Aquatic biodiversity values of headwater streams in the Wellington region

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Executive Summary

Headwater streams too small to appear on 1:50 000 topographic maps account for a high proportion of total stream length in the landscape. Although they often have aquatic invertebrate communities that are distinct from higher order streams, and contribute significantly to regional biodiversity, unmapped (or zero-order) streams are commonly overlooked in surveys of stream biodiversity. Such streams are highly vulnerable to degradation due to land use changes, or re-engineering. In many new urban developments in Wellington, cut and fill methods to reclaim land are resulting in extensive piping of headwater streams. In rural areas of the Wellington region, headwater streams are affected by habitat degradation from livestock access. Describing the biological values of headwater streams is an essential first step to protecting them from further biodiversity loss.

The aims of this study were 1) to describe the aquatic invertebrate communities of unmapped headwater (zero-order) streams in native forest catchments at a number of sites across the Greater Wellington region, in comparison to those of nearby first-order streams, 2) to determine the contribution of headwater streams to regional, or landscape-level, biodiversity, and 3) to develop a standard method for sampling headwater streams and assessing their macroinvertebrate communities and ecological values. The headwater streams were expected to be intermittent, i.e., without flow in summer, whereas the first-order streams were expected to be perennially-flowing. Sites were labelled accordingly, though their actual flow regimes were not known until the end of the study. Six streams, from Porirua to near Masterton, were visited first in November 2009. At this time, parameters of the physical habitat and water quality of the streams were measured, including the length of stream channel (upstream of a fixed marker) with flowing water or wet sediments. Benthic macroinvertebrates were sampled in perennial and intermittent sites, and from wet sediments near the channel head, and loggers to record the presence of surface water were placed at intermittent sites. Sites were re-visited in April 2010, when the extent of surface water was re-measured and water loggers were retrieved.

Four of the six study streams showed signs of intermittency (loss of surface water flow) at times between November 2009 and April 2010. On two of these streams, bed sediments up to the channel head remained wet even after surface flow had stopped. On the two streams where flow did not cease, at the sites labelled “intermittent”, surface water was reduced to a thin film in April 2010. Intermittency in these headwaters may be greater than this in some years and less in others.

Across all sites, the density of aquatic invertebrates was very similar in intermittent and perennial habitats, but significantly higher in the wet sediment habitat. “Alpha richness”, i.e., richness per sample, of aquatic invertebrates and of EPT taxa was slightly higher in perennial than intermittent habitats. In wet sediments, invertebrate richness was comparable, but EPT richness appeared to be somewhat reduced compared to intermittent and perennial habitats.

Perennial, intermittent and wet sediment habitats each had a distinct invertebrate community composition. The community composition of each habitat type was distinct across all streams, despite the large geographic distances (up to 70 km) between streams. Wet sediment sites were characterised by a higher proportion of Diptera (mostly Chironomidae and Tipulidae) and lower proportions of EPT taxa (including absence of Ephemeroptera) than the other habitat types. The community at perennial sites had relatively even percentages of Diptera, Ephemeroptera, Crustacea and Mollusca, and had some EPT taxa that were absent from other habitat types. The composition of intermittent sites was intermediate between that of wet sediments and that of perennial sites.

Patterns of taxon richness between streams suggested that intermittent sites may add to the landscape-level diversity of aquatic invertebrates in Wellington region. However, it was not clear whether the wet sediment sites also contribute to regional biodiversity.

The biodiversity value of these headwater sites was further underscored by the presence of several habitat specialists and several taxa of special conservation interest. Five caddisfly taxa found in this study are seepage specialists, another five are known mainly from seepages and small streams, and the giant bush dragonfly, *Uropetala carovei*, appears to show affinity for stream sources (which are often seeps or springs). Two uncommon caddisfly taxa and one taxon with a highly-restricted distribution were found, and one stonefly species was recorded for the first time in the North Island. Ten taxa found at these sites are considered obligate forest-dwellers, showing the importance of native forest around headwater streams for maintaining the invertebrate community composition in pristine condition.

Assessing the ecological health and value of headwater streams requires test sites to be paired with comparable reference sites. The Index of Biotic Integrity, a multi-metric that incorporates reference sites, is recommended as a suitable tool for assessing ecological health, though it is expected to be less sensitive in headwaters than in larger streams. The Stream Ecological Valuation (SEV) is likely to be suitable for assessing ecological functioning of headwaters, though it is not validated for intermittent sites.

1. Introduction

Though often overlooked, headwater streams are numerically important in stream networks. For example, Storey & Wadwha (2009) estimated that across Auckland region, perennial streams too small to be included on 1:50 000 topographic maps total 7200 km, representing 44% of perennial stream length in the region, and intermittent (seasonally dry) streams add a further 4500 km to the total stream length.

