. Generally there was little difference in invertebrate densities between the perennial habitat and the flowing section of the headwater streams across all land uses.

Figure 4.1:

Mean densities (+SD) of aquatic invertebrates from the three headwater habitats (mud, pools, flow) and the perennial stream sampled in three land uses.

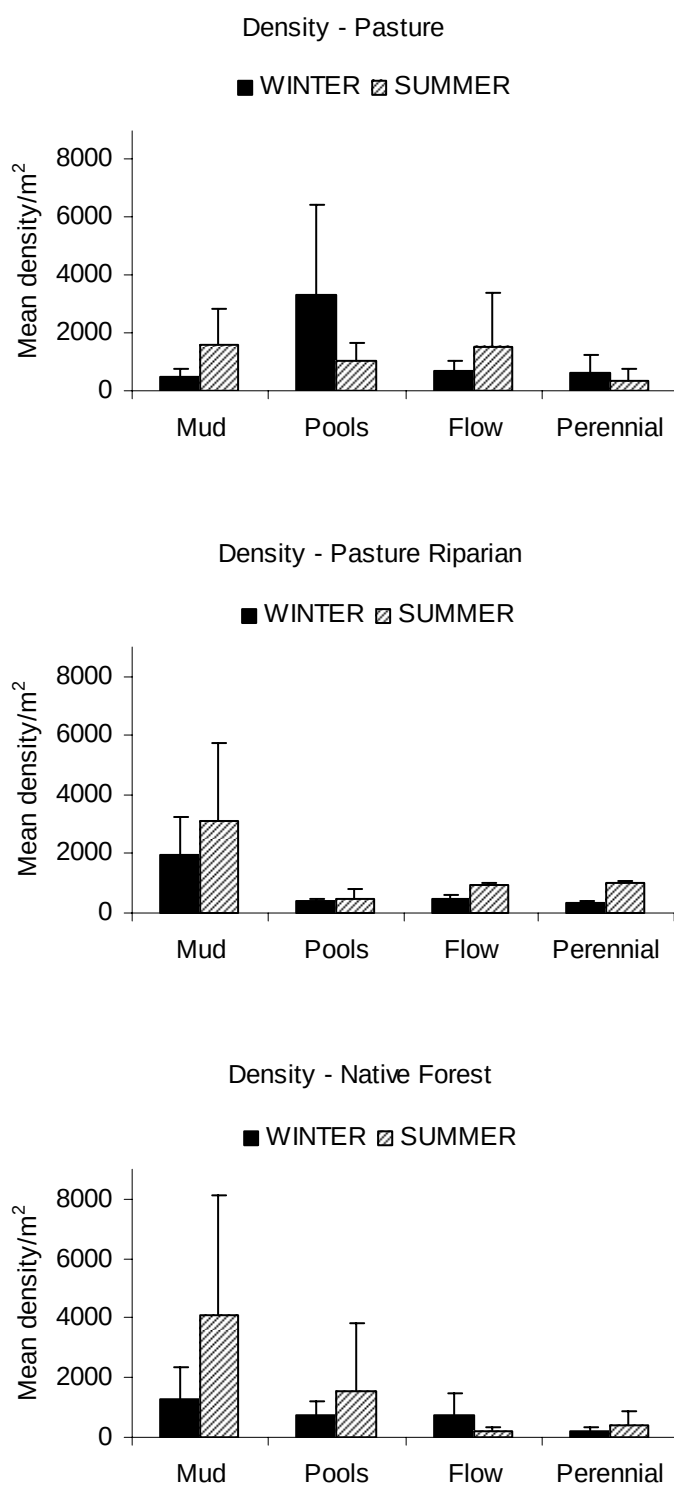


Figure 4.2:

Mean taxon richness (+SD) of aquatic invertebrates from the three headwater habitats (mud, pools, flow) and the perennial stream sampled in three land uses.

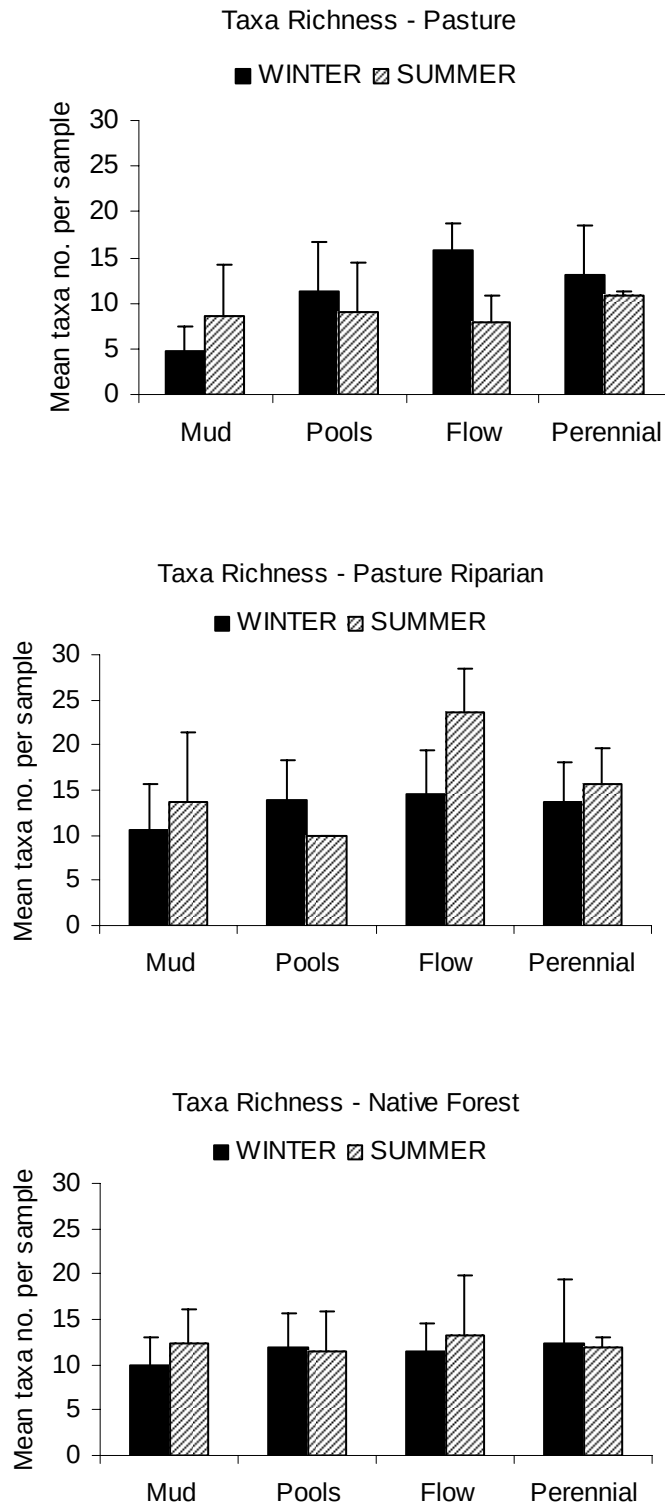
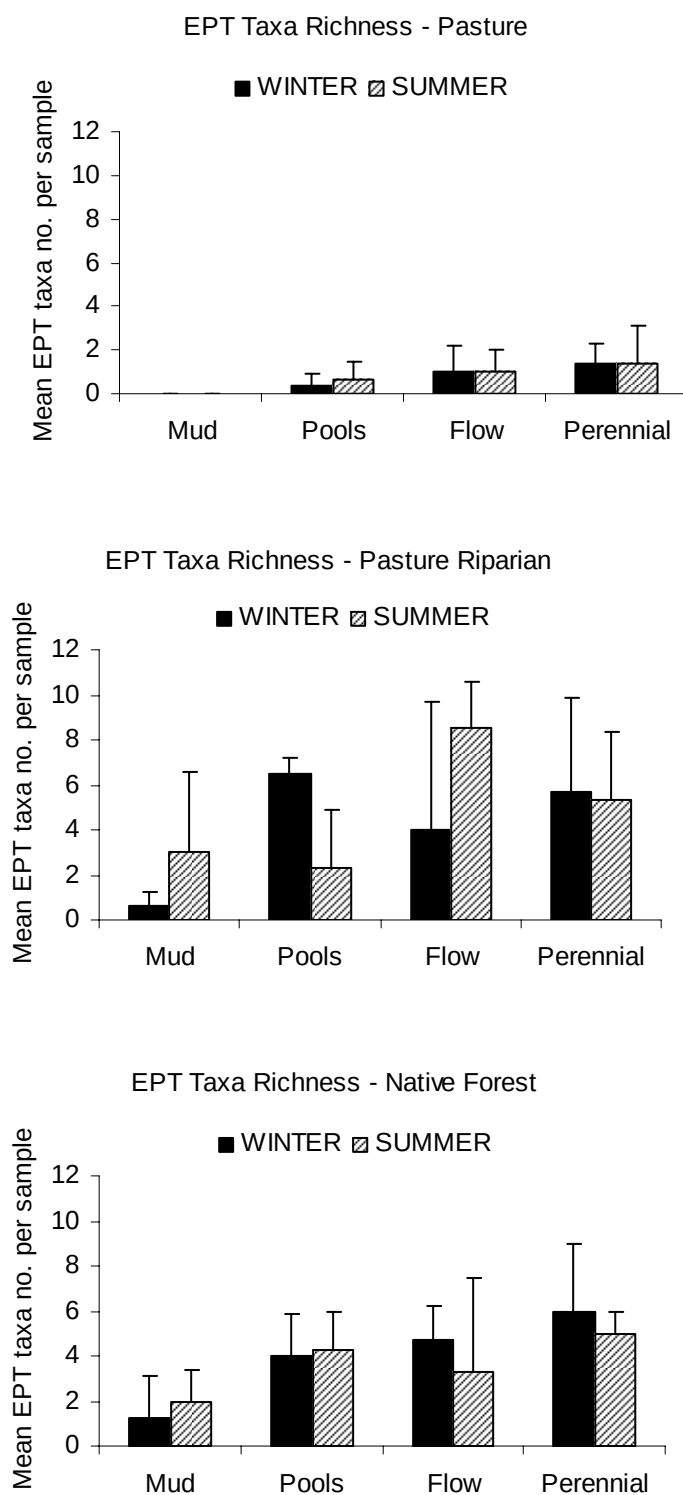


Figure 4.3:
Mean EPT (Ephemeroptera, Plecoptera, Trichoptera) taxon richness (+SD) from the three headwater habitats (mud, pools, flow) and the perennial stream sampled in three land uses.