In recent years headwater streams have received increasing attention, with several North American and Mediterranean studies highlighting their local- and landscape-level importance (Freeman et al., 2007, Meyer et al., 2007, Wipfli et al., 2007, Maasri et al., 2008, Clarke et al., 2008). Headwater streams may harbour unique species of aquatic invertebrates. Intermittent headwaters, in particular, often have a different fauna from nearby perennial reaches, sometimes including endemic species, due to the extreme environmental constraint of seasonal drying (e.g., Dieterich & Anderson 2000; Muchow & Richardson 2000). Typically, a single headwater or intermittent stream has lower invertebrate diversity than a larger stream, i.e., the "alpha diversity" of headwater streams is relatively low. However, because headwater streams often differ from one another in their physical and chemical characteristics, invertebrate diversity often is greater among headwater streams than among larger streams, that is, the landscape-level, or "gamma", diversity is often high among headwater streams (Clarke et al., 2008). Thus, the contribution of headwater streams to landscape-level diversity may be greater than indicated by the diversity or richness at a single site.

In New Zealand, there have been few studies of headwater streams, but those few indicate that headwaters typically have high biodiversity values. Storey & Quinn (2008) found 95 taxa of aquatic invertebrates, including 8 mayfly, 6 stonefly and 16 caddisfly species, in stony-bottomed intermittent headwaters in Hawke's Bay. Similarly, Parkyn et al., (2006a) found the aquatic invertebrate richness in "non-perennial" headwater habitats was only slightly lower than that in nearby perennial streams in the Waikato region. Even where surface water is reduced to a thin film, aquatic biodiversity may be high, and in fact such habitats may harbour endemic species (Collier & Smith 2006). Collier et al., (2009) found that in Hamilton City, seepage habitats harboured about 30% of the known caddisfly diversity, and concluded that these small habitats play an important role in maintaining aquatic biodiversity in an urban area.

Headwater streams are under significant pressure in the Wellington region. In urban areas the cut and fill methods used in many developments to reclaim land are resulting in extensive piping of headwater streams. In rural areas headwater streams are affected by habitat degradation from livestock access.

To better protect headwater streams in the next regional plan, information regarding the ecological values of headwater streams in the Wellington region is needed. In addition, there is a need for identification of standard sampling and assessment methods for headwater streams which can be used for ongoing regional council monitoring or as part of ecological assessments for consent applications.

To our knowledge, no previous studies in Wellington region have described the invertebrate community of headwater streams that are too short to appear on topographic maps, or those that run dry in summer. The first two aims of this study were 1) to describe the benthic macroinvertebrate fauna of such streams in native forest catchments, in comparison to the fauna of larger (mapped) first-order streams, and 2) to determine the contribution of headwater streams to regional, or landscape-level, biodiversity. The reason for focusing on forested sites was to determine the faunal values of unimpacted streams, providing a baseline to which the values of streams affected by human activities can be compared. Effort was made to include the range of aquatic habitats occurring from the channel head to the confluence with a mapped stream, including wet sediments, flowing and still-water habitats. The third aim of the study was to develop a standard method for sampling headwater streams and assessing their macroinvertebrate communities and ecological values.

2. Methods

2.1 Sites

The six streams chosen for study were all in near-natural condition, with catchments and riparian zones predominantly in native forest. The streams represented a broad geographic spread (Fig. 1, Table 1, Appendix 1), most being located on the outskirts of the Porirua, Hutt and Eastbourne urban areas, but two located in the Wairarapa, up to 74 km from the peri-urban streams. According to the River Environment Classification, all streams drained steep valleys with hard sedimentary rock, but were located in a variety of climate types (Table 1).

Table 1: Study streams, with map coordinates (NZ Map Grid) and River Environment Classification properties (abbreviations: cool extrm wet = cool, extremely wet; low elev = low elevation; hard sed = hard sedimentary; high grad = high gradient).

Stream name	Easting	Northing	Climate	Source of flow	Geology	Valley landform
Kiriwhakapapa	2724995	6041298	cool extrm wet	hill country	hard sed	high grad
Korokoro trib	2667510	5999335	cool wet	low elev	hard sed	high grad
Rimutaka	2702312	6009004	cool wet	low elev	hard sed	high grad
Takapu Wahia	2662914	6007317	warm dry	low elev	hard sed	high grad
Waiwhetu trib	2675680	5998696	cool wet	low elev	hard sed	high grad
York Bay	2670493	5991214	warm wet	low elev	hard sed	high grad

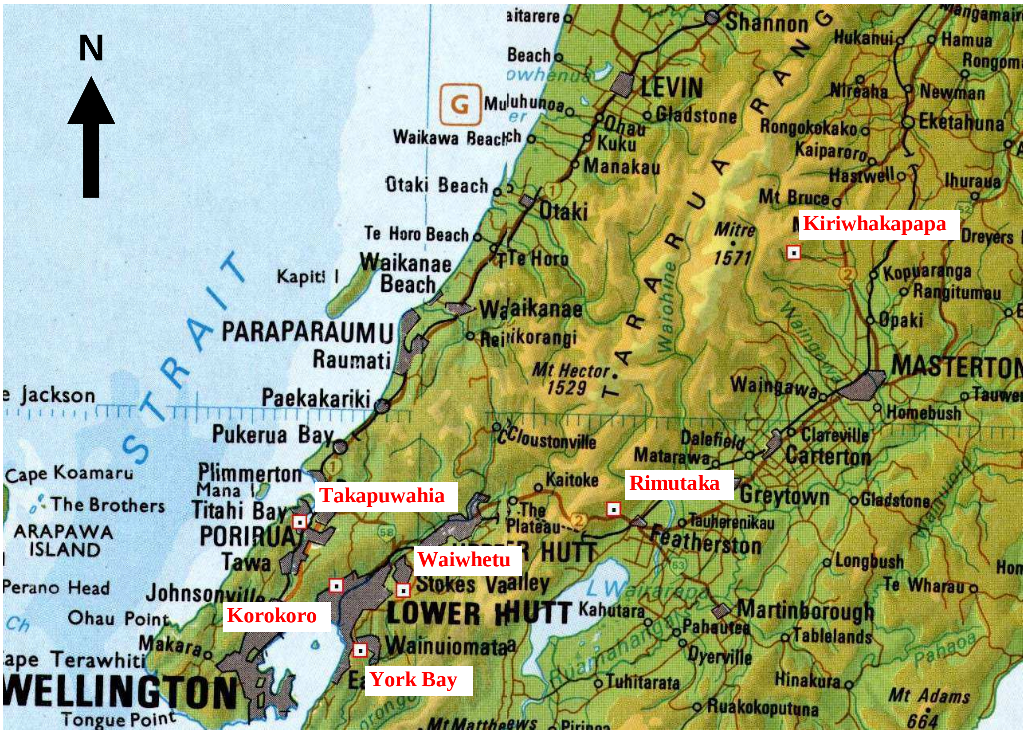

Figure 1: Map of Wellington region showing locations of study sites.

On each stream, a sampling site was located in each of three different habitat types, based on the conditions observed on the first field visit in November 2009. Near the channel head, a “wet sediment” site was located in the stream channel (or in the valley bottom if a stream channel was not defined) where sediments were wet but there was no surface water. An “intermittent” site was located 65-350 m downstream of the channel head where surface flow was present but was expected to cease during the dry part of the year. A “perennial” site was located several hundred metres downstream (in most cases, below a confluence with another tributary) or on an adjacent stream, where stream flow was expected to persist throughout the year. All perennial sites were located on small, first-order streams so that, as far as possible, differences in the invertebrate fauna were due to intermittency rather than stream size.

2.2 Data collection

R. Storey (NIWA) and S. Warr (GWRC) collected data from stream sites in early November 2009 and again in late April 2010. In November 2009, water physicochemical parameters were measured in the field using a Hach HQ40d multi-meter. Channel morphology was measured with a meter stick, and riparian shading by visual estimation. Stream bed substrate was characterised using a “Wolman walk” (Wolman, 1954), whereby 50 or more particles were picked up randomly from the stream bed and classified according to Wentworth size classes (sand/silt <2 mm, gravel 2-16 mm, pebbles 16-64 mm, cobbles 64-256 mm, boulders >256 mm, or bedrock). On each stream, the channel head was identified as the point where sediments became dry and/or there was a definite transition from a smooth valley bottom to a channel cut by water. This point was marked with a spray-painted dot, and the distance from there to the intermittent site was measured with a tape measure. Flow and channel types (Table 2) occurring over this distance were recorded.

At each intermittent sampling site a "water logger" was placed in the centre of the stream channel (Fig. 2). These loggers, which were modified temperature loggers, recorded the presence or absence of surface water in the stream channel at 12-hourly intervals.

In late April 2010, all sites were re-visited by S. Warr. The water loggers were retrieved, and the lengths of different flow types occurring between the intermittent site and the channel head (as marked in November 2009) were measured with a tape measure.

Figure 2: Loggers placed in the stream beds at intermittent sites to record the presence/absence of water at daily intervals.

Table 2: Codes for recording channel and water flow types.

	Obvious flow	Slow flow or standing water	Isolated pools	No water, moist sediments	Dry
Channel incised, definite banks, no terrestrial veg.	1A	2A	3A	4A	5A
No banks, stream bed substrate, no terrestrial veg.	1B	2B	3B	4B	5B
No banks or stream substrate, terrestrial veg.	1C	2C	3C	4C	5C

2.3 Invertebrate sampling

Invertebrate samples were collected in November 2009. At intermittent and perennial sites, invertebrates were collected by disturbing the stream bed sediments and organic matter over a 0.4 m^2 area, and sweeping the disturbed area with a 0.25 mm mesh hand net. Within the sampled area, effort was made to include the full variety of substrate and flow types present (e.g., cobbles, gravel, leaf packs, large wood, slow-flowing and fast-flowing areas). This procedure was repeated twice more at each site, giving three replicate samples at each site in each stream.