4.1.2 Taxon Richness

In native forest streams, taxon richness averaged around 10 - 12 taxa per sample (Fig. 4.2), which is relatively low compared to native forest streams nationally. Surprisingly, taxon richness was very similar between summer and winter and between each of the habitat types, showing no significant differences between any of the headwater stream habitats, even mud, and the perennial stream. The only significant difference between habitats occurred in pasture streams where taxon richness of mud samples was lower than that of flowing habitats ($P < 0.01$, $F = 4.03_{(3,30)}$). This was due to the winter trend of increasing taxon richness from mud (average of 5 taxa per sample) to pools to flowing habitats (average of 15 taxa per sample).

Pasture streams had lower taxon richness (averaging 8-10 taxa per sample) than the other land use types in summer but this difference disappeared in winter.

The riparian protected pasture streams had significantly higher taxon richness than the other two land uses ($P < 0.01$, $F = 5.2_{(2,80)}$), which is consistent with these streams being in transition between aquatic communities associated with pasture and those associated with native forest conditions. Typically, we may expect increased taxon richness as forest species recolonise the streams but before conditions have changed sufficiently to exclude those species that tolerate pastoral land use. In winter, taxon richness in the riparian protected streams showed high similarity across the habitat types, similar to the pattern in the native forest streams. However in summer, the average taxon richness of the flowing habitats in the headwater streams increased to 20 taxa per sample, which was greater than the average found in perennial streams. The reasons for this are unclear. Possibly it would suggest that a greater range of invertebrates were colonizing flowing habitats when these were becoming scarce in summer, but this pattern was not repeated in the other two habitat types.

4.1.3 EPT taxa

Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa groups include sensitive species that are generally associated with clean water or native forest conditions. Presence of EPT taxa can be used as a measure of the quality of the environment. Not surprisingly, the pasture stream habitats had significantly lower numbers of EPT taxa than the other land uses ($P < 0.0001$, $F = 32.8_{(2,63)}$). Pasture streams had no EPT taxa in mud samples in summer or winter, and mud habitats were therefore significantly different from the other habitats ($P < 0.05$, $F = 3.48_{(3,33)}$). In native forest streams, EPT taxa were able to persist in mud habitats, possibly because the litter layer and shading provided by riparian vegetation generated a moist, cool environment with sufficient oxygen transfer to invertebrate gills. However, in native forest streams too numbers of EPT taxa were significantly lower in mud than the other habitats ($P < 0.01$, $F = 5.2_{(3,24)}$). It was interesting to see that the riparian protected pasture streams had high numbers of EPT taxa, similar to native forest

streams, but in riparian-protected streams there were no significant differences between the habitat types.

In general, the largest differences in taxon richness and EPT taxa were between mud samples and the other habitat types, but the headwater pools and flowing habitats supported similar numbers of taxa and EPT taxa to the perennial stream reaches.

4.1.4 Biodiversity

In addition to the total number of taxa found in each of the habitat types, it is important to consider the number of taxa that occur only in headwater habitats and not in the perennial streams. When the invertebrates occurring in headwater pasture streams were added to those in perennial pasture streams, on average 14 extra taxa (range 9 – 17) in winter and 10 (range 4 – 20) in summer were added to the overall biodiversity (Table 4.1, 4.2). Pasture headwater streams with riparian protection added an average 17 extra taxa (range 14 – 19) in winter and 13 (range 6 - 19) in summer to the overall biodiversity in this land use type. In native forest also, an average additional 13 (range 11-15) in winter and 11 (8 -19) in summer species were found in temporary headwater habitats. Headwater streams in summer probably showed greater variability in additional taxa because of the greater variability and degree of drying creating harsher conditions in some streams. It should be recognized that the area of habitat sampled in perennial streams (c. 1m²) was less than that of the temporary headwater habitats when they are grouped together as in this analysis (c. 2.1m²). Nevertheless, the average number of additional taxa not found in perennial streams was approximately 50% of the total number of taxa recorded in all of the habitats, indicating that the temporary headwater habitats together add significantly to the overall biodiversity of the stream network.

Table 4.1:

Winter numbers of taxa in all headwater habitats and in the perennial habitat, and the additional taxa gained when headwater stream habitats are included in sampling designs.

Winter	Site	All headwater habitats	Perennial	Total	Additional taxa
Pasture	WS8	21	17	26	9
	FV7	23	12	28	16
	WS9	19	19	32	13
	M5	25	12	29	17
	S5	17	5	19	14
Mean (SD)		21(3.2)	13(5.4)	26.8(4.9)	14(3.1)
Pasture Riparian	WS7	14	9	28	19
	WS2	23	14	28	14
	WS1	30	18	35	17
	Mean (SD)	22.3(8)	13.7(4.5)	30.3(4)	17(3.5)

Winter	Site	All headwater habitats	Perennial	Total	Additional taxa
Native Forest	WS6	20	6	21	15
	FV6	27	20	33	13
	S3	14	11	22	11
	M2	26			
Mean (SD)		21.8(6)	12.3(7.1)	25.3(6.7)	13(2)

Table 4.2:

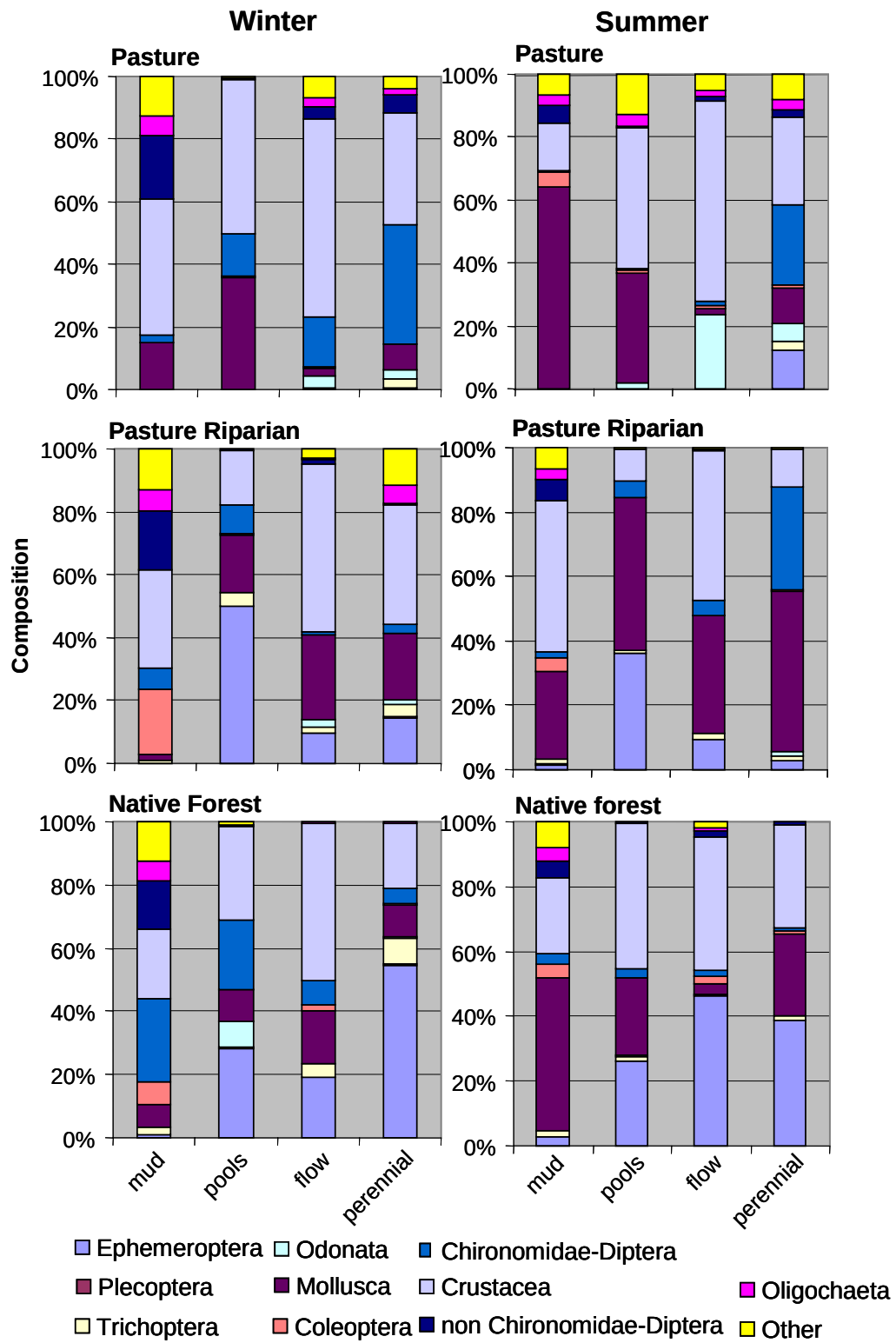
Summer numbers of taxa in all headwater habitats and in the perennial habitat, and the additional taxa gained when headwater stream habitats are included in sampling designs.