At the wet sediment sites, the lack of surface water required a different method. At these sites, two replicate 10 cm-diameter circles were marked on the ground, and sediments and organic matter inside these circles, to a depth of 0.5-1 cm, were scooped into a single plastic pottle, giving one sample per site.

All samples were preserved on site in 70% isopropyl alcohol and sent to EOS Ecology (Christchurch) for sorting and identification.

2.4 Data analysis

Differences in invertebrate density (log (x+1)-transformed to improve data normality) and taxon richness (square-root transformed) were analysed by analysis of variance (ANOVA) using SPSS v11™. When comparing perennial to intermittent sites, two-factor ANOVAs were used, with habitat type (i.e., flow permanence) and stream as the two factors. However, when comparing wet sediment to perennial and intermittent sites, one-factor ANOVAs were used (with habitat type as the one factor; replicates at each intermittent and perennial site added together), because wet sediment sites had only one replicate on each stream. Differences in invertebrate community composition between sites were displayed with multidimensional scaling (MDS) on the log(x+1)-transformed density data, and differences between sites were analysed for statistical significance with ANOSIM, using Primer 6™. Species accumulation curves were plotted using the *S*obs method in Primer 6™. *S*obs plots the increasing number of taxa observed as samples are successively pooled. A permutation routine was used to smooth the accumulation curve by entering samples in random order, repeating the process 999 times and averaging the results.

3. Results and discussion

3.1 Physical characteristics of study streams

At the perennial sites, the six streams were 0.8-1.15 m wide, 0.013-0.1 m deep and with an estimated discharge of 0.3-2.5 L/s (Table 3). Kiriwhakapapa and Waiwhetu were about 10 times larger than other perennial sites in terms of discharge, due to the difficulty of finding smaller suitable sites on these streams. The Rimutaka perennial site was smaller and closer to the intermittent site than other perennial sites were, also because this was the most suitable site.

At the intermittent sites, the six streams were 0.25-0.88 m wide, 0.008-0.4 m deep and with an estimated discharge of 0.05-0.2 L/s (Table 3).

At the perennial sites, stream beds were composed mostly of gravels, pebbles and cobbles, except for Rimutaka, which was 52% sand and silt (Fig. 3). At the intermittent sites, stream beds were composed mostly of sand/silt, gravels and pebbles, and at the wet sediment sites, the stream beds were mostly sand/silt with some gravel.

The system for classifying channel and water flow types (Table 2) did not describe Wellington headwater streams as well as the Auckland streams for which it was designed (Wilding and Parkyn 2006). Whereas the headwater streams surveyed by Wilding and Parkyn (2006) were low-gradient and soft-bottomed, the headwater streams in the present study were mostly very steep and dominated by gravels, pebbles or cobbles. In Auckland headwater streams, disconnected pools, up to a metre or more long and more than 10 cm deep, typically occurred between the channel head and where obvious flow began (Fig. 4a). In contrast, in Wellington headwater streams, the stream became progressively shallower and narrower as one approached the channel head. There was a gradual transition between obvious flow and wet sediments, where the stream reduced to a film of water (Fig. 4b). In places, flow disappeared below the stream bed surface for several metres before emerging again. Thus, in this study, streams near the channel head were physically similar to the seepages sampled by Collier et al., (2009).

Table 3: Basic physical characteristics of stream sites: channel dimensions, stream discharge and riparian shading.

Stream	Habitat	Width (m)	Bankfull width (m)	Max depth (m)	Discharge (L/s)	Riparian shade %
Kiriwhakapapa	PER	1.13	6	0.013	2.5	90
	INT	0.88	2.2	0.024	0.07	90
	WETSED					90
Korokoro	PER	0.87	1.52	0.098	0.3	80
	INT	0.25	1	0.008	0.05	90
	WETSED					90
Rimutaka	PER	0.34	0.99	0.06	0.3	90
	INT	0.52	0.88	0.03	0.2	
	WETSED					80
Takapuwahia	PER	0.8	1.95	0.055	0.7	80
	INT	0.52	1.46	0.014	0.05	80
	WETSED					85
Waiwhetu	PER	1.15	2.4	0.105	2.1	85
	INT	0.45	1.482	0.043	0.1	65
	WETSED					85
York Bay	PER	0.9	1.65	0.094	0.7	70
	INT	0.56	0.98	0.098	0.07	70
	WETSED					80