Summer		All headwater habitats	Perennial	Total	Additional taxa
Pasture	WS8	18	12	20	8
	FV7	14	10	16	6
	WS9	8	11	15	4
	M5	21	11	22	11
	S5	23	11	31	20
Mean (SD)		16.8(6)	11(0.7)	20.8(6.4)	9.8(6.3)
Pasture Riparian	WS7	7	11	17	6
	WS2	24	18	31	13
	WS1	33	18	37	19
Mean (SD)		21.3(13.2)	15.7(4)	28.3(10.3)	12.7(6.5)
Native Forest	WS6	28	11	30	19
	FV6	20	12	20	8
	S3	15	13	22	9
	M2	20	13	22	9
Mean (SD)		20.8(5.4)	12.3(1)	23.5(4.4)	11.3(5.2)

4.1.5 Community Composition

The relative abundances of the major taxa groups for each of the land use and habitat types in winter and summer are shown in Figure 4.4. Generally, in each land use, mud habitats were most different to other habitat types in the proportions of taxa groups. Notably, mayflies (Ephemeroptera) were absent from all mud habitats. In the pasture stream habitats, they occurred only in the perennial streams in summer, but in the PR and NF sites they were abundant in most of the headwater habitats and perennial streams. Molluscs (predominantly *Potamopyrgus antipodarum*) and Crustacea (largely amphipods) were the two most dominant taxa groups across all land uses and habitat types. Plecoptera (stoneflies) were rare and Trichoptera (caddisflies) were mostly found in the flowing and perennial habitats of the native forest and riparian protected streams.

Figure 4.4:
Average percent composition of each of the main taxa groups across the headwater habitats (mud, pools, flow) and perennial habitats in three land uses.



MDS plots of the relative abundance of the invertebrate community according to land use in summer (A) and winter (B). Labels indicate the site codes that show the different HGA categories; WS = Waitemata sandstones, FV = Franklin volcanics, S = Sand, M = Mudstone.

Land use - Summer data



Land use - Winter data

Figure 4.6:

MDS plot based on the relative abundance of the invertebrate community from all sites and habitats in summer and winter.

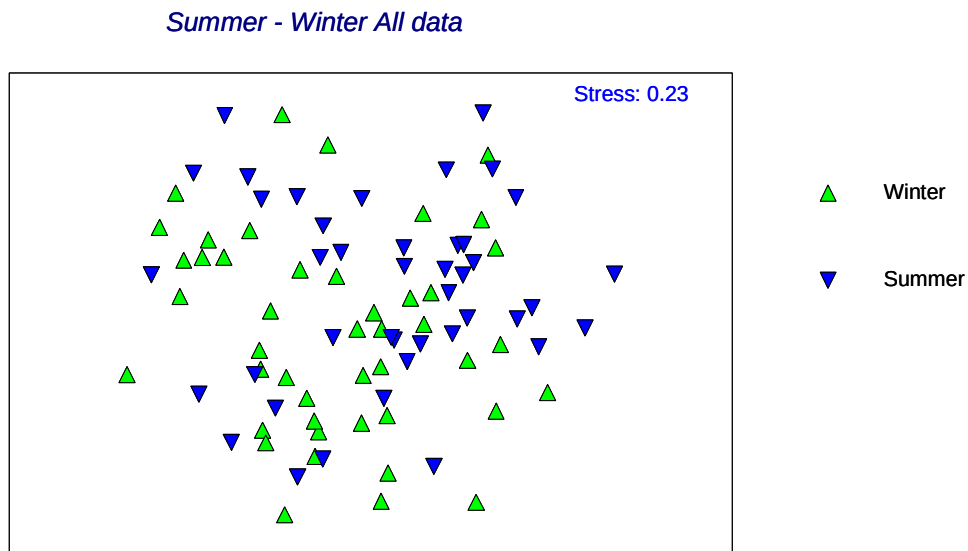
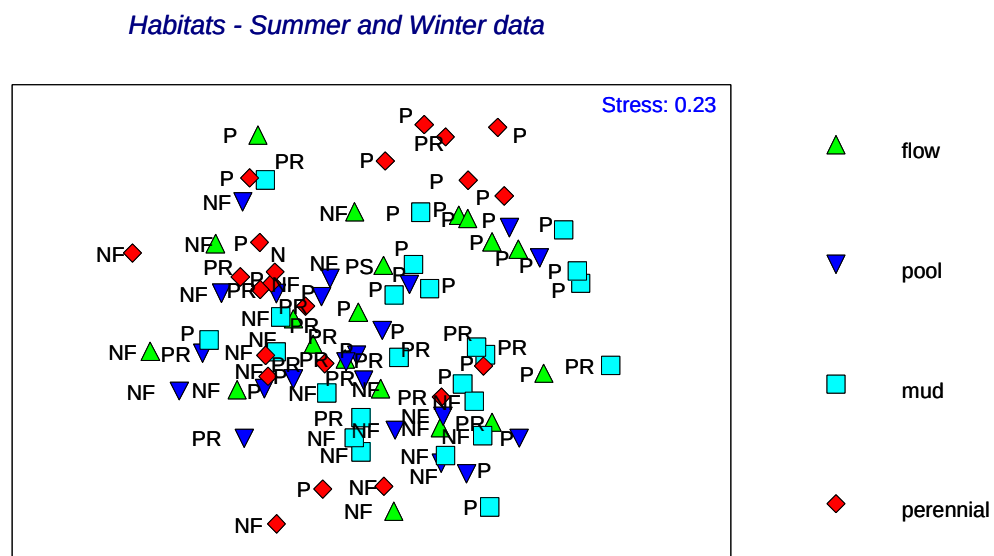


Figure 4.7:

MDS plot based on the relative abundance of the invertebrate community showing the similarity of data from flow, pool, mud and perennial habitats in pasture (P), native forest (NF) and pasture with riparian protection (RP) from summer and winter data combined.



4.1.5.1 Relative Abundance Ordination

The overall comparison of community composition between all of the samples was investigated with multidimensional scaling (MDS) plots. Figs. 4.5-4.7 compare, in turn, the effects of land use, season and habitat type on community composition. Among these the only differences appeared to be between land uses, where pasture stream communities plot out slightly separately to the NF and PR sites in summer (Fig 4.5A) and with a somewhat greater degree of separation in winter (Fig. 4.5B). However, ANOSIM (Primer 5.0) comparisons indicated a large degree of overlap between land uses, averaged across all habitat types ($R = 0.16$, $P = 0.001$). The overlap between sites may be due to the variation between the different HGAs, although these have been labeled on the graphs and samples from each HGA do not group together. No difference in community composition between summer and winter was detected (Fig 4.6, ANOSIM $R = 0.05$, $P = 0.009$). There was large overlap between the communities in mud, pools, flow, and perennial habitat of all land uses (Fig. 4.7, ANOSIM $R = 0.14$, $P = 0.001$). ANOSIM R values >0.75 indicate big differences between groups; >0.5 indicate overlapping but clearly different groups; <0.25 indicate barely separable groups. Significant P values indicate that the R value did not occur by chance.

SIMPER analysis (Primer 5.0) showed that samples in pasture sites were dominated by ostracods, the amphipod *Paraleptamphopus* sp. and the snail *P. antipodarum*. Riparian protected sites and native forest sites were dominated by the amphipods *Paraleptamphopus* sp. and *Paracalliope* sp., and *P. antipodarum*. The dominant taxa within land uses were very similar across all habitat types, masking many of the differences between the samples.