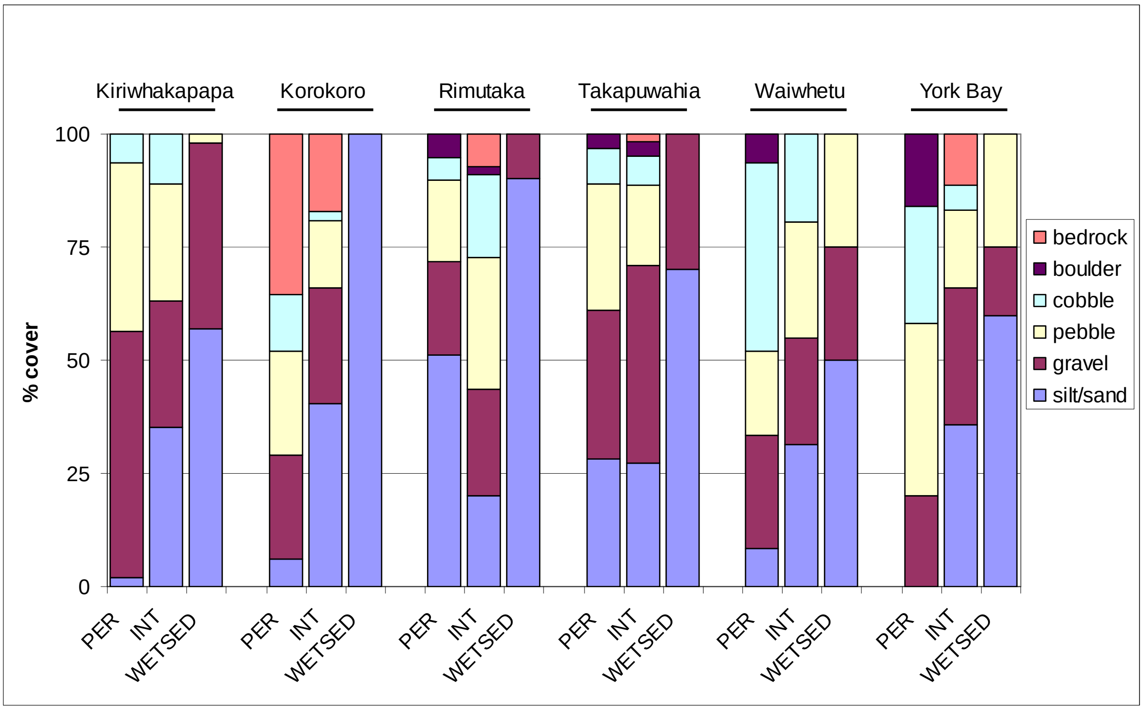

Figure 3: Stream bed composition of the six streams as percentage of particle size classes. Abbreviations are: PER = perennial; INT = intermittent; WETSED = wet sediment.

A

B

Figure 4: A. Disconnected pool in Auckland headwater stream (from Wilding and Parkyn 2006); B. stream width and depth gradually decreases towards the channel head in a Wellington headwater stream (Takapuwahia).

3.2 River flows and rainfall during the study period

In an average year, river flows at GWRC monitoring sites near the study streams are highest in October and/or July, and lowest in March or April (Fig. 5). In 2009-10, monthly mean river flows were higher than average at most monitoring sites in October, December and January, due to heavy rains in October and January, but mostly less than average in the other months (Figs. 6 and 7). In the months when we visited the stream sites, river flows at GWRC monitoring sites were 60-75% of long-term average flows in November and 30-75% of long-term average flows in April. It is expected that stream flows at the headwater sites would be lower than average by a similar amount.

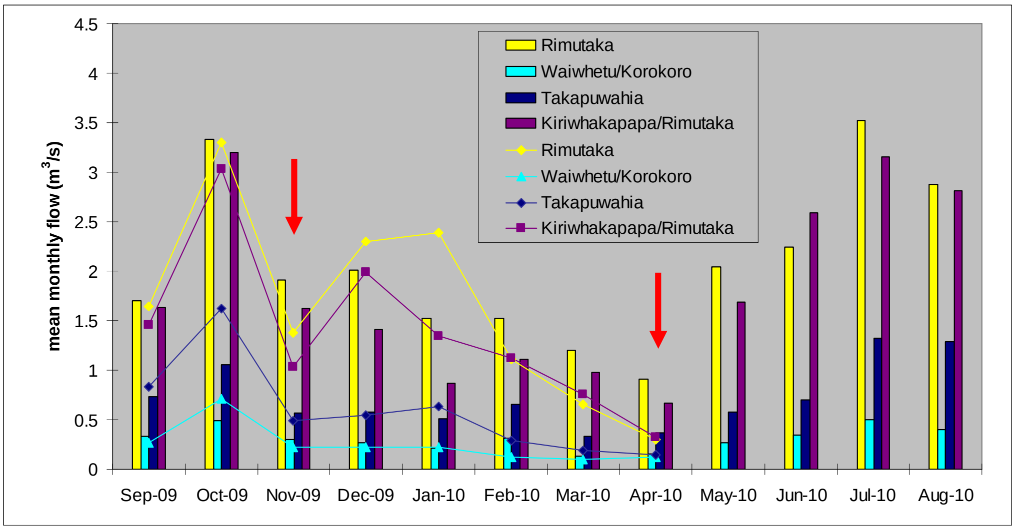

Figure 5: Mean monthly flows at Greater Wellington Regional Council river monitoring sites averaged over the last 9-10 years (bars), and in 2009-10 (lines). Red arrows indicate times of spring and autumn field visit. Monitoring sites are labelled by the study stream closest to them. Actual flow monitoring site names were: Pakuratahi at Truss Bridge (Rimutaka), Waiwhetu at Whites Line East (Waiwhetu/Korokoro), Porirua at Town Centre (Takapuwahia) and Mangatarere at Gorge (Kiriwhakapapa/ Rimutaka). No monitoring sites were near York Bay.