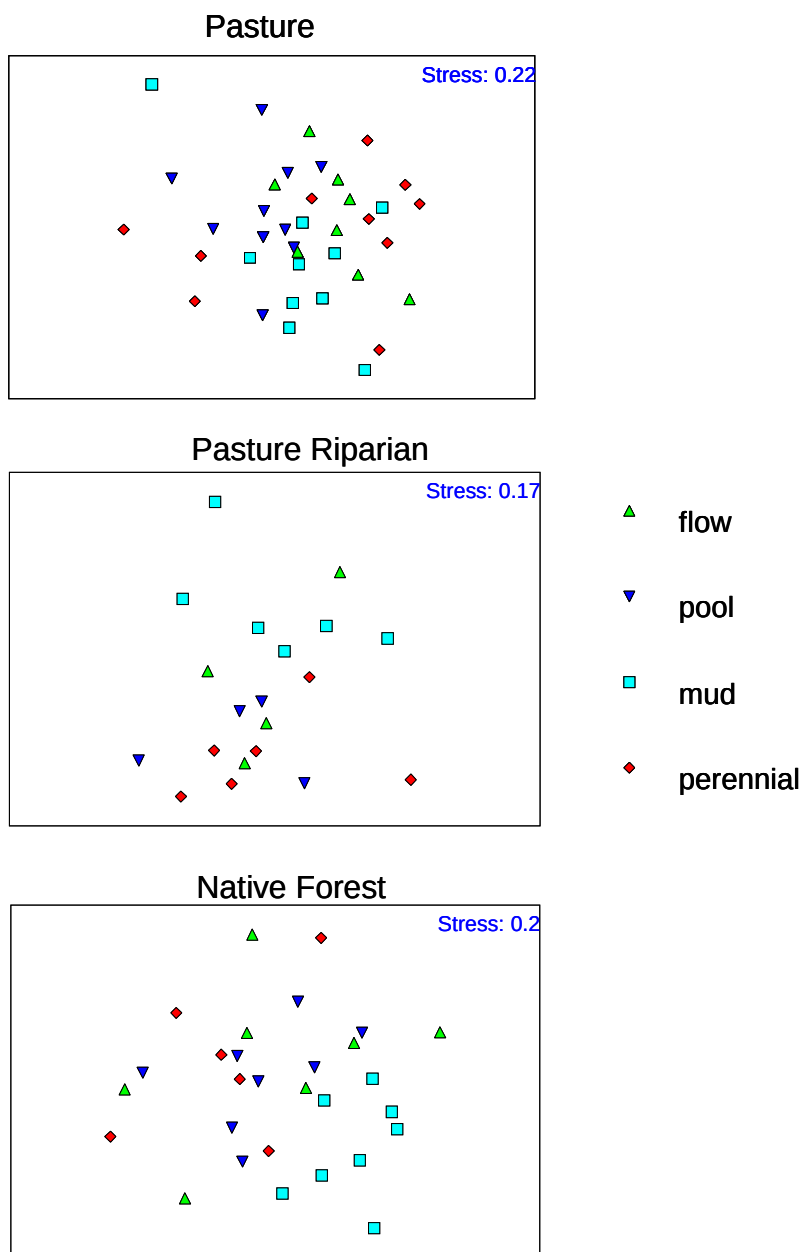
The main difference between headwater habitat types and perennial streams seems to lie in the additional rare taxa that the headwater habitats harbour, rather than a change in the relative abundance of taxa types, or dominant taxa.

4.1.5.2 Presence/Absence Ordination

Additional ordination analyses were run using presence/absence data to see if any patterns were detectable between habitat types when the abundance of taxa is disregarded. Figure 4.8 shows invertebrate community similarity for each land use with summer and winter sampling dates combined. In each of the land uses, there were once again no overall detectable differences between the headwater habitat types (ANOSIM $R = 0.2$, $P = 0.001$). The analysis was also unable to detect differences in the land use groups across all of the habitat types (ANOSIM $R = 0.3$, $P < 0.001$).

Figure 4.8:

MDS plot based on the presence/absence of invertebrate taxa showing the similarity of data from flow, pool, mud, and perennial habitats in pasture (P), native forest (NF) and pasture with riparian protection (PR) from summer and winter data combined.



In pasture, taxa that were typical of mud habitats included Ostracods, fingernail clams (*Sphaerium* sp.), and gastropod snails (*P. antipodarum*), which were also present in some of the other headwater stream habitats (Table 4.3). The large dipteran larvae *Zelandotipula* sp. was typical of mud habitats in both pasture and pasture with riparian protection but was not a characteristic component of the fauna in other habitats. The beetle *Liodessus deflectus* was typically found in pool habitats but not commonly in the other habitats in pasture streams.

In native forest streams, amphipods, dipteran larvae, particularly chironomids, and also the Scirtidae (beetles) typified mud habitats in native forest. Koura (*Paranephrops planifrons*) occurred in almost all of the perennial native forest stream samples, but not surprisingly, were not found at all in mud habitats. Koura were present in pools and flowing headwater streams of native forest and pasture with riparian protection, and high numbers of koura were noted in pools in summer as the streams dried up and water resources become concentrated in these isolated pools. In pasture streams, koura were only found in perennial habitats, although the sampling method may be inadequate to sample koura numbers effectively.

Table 4.3:

Results of SIMPER analysis of characteristic taxa representative of each land use and habitat type.

Land use	Mud	Pool	Flow	Perennial
Pasture	Ostracoda Paralimnophila skusei Zelandotipula sp. <i>Sphaerium</i> sp. <i>P.antipodarum</i>	Paraleptamphopus <i>Sphaerium</i> sp. <i>Liodessus</i> <i>deflectus</i> <i>P.antipodarum</i>	Ostracoda <i>Chironomus</i> <i>zelandica</i> Paraleptamphopus	Ostracoda <i>P.antipodarum</i> Oligochaeta <i>Chironomus</i> <i>zelandica</i>
Pasture Riparian	Zelandotipula sp. Scirtidae Paraleptamphopus Hexatomini	Polypedilum sp. <i>P.antipodarum</i> Polypsectopus sp. Paracalliope fluvialis	Tanypodinae Paraleptamphopus <i>P.skusei</i>	Polypsectopus sp. Tanypodinae <i>P.antipodarum</i> <i>Xanthocnemis</i> <i>zelandica</i>
Native Forest	<i>Paraleptamphopus</i> Tanypodinae <i>Molophilus</i> Hexatomini Scirtidae <i>Polypedilum</i> sp.	Tanypodinae Polypsectopus sp. <i>P.antipodarum</i> <i>Sphaerium</i> sp.	Paraleptamphopus Polypsectopus sp. <i>P.antipodarum</i> <i>Polypedilum</i> sp.	<i>Paranephrops</i> <i>planifrons</i> <i>P.antipodarum</i> Paraleptamphopus Paracalliope fluvialis

Figure 4.9:

Fauna collected from headwater streams can include *Oeconesus* sp. (left). The invertebrates in the right hand picture were found in mud habitats.



4.2 Other Biota

During our sampling and spatial extent surveys we noted other species that appeared to occur in headwater stream areas. The most commonly seen fish were banded kokopu (*Galaxias fasciatus*) and eels (*Anguilla* sp.). The bush dragonfly *Uropetela* appears to use the soft mud habitat of headwater streams in native forest to burrow down to groundwater as larvae. We saw exuviae of the pupal forms on trees after the larvae have burrowed out from the mud and climbed trees to pupate and become adults (Fig.4.10) These endemic dragonflies are part of the internationally significant primitive groups of fauna still in existence in New Zealand (Collier 1993).

Figure 4.10:

Uropetela pupal case and the exit holes in mud areas of headwater streams.



Certain types of plants appear to be indicative of the wet headwater areas, such as parataniwha (*Elatostema rugosum*) in native forest. Birds were particularly prevalent in the riparian protected areas, which appeared to represent the only suitable habitat within the wider pasture landscape ; we saw nesting pukeko in these habitats.

Figure 4.11:

Pukeko nesting in riparian protected habitats.



4.3 Dissolved Oxygen and Temperature

Aquatic life can be very sensitive to low levels of dissolved oxygen and high water temperatures. These two variables were expected to be limiting factors for aquatic life in headwater streams. We made spot measurements at the time of sampling to gain an indication of the stresses affecting biota in headwater streams, and patterns between the land use and habitat classes. Clearly the biota would have experienced a range of values higher and lower than those shown here and the data should be taken as indicative only.

Dissolved oxygen (DO) was maintained at healthy levels in all land uses and in each of the habitat types in winter (>8 mg/L)(Fig 4.12A). However in summer, dissolved oxygen dropped below 5 mg/L on average in pasture headwaters in all habitat types, indicating poor habitat conditions. In native forest and pasture with riparian protection, dissolved oxygen was higher than that of open pasture probably because shading reduced water temperatures, allowing greater dissolution of oxygen, but average levels were lower than in winter (now <8 mg/L). On occasions in summer, very low DO levels were recorded at sites in all land use types (<1 mg/L) and fish kills were also noted (Fig 4.13).

The main differences in water temperature were between land uses, with pasture reaching warmer temperatures than NF and PR in both summer and winter. However, all mean water temperatures were lower than 20°C , the level considered limiting for invertebrate communities. As with DO, there was little difference between flowing, pool or perennial habitats, with the same pattern repeated across each.

Figure 4.12:

Mean (+SD) dissolved oxygen (mg/L (A)) and water temperature (°C (B)) at each of the habitat types containing water for each land use in summer and winter.

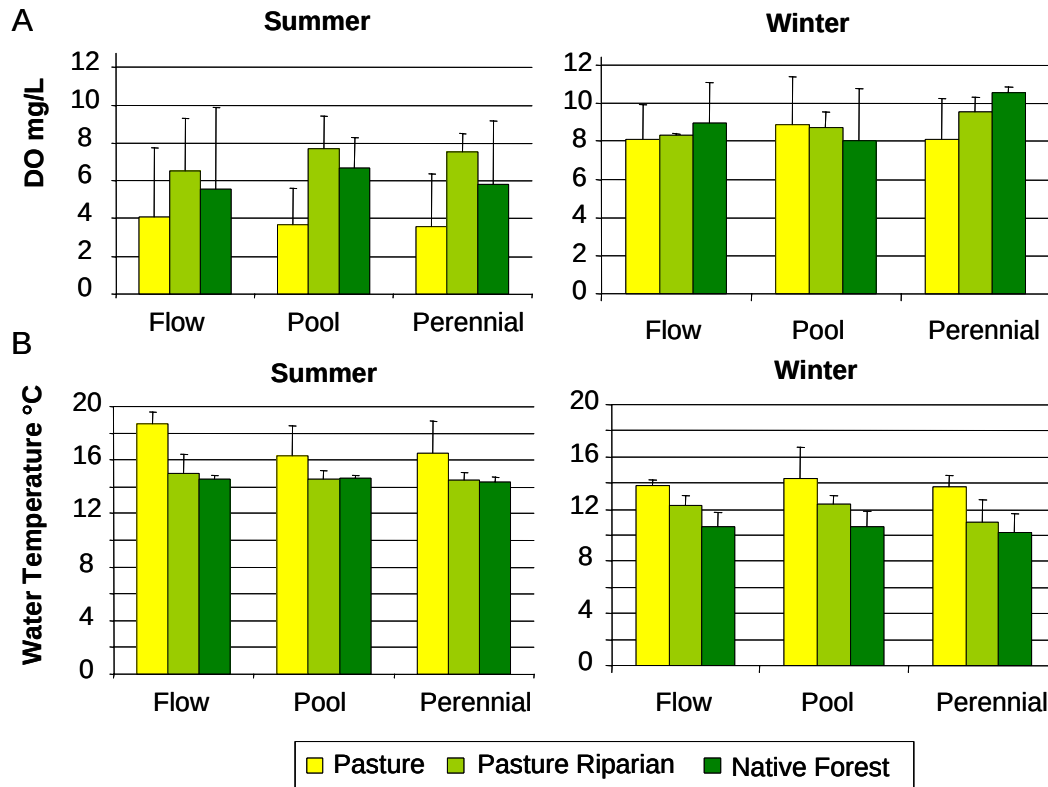


Figure 4.13:

Banded kokopu found dead in a pool with very low dissolved oxygen in summer.



4.4 Pools

Pool dimensions are used as defining characteristics in the current definitions of Category 1 and 2 streams. Streams with permanent pools with depth of at least 150mm and area of 0.5m² would be Category 1 streams. The width and maximum depth of the pools that were sampled for aquatic invertebrates are listed in Table 4.4. Depths were lower in winter generally, but this may be a sampling artifact as there may have been more pool habitat and more connectivity between pools in winter, whereas the few pools remaining in summer were likely to be the deeper ones and more likely to have been the only size of pools available to sample. Mean depths in summer were similar across land uses and ranged from 0.22m – 0.32m. In winter, mean depths of pools sampled were 0.08 – 0.2m.

Widths of the pools that we sampled were similar between summer and winter and across land uses and means ranged from 0.47m – 1.03m.

Clearly, a number of the pools sampled were shallower than the depth specified for Category 1 streams and these habitats seem able to support diverse invertebrate communities that are not significantly different from that of perennial streams.

Table 4.4:

Mean (SD), minimum, and maximum depths (measured at deepest point) and width of pools where invertebrate communities were sampled in each land use.

	Summer			Winter		
	Mean (SD)	Minimum	Maximum	Mean (SD)	Minimum	Maximum
Depth (m)						
Pasture	0.28 (0.11)	0.07	0.7	0.09 (0.05)	0.02	0.5
Pasture Riparian	0.32 (0.17)	0.05	0.8	0.08 (0.06)	0.03	0.25
Native Forest	0.22 (0.06)	0.1	0.6	0.20 (0.06)	0.03	0.53
Width (m)						
Pasture	0.75 (0.22)	0.3	1	0.99(1.4)	0.2	5
Pasture Riparian	1.03 (0.06)	0.45	1.5	0.47(0.2)	0.25	0.8
Native Forest	0.82 (0.26)	0.1	1.4	0.79(0.1)	0.4	1.3

5 Summary

Overall, results from the invertebrate community analyses suggest that there is very little difference between the aquatic values of temporary or intermittently flowing headwater streams and those of perennial headwater streams. Taxon richness and EPT taxon richness were generally similar across each of the water habitat types (perennial, flowing, isolated pools), and EPT taxa were even present in mud in native forest and riparian protected pasture streams. Therefore, under the current definition of Category 1 and 2 streams, all the habitats except the mud habitats of pasture streams, which had no EPT taxa, would be classed as Category 1.

Furthermore, additional taxa were found in the headwater habitats (combined mud, pools, flowing) that were not present in the perennial stream and this suggests that these areas contain specialist species that do not occur commonly in perennial streams. If these areas were included in assessments of natural values, overall biodiversity of stream networks would be increased.

The relative abundance and presence/absence of taxa typical of each of the habitat types were similar and differences between these groups were not apparent using multivariate analyses.

The headwater stream habitats, particularly those in pasture, experienced higher water temperatures and lower dissolved oxygen (DO) levels in summer than in winter. The isolated pools and flowing habitats experienced similar levels of DO and temperature to that of perennial streams, which may in part explain why there is little difference in aquatic values between those habitats.

The biggest differences between the invertebrate communities were between the land uses. Pasture streams had generally lower overall richness and EPT richness than native forest and riparian protected sites. Encouragingly, riparian protection of pasture streams offered sufficient habitat to improve natural values of the streams towards that of native forest streams.

From this assessment, we conclude that small headwater streams should be given the same status as small perennial streams regarding management for the protection of natural values.

6 Conclusions & Recommendations

This report is part of four volumes of research on the values of headwater streams and overall conclusions and recommendations are summarized below.

6.1 Implications for Management

6.1.1 Values of headwater streams

Collier (1993), in his review of the conservation of freshwater invertebrates, advocated a habitat- rather than species-based approach to conserving biodiversity. The protection of a range of rare, endangered, or representative habitats is most likely to ensure the protection of a wide range of invertebrate species, as well as maintain natural ecosystem processes.

Our research on the natural values of headwater streams has shown that there are significant biodiversity values associated with headwater habitats that dry up or contract in length for part of the year and are often not mapped as blue lines on topographic maps. For all land uses assessed, additional taxa occurred in the mud, pools, and flowing habitats that were not found in the perennial streams sampled. Therefore, protection of these habitats would enhance the overall biodiversity of stream communities.

However, our research also showed that despite the presence of additional taxa, the overall community composition and structure, and invertebrate metrics of ecosystem health were not significantly different between perennial stream habitats and the smaller headwater habitats. Mud samples were the most different from perennial samples as might be expected, but surprisingly, mud also contained communities of freshwater invertebrates. It seems likely that mud can act as a short-term refugium for some species, but other species may have adapted to exploit this habitat more permanently.

Based on the invertebrate species composition, there does not seem to be a rationale to separate Category 1 and 2 streams. However, it seems reasonable to suggest that stream reaches that are completely dry would have less value than streams with moisture, at a given point in time. In order to rank the differences between streams that all have a dry phase we would need to know the proportion of time that streams are wet and able to support aquatic life. Hydrological studies in one area of Auckland (Totara Park, Waitemata sandstones) indicated that 2 of the 4 streams ceased flowing for part of the year at the point where the weirs were placed (McKergow et al. 2006). In the smallest pasture catchment (0.7 ha) the stream

stopped flowing for only 10 days in summer, while in a larger pastoral catchment (2.1 ha) stream flow dried up to occur only as storm flow between January and mid-April. Because of the influence of groundwater on these headwater areas, it is difficult to predict flows based on catchment areas. Currently we have estimates of the stream length per hectare that is intermittently flowing (or changing in length) from the Spatial Extent survey (Wilding & Parkyn 2006), but little understanding of how flow varies over time for these headwater systems.

The main differences in natural values occurred between land uses. Clearly, riparian vegetation improved the conditions of the streams towards that of native forest and allowed the existence of aquatic species associated with native forest streams. This suggests that riparian planting is a valuable method for managing headwater streams and it also shows that headwater streams with existing vegetation could be valuable sources of recolonists for stream restoration. Small, vegetated gullies are often pockets of refugia for native forest stream species within a pastoral catchment. Protecting these areas could be particularly valuable as source areas for restoration downstream and could mean that successful restoration is achieved after several years rather than several decades. For instance, if the headwater streams in a catchment were piped and filled (e.g., during urban development of a pastoral area), and only the perennial streams were restored with riparian planting, then it would take much longer for the recolonisation of stream communities to occur as there would be no upstream source of recolonists. Retaining headwater streams that already have riparian vegetation would improve the speed and success of the restoration process.

6.1.2 Recommendations for current management

Small headwater streams and wetlands are extensive in the Auckland region compared to the length of higher-order streams. Management of these areas is complex and decisions on the protection of these areas may ultimately depend upon socio-economic factors as well as ecological factors. An important question that remains unanswered is that of the cumulative effect of widespread loss or deterioration of headwater stream habitat. However, our research does provide information to help with management of rural and urban headwater streams.

Rural

There are several ways that headwater streams and wetlands could be managed under dry stock agriculture. One way is to fence all small waterways and plant them with native riparian plants, as was the case in the PR streams that we studied. This clearly has biodiversity benefits, particularly in summer, when even the remaining moist mud habitat was able to support EPT taxa. Communities of invertebrates in pastoral streams have changed from that of the original forested condition, but significant improvements in habitat and biodiversity of pastoral streams could be gained by fencing and planting riparian buffers. When there is adequate shade from riparian vegetation, water temperatures are lower and dissolved oxygen levels are higher during the summer months, creating healthier conditions for the invertebrate communities. Shade and cover from planted buffers also provides habitat for fish and

koura (no koura were found in non-perennial pastoral headwater streams, but they were common in native forest).

The other important function of riparian buffers is for water quality in most stream systems. Fencing stock out of streams at Totara Park produced lower annual loads of *E.coli* than in streams open to stock (McKergow et al. 2006). However, headwater stream flow is greatly influenced by groundwater and subsurface flow. This means that the water can be carrying leached pollutants from the surrounding land use or historical land uses that have bypassed the riparian zone. Nitrogen loads in the riparian protected stream at Totara park were similar in the protected (Bush) and open (Swamp) sites.