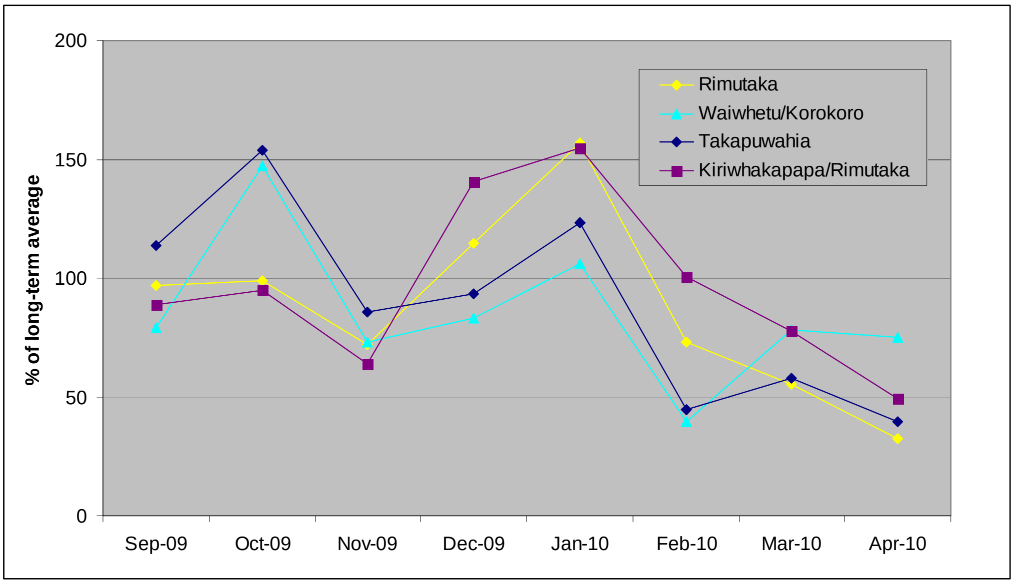

Figure 6: Mean monthly flows at Greater Wellington Regional Council river monitoring sites during the 2009-10 study period as a proportion of average monthly flows over the last 9-10 years. Monitoring sites are labelled by the study stream closest to them. Actual flow monitoring site names were: Pakuratahi at Truss Bridge (Rimutaka), Waiwhetu at Whites Line East (Waiwhetu/Korokoro), Porirua at Town Centre (Takapuwahia) and Mangatarere at Gorge (Kiriwhakapapa/ Rimutaka).

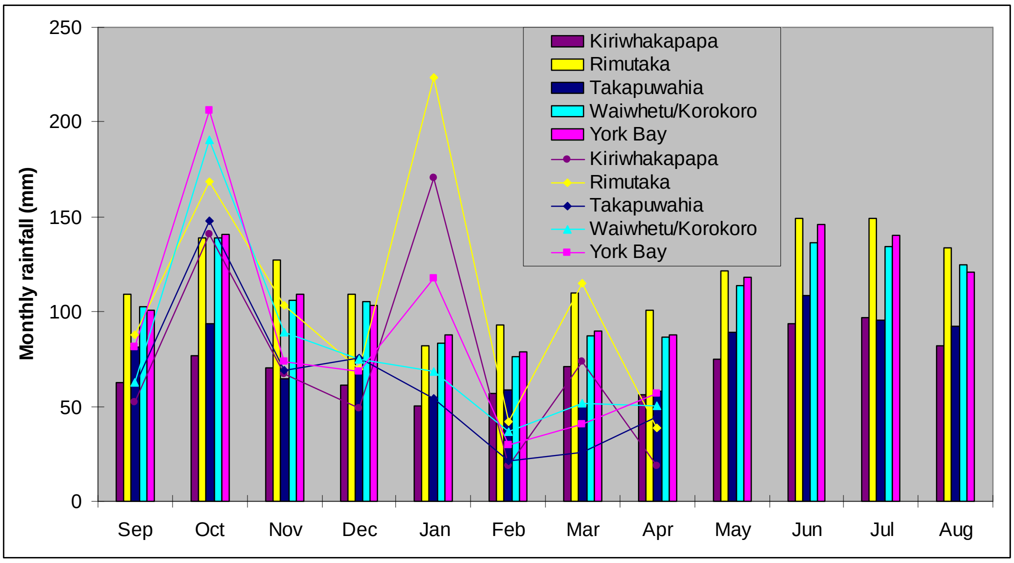

Figure 7: Total monthly rainfall at weather stations nearest to study sites, averaged over the last 30 years (bars), and before and during the study period (September 2009-April 2010; lines) Rainfall stations were: Wairarapa Cadet Farm (for Kiriwhakapapa), Woodside 2 (for Rimutaka), Titahi Bay T. Plant (for Takapuwahia), Trentham Racecourse (for Waiwhetu/Korokoro), Maungaraki No. 2 (for York Bay).