Significant processing of nitrate and phosphorus (>90%) can occur in headwater wetlands under base flow conditions but this function can be reduced by stock access (Sukias & Nagels 2006). Hoof prints can create holes in wetlands that allow subsurface water to flow up and over the surface of the wetland where negligible denitrification occurs. Stock can also eat vegetation that would have naturally added to the organic build up in the wetland and therefore, stock reduce the processing capacity. Where headwater wetlands occur, best practice would be to fence stock out and allow wetland vegetation to develop. Planting with taller tree species is not recommended if the goal is to reduce nitrogen loads, as wetlands will revert to streams once shaded. Storm flows contribute significant amounts of pollutants and reduce the functioning of the wetlands. Efforts to extend protection or rough vegetation (e.g., encourage long grasses above wetlands by electric fencing in winter) may help to slow flood flows and give time for settling and infiltration of contaminants from the water flow.

The consequences of not managing these areas by removing stock are a continued export of sediments and faecal bacteria that will contribute to pollution and, in the case of sediment, accumulation downstream. With no riparian buffers on headwater streams, direct fertilizer additions and open access to stock, exports of nitrogen and phosphorus will remain high.

If fencing and/or planting headwater streams is not feasible then an alternative could be to construct wetlands at the base of catchments before the streams enter significant waterbodies (e.g., lakes, estuaries). However, this option would provide no biodiversity protection for the headwaters and may impede fish passage. Another alternative could be strategic protection of some of the headwater stream network. Existing tools for predicting fish assemblages could assist with this process, at least for fish biodiversity (John Leathwick, NIWA. pers. comm.). We recommend further research in order to make predictions about the placement, or the percentage, of streams that should be protected.

Recommendations

Based on research carried out over the last three years, we strongly recommend fencing stock out of headwater streams and wetlands for water quality improvements. For wetlands, fencing could take the form of hotwire fences that could be removed for stock grazing if the wetland dried up in summer.

For biodiversity goals in headwater streams, we recommend riparian protection with planted buffers of native trees. While shaded buffers reduce the nutrient processing capacity of headwaters, they provide multiple ecological benefits.

It may not be necessary to protect every headwater tributary to achieve improved biodiversity and water quality. We recommend further research into catchment-based approaches to assess the cumulative impacts of not managing all pastoral headwater streams and potential methods to select important or representative reaches.

Urban

When catchments are converted to urban land use there is potential for severe loss of stream function through piping and infilling (Rowe et al. 2006, Wilding 1996). Effectively all habitat values are lost and functions such as natural attenuation of contaminants, connectivity for species dispersal, food webs etc., are impaired. Urbanisation of catchments can also mean a loss of groundwater recharge from the increased impervious area. Therefore, it is likely that streams in urbanized catchments dry up for longer periods of time in summer and/or over a greater length.

Our research has shown that temporary headwater streams have similar aquatic invertebrate communities to those in perennial streams, but can also provide habitats that add additional species to the overall biodiversity of the catchment. The consequences of losing these streams will be loss of habitat values and a decline in overall biodiversity. Furthermore, urbanization that increases the duration of the dry period may decrease the biodiversity values of these headwater streams.

While intercepting nitrogen and phosphorus in urban streams may not be as necessary as it would be in pasture, it is worth noting that groundwater flow to these streams may still be carrying nutrients from historical land use, and simply piping them would transport these nutrients downstream without any instream attenuation. In addition, headwater streams may be just as important for the processing of stormwater contaminants as for rural contaminants, and incorporating natural stream functioning into urban design could make these streams important resources for treating urban runoff.

Recommendations

Our recommendation is that headwater streams be protected with riparian planting when catchments are converted to urban land use, for the sake of instream habitat, biodiversity, and ecosystem functioning – i.e., contaminant processing.

We recommend further research into the cumulative effects of the loss of headwater streams and better spatial modeling of the impact of urban development on catchment biodiversity and stream functioning.

6.2 Recommendations for future research

From the state of the science currently, we have concluded that intermittently flowing headwater streams do have values similar to that of perennial streams and

their management should therefore be similar. However, we recognize that it may not be feasible for all headwater streams to be protected. Thus, there are a number of additional research areas that could allow us to differentiate between streams of higher and lower ecological value or provide a process for sustaining ecological and economic values.

Cumulative effects

Currently, the ARC has to deal with applications to alter headwater streams and wetlands on a piecemeal basis. There are no tools available to assess the cumulative effects of changing land use, or piping and damming streams. How many waterways can be lost (to infilling, piping or damming) in a catchment before this has impacts on catchment functions such as downstream water quality and quantity, or habitat provision? Conversely, is there a proportion or spatial arrangement of streams in a catchment that could be restored to enhance habitat and biodiversity, and improve water quality but still be affordable for the region?

This will be a difficult question to answer but one that is very important to consider. The first step would be to ascertain whether it is possible to assess the cumulative effects of stream loss and to consider the wide-ranging implications from species protection and habitat provision through to downstream effects on water quality and quantity and ecosystem functioning.

Variation through time

Can the length of time that headwater streams are wet be used to rank or value the headwater streams? At present, we have a widespread estimate of the amount of stream length that is intermittently flowing or changing in length (Wilding & Parkyn 2006), but no widespread estimates of the variability in flow through time of these headwater systems. Are headwater streams typically dry for a matter of days or a matter of months through the year, and how does this period differ between years? Do the streams typically dry out at the same time each year? Is this the best time of year to make a stream valuation?

These questions could be answered by incorporating monitoring of the weirs installed at Totara Park into a monitoring network and by investigating means to economically survey the temporal variation in hydrology of a wide range of headwater streams.

Urban headwaters

Traditional urban development creates large areas of impervious surfaces, which means a large proportion of rainfall can no longer infiltrate and extensive stormwater systems are required. This can have a profound impact on stream hydrology, resulting in a stream flow regime that is more flashy, has a higher risk of flooding in lowland areas. Water quality is also affected, as pollutants that accumulate on impervious surfaces enter streams more rapidly and effectively (Brydon et al. 2006). Headwater wetlands can provide water detention and water storage during rain events, and water release during dry periods. Headwater streams and swales could be managed to slow flood flows and trap contaminants to reduce downstream effects. Together with measures to reduce impervious area in urban catchments, headwater streams and wetlands could be managed as important resources to ameliorate the effects of stormwater run-off and they could also provide significant areas of natural and biodiversity values within an urban context. To further the

management of headwater streams in urban areas, studies of the present values and functions of urban headwater streams are needed and, in particular, investigation of the effects of low-impact urban design on the values and functions of urban headwater streams.

7 Acknowledgements

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9 Appendix 1: Auckland Regional Plan: Air, Land, Water stream definitions

The following definitions of a river/stream are taken from the Proposed Auckland Regional Plan: Air, Land and Water (Variation 1, June 2002, downloaded September 2005). This can be accessed at <http://www.arc.govt.nz/arc/publications/proposed-arp-alw.cfm> and following the links to Section 12, Definitions And Abbreviations. This terminology is the subject of appeals to the Plan and may change.

Definitions and Abbreviations – 12

Proposed Auckland Regional Plan; Air, Land and Water Plan

Category 1 River or Stream

A river or stream which meets any one or more of the following criteria:

- (a) has continual flow; or
- (b) has natural stable pools having a depth at their deepest point of not less than 150 millimetres and a surface area of not less than 0.5 square metres present throughout the period commencing 1 February and ending 30 April of any year;
- (c) has any of the following aquatic biota at any time of year:
 - eels
 - kokopu
 - crayfish
 - shrimp
 - mayflies, stoneflies or caddisflies
 - oxygen weed species *Elodea* sp., *Egeria* sp. and *Lagarosiphon* sp.
 - pondweed species *Potamogeton* sp.

Notes:

(1) This definition does not include:

- a. any artificial watercourse (including an irrigation canal, water supply race, canal for the supply for electricity power generation, and farm drainage canal); or
- b. any stream which does not meet criterion (a) or (b) of the definition and which only meets criterion (c) because there is a dam or artificial pond (on the stream) containing any of the listed fauna and flora.

(2) Most, but not all, streams which appear as blue lines on Map Series 1 of the Proposed Auckland Regional Plan: Air, Land and Water are Category 1 rivers or streams. In addition some Category 1 rivers or streams do not appear on this map series.

(3) Where there is uncertainty over the status of any stream the ARC will provide assistance and advice concerning the steps involved in making that determination.

Category 2 Stream

Any stream that is not a Category 1 stream.

Note:

This definition does not include any artificial watercourse (including an irrigation canal, water supply race, canal for the supply for electricity power generation, and farm drainage canal).

10 Appendix 2: Site Maps and photos

Maps of each site, overlain on NZMS260 Topomaps. The top and bottom of each site is shown as red points, obtained using Garmin E-trex GPS. The tops of side tributaries are sometimes shown. The gridlines provide scale at 1 km spacing. Photos are also presented for each site.

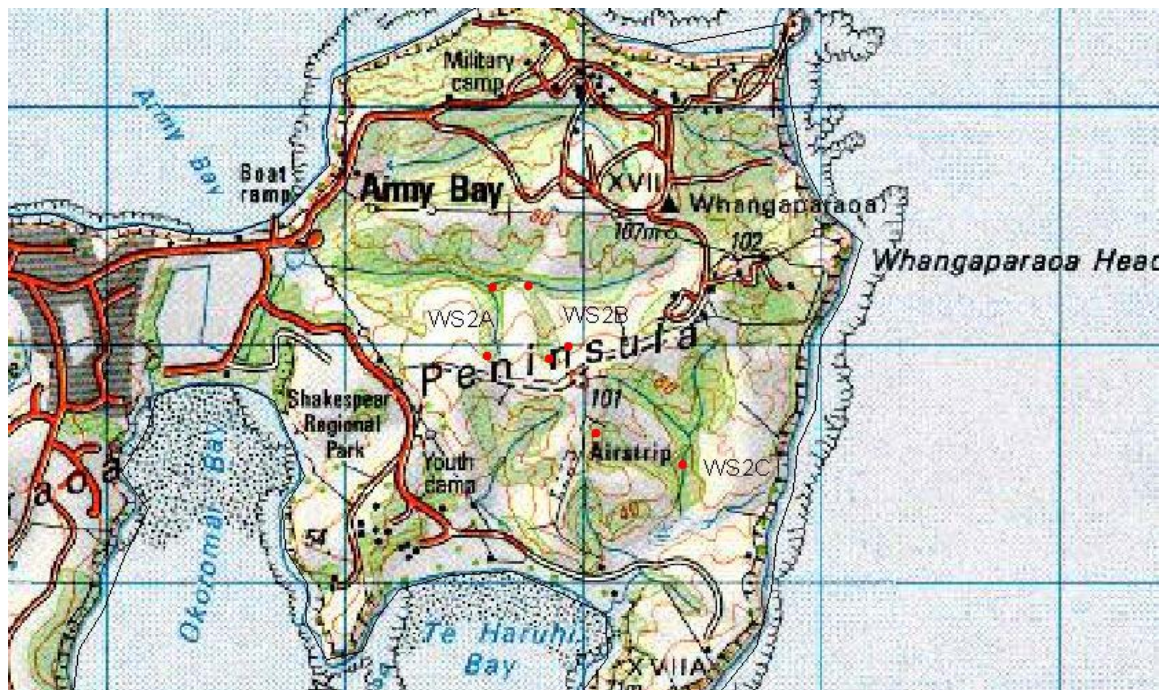
WS1 A, B, C & D Puhinui Stream Totara Park





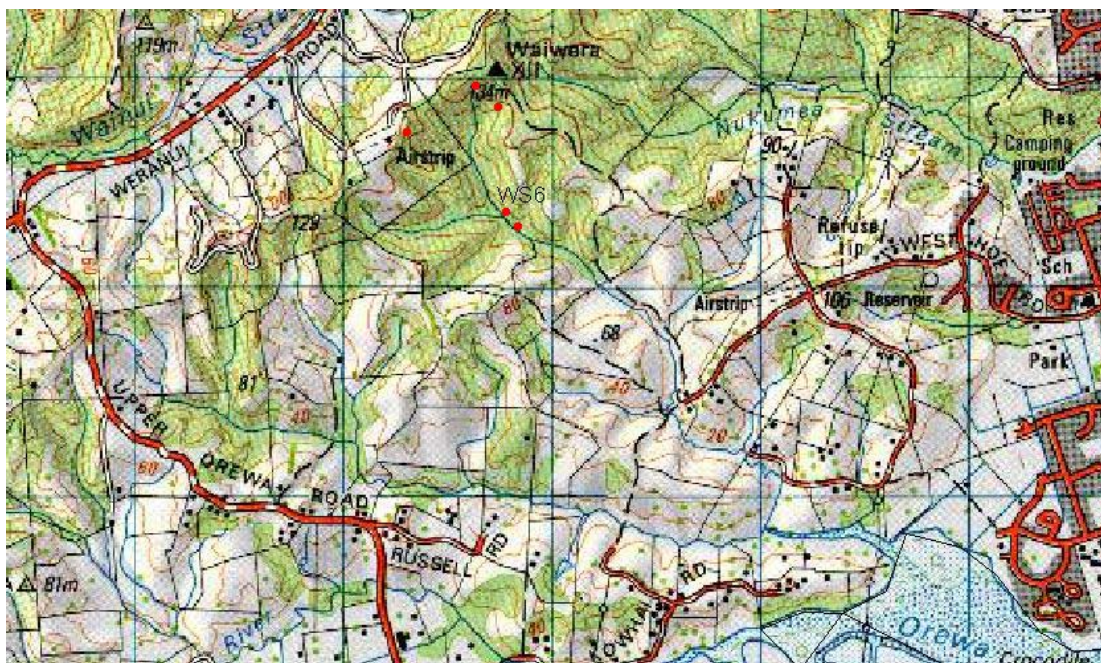
WS1 D

WS2 A, B & C Waterfall Gully Shakespeare Regional Park



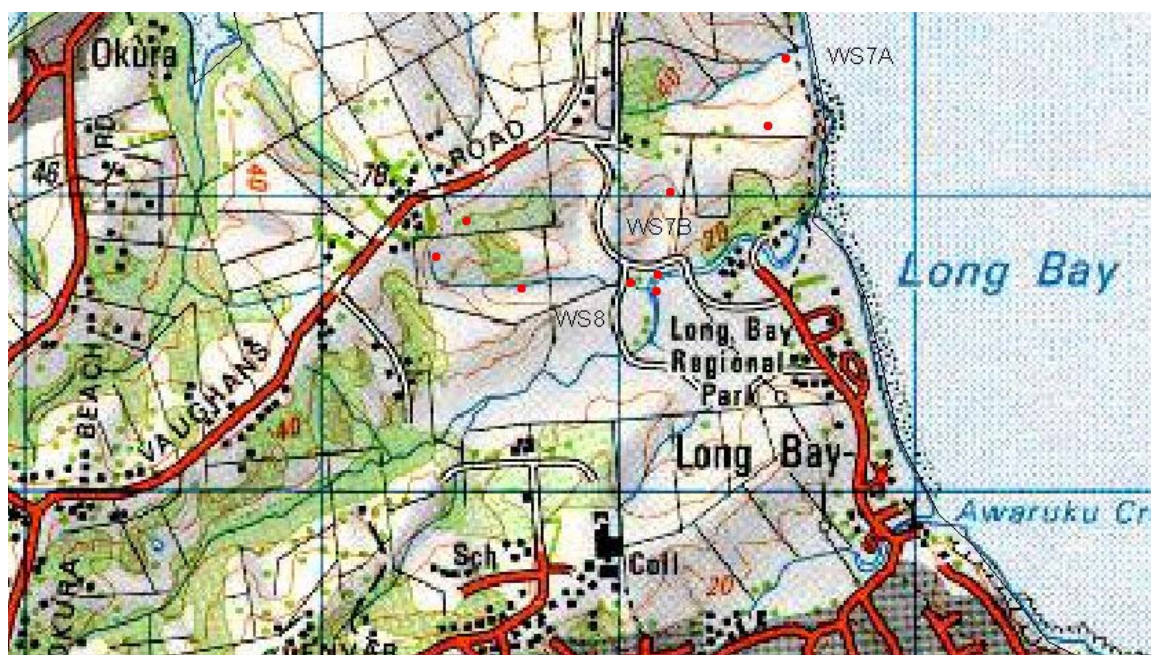
WS2 A

WS6 West Hoe Stream Orewa



WS6

WS7 A + WS8 Long Bay

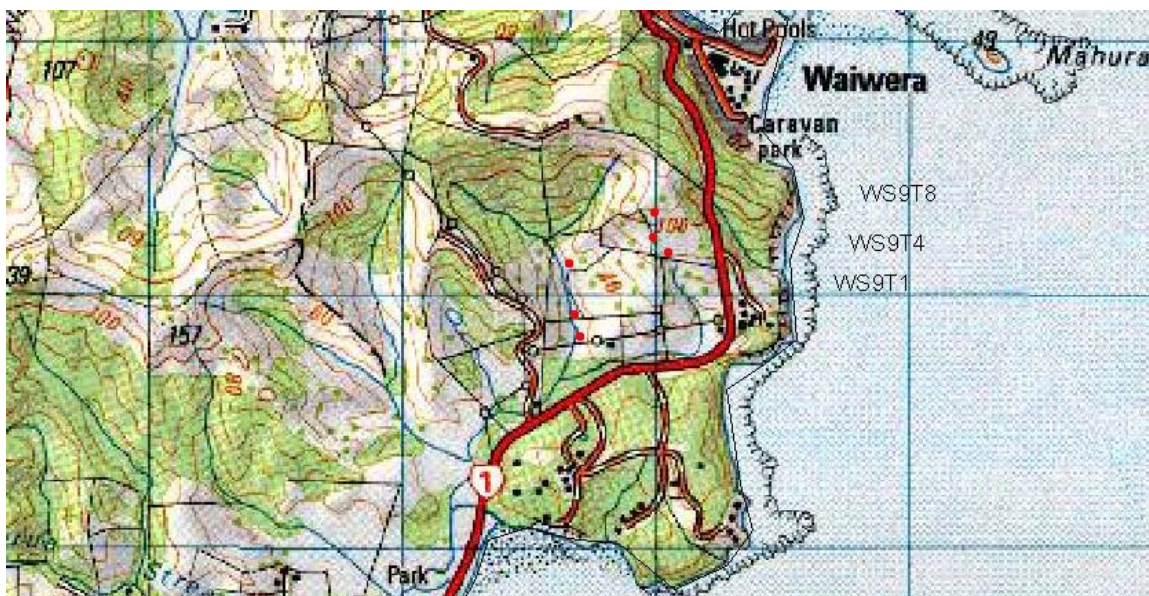


WS7 A



WS8 (top of catchment)

WS9 Hatfields Beach (Orewa)





WS9, top of one of the tributaries.