3.3 Intermittency and seasonal changes in stream habitat lengths

On all streams, the water level declined and the length of stream lacking surface water increased between spring and autumn (Table 4). From the intermittent sampling site to the channel head, obvious flow (flow code 1) was present in spring but was replaced in autumn by slow flow/standing water, isolated pools or moist sediments (codes 2, 3 or 4, respectively; Table 4). In autumn, surface water in this reach of each stream was present only as pools or as a film <1 mm deep. The length of dry sediments increased noticeably from spring to autumn on only two streams, Takapuwahia and Waiwhetu, as indicated in Table 4 by a decrease in total stream length. However, the length of unsaturated wet sediments (where surface water was absent) increased on at least four of the streams. The water table where the water loggers were located dropped below the stream bed surface in Takapuwahia, Rimutaka, Waiwhetu and York Bay streams more than once during summer, and (in the latter three streams) for an extended period in autumn (Table 4).

Table 4: Lengths of intermittent sections, from sampling site to the point where the stream bed surface sediments are dry, and periods of time when surface water was absent where water loggers were located. The end of the survey ("end") was 20-22 April.

	November 2009 (Spring)			April 2010 (Autumn)			Water absent at loggers
Stream	**Length (m)**	**dry sections**	**Flow/channel codes present**	**Length (m)**	**dry sections**	**Flow/channel codes present**	
Kiriwhakapapa	142	60-82 m	1A, 1B, 4B	145		2A, 2B, 4A, 4B, 4C	
Korokoro	116	30-45 m	2B, 4B, 4C	116		2A, 4A, 4B	
Rimutaka	175		1A, 1B, 1C	175		2A, 2B, 4B	9 Mar, 21 Mar, 7 Apr-end
Takapuwahia	315		1A, 1B, 2A, 2B, 4A, 4B	151		2A, 4A, 4B	17 Nov, 9 Mar
Waiwhetu	150		1A	127	0-4 m, 28-38 m	2A, 4A	18-22 Jan, 2 Feb-end
York Bay	335	90-105 m, 150-174 m	1A	335	160-178 m, 216-255 m	2A, 3A, 4A	12 Dec-15 Jan, 20-23 Jan, 28 Jan-end

3.4 Water physicochemical characteristics

In November 2009, dissolved oxygen was above 9.7 mg/L (about 90% saturation) at all sites (Table 5), indicating that oxygen was not limiting for aquatic life at any site at the time of measurement. This is not surprising, given the high surface area:volume ratio of these small channels, which would allow rapid gas exchange with the atmosphere. Where water depth is very shallow, or surface flow continues, oxygen is unlikely to become limiting during the critical summer season. However, in pools where water flow ceases during summer, oxygen may become limiting if the pools accumulate decaying leaves. Water temperatures (Table 5) were low, as would be expected for shaded forest streams that probably are closely connected to ground water. Water temperatures were well within the tolerance limits of aquatic invertebrates at the time of measurement (Quinn et al., 1994), and, given the heavy shading of these sites, would be unlikely to exceed tolerance limits even in mid-summer. Conductivity varied widely between sites, possibly indicating some maritime influence at sites near the coast (e.g., Takapuwahia and York Bay). pH was close to neutral at all sites.

Table 5: Water physicochemical parameters at perennial (PER) and intermittent (INT) sites on the six study streams in November 2009.

Stream	Habitat	D.O. (mg/L)	Temperature (ºC)	Conductivity (µS/cm)	pH
Kiriwhakapapa	PER	10.7	10.3	79	7.50
	INT	10.5	10.0	72	7.42
Korokoro	PER	10.5	11.1	247	7.34
	INT	10.2	12.1	305	7.27
Rimutaka	PER	10.2	11.3	101	7.44
	INT	10.7	10.9	98	7.05
Takapuwahia	PER	9.7	12.1	418	7.50
	INT	9.8	11.2	538	7.52
Waiwhetu	PER	11.1	10.2	141	7.50
	INT	11.1	10.2	143	7.32
York Bay	PER	10.8	10.5	298	7.42
	INT	9.9	10.6	231	6.60

3.5 Invertebrates

3.5.1 Density

The mean density of aquatic invertebrates among the perennial sites (2650/m^2) was similar to that among the intermittent sites (2300/m^2), though invertebrate density was more variable among the perennial sites (Fig. 8). No significant difference between perennial and intermittent habitats was found ($F_{1,36}$=0.12, p=0.74). In the wet sediments, however, the density of aquatic invertebrates (average 8600/m^2) was significantly higher than in perennial or intermittent habitats ($F_{2,17}$=7.539, p=0.005). This pattern among sites is similar to that found in similar New Zealand studies (e.g., Parkyn et al., 2006a, Parkyn et al., 2006b, Storey et al., 2009), though the densities found in the present study were higher than were generally found previously (e.g., 2-10 times higher than corresponding native forest sites in Wilding and Parkyn (2006)).