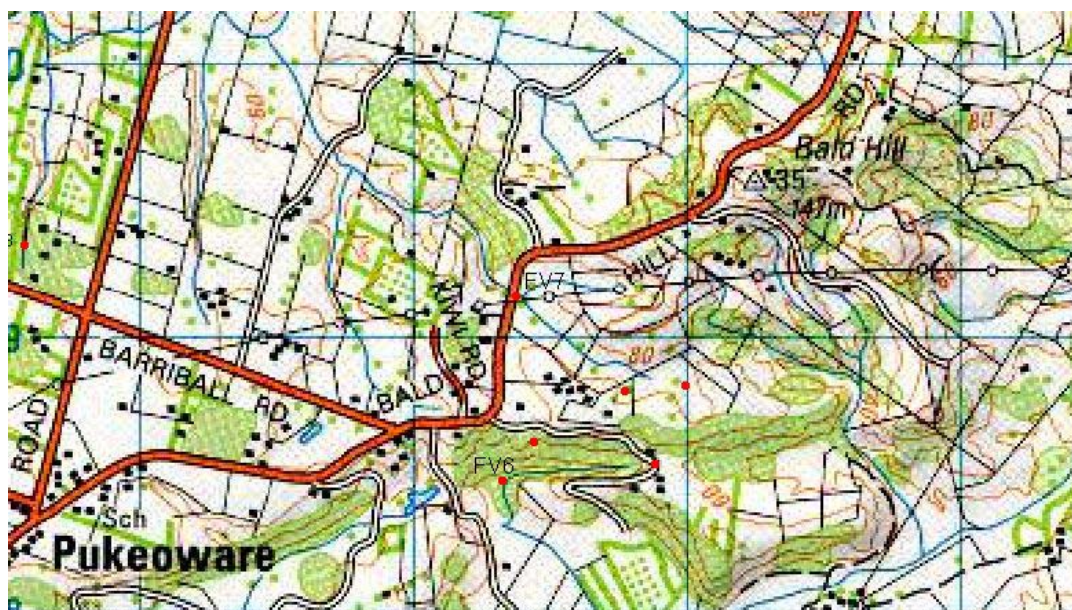


WS9, tributaries visible as lines of tussock/reeds running up the opposite slope.

FV6 & FV7

Bald Hill

Waiuku



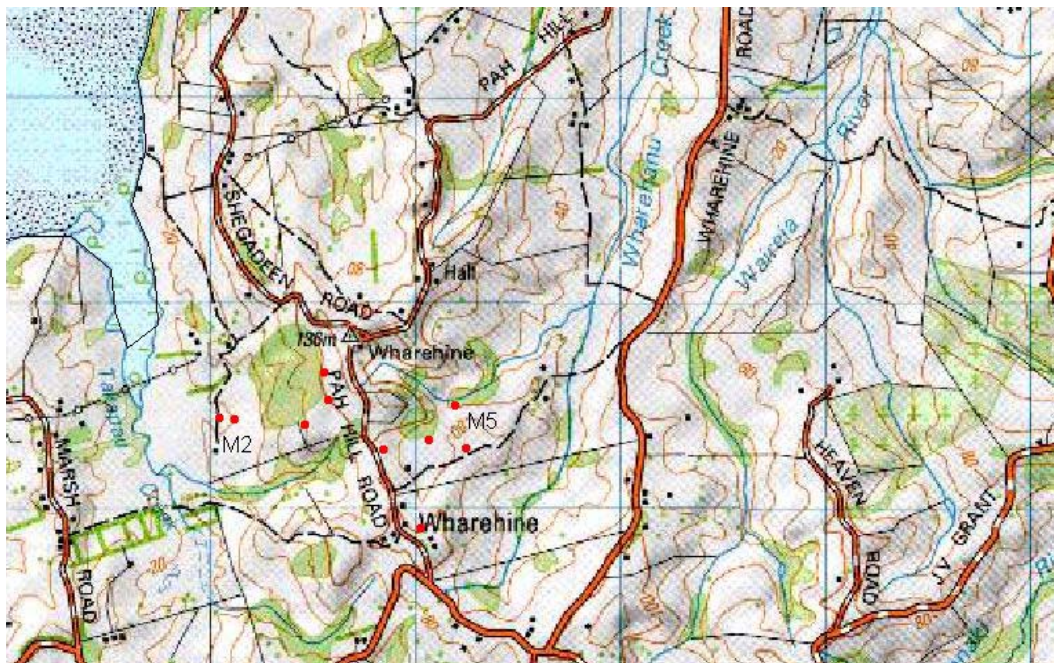


FV6



FV7

M2 & M5 Pah Hill Road Wellsford

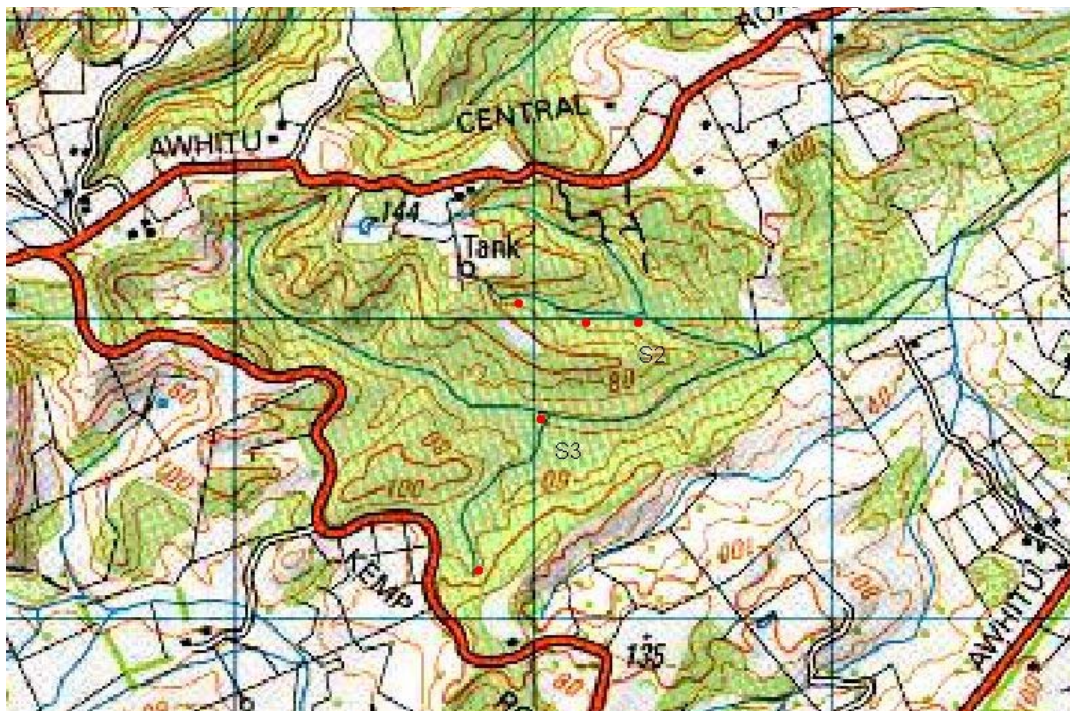


M2



M5, lower section bordering bush.

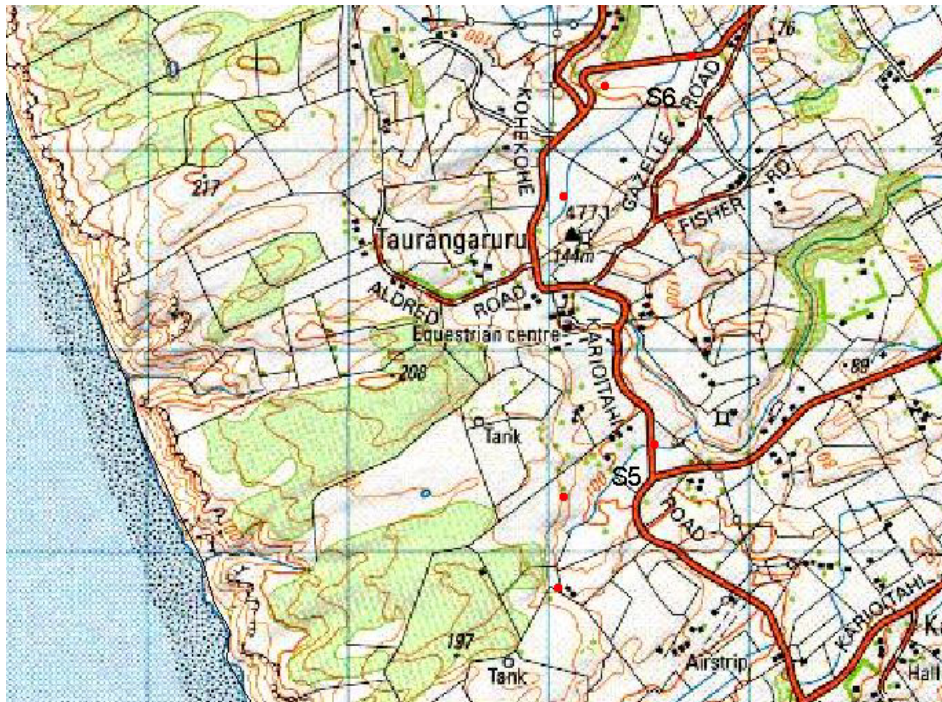
S3 Awhitu Peninsula



S3, wetland section.

S5 Karioitahi Road

Waiuku



S5, wetland tributary.