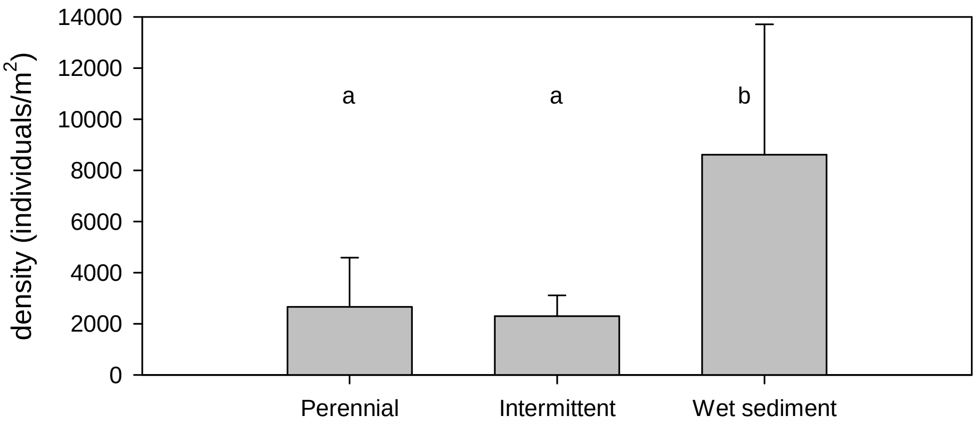

Figure 8: Average density of aquatic invertebrates (+S.D.) among the six streams in perennial, intermittent and wet sediment habitats. Letters above bars indicate results of Tukey's HSD post-hoc test; bars that share a letter are not significantly different to each other.

3.5.2 Alpha taxon richness

Alpha taxon richness, the average richness of aquatic invertebrate taxa per sample, was only slightly lower in intermittent than in perennial sites (average 29.4 vs 33.3 taxa per sample; Fig. 9), but the difference was significant ($F_{1,36}$=6.8, p=0.016). Average richness of EPT taxa also was significantly lower in intermittent than in perennial sites (Fig. 9; $F_{1,36}$=16.4, p<0.001). Alpha taxon richness in the wet sediment sites could not be formally compared to intermittent and perennial sites, since the sample area was about seven times smaller. Given that a lower number of taxa would be expected in a smaller area, taxon richness in the wet sediments appeared comparable to that in intermittent and perennial habitats. EPT richness, however, appeared to be lower than expected on this basis.

In Auckland and Waikato headwater streams studies (Parkyn et al., 2006a; Parkyn et al., 2006b), the same patterns in taxon richness and EPT richness appeared, though in these studies, taxon richness in wet sediment sites was only slightly lower than in perennial and intermittent sites.

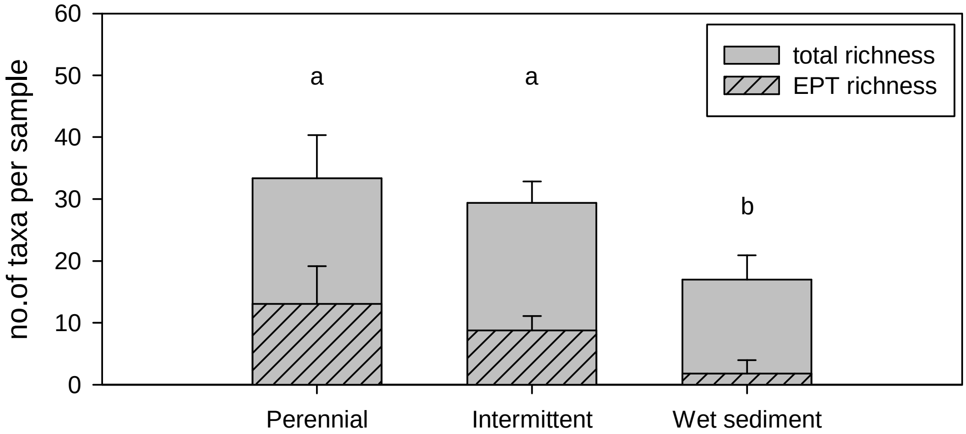

Figure 9: Average invertebrate taxon richness and EPT (Ephemeroptera, Plecoptera and Trichoptera) richness per sample (+S.D.) among the six streams in perennial, intermittent and wet sediment sites. Letters above bars indicate results of Tukey's HSD post-hoc test; bars that share a letter are not significantly different to each other.

3.5.3 Community composition: higher taxa

With respect to the higher taxa (orders, classes and phyla), a characteristic community composition could be identified for each habitat type (perennial, intermittent and wet sediment). In perennial sites, invertebrate % abundance was evenly distributed among several major taxa, Diptera, Ephemeroptera, Crustacea and Mollusca each comprising 10-30% of the fauna (Fig. 10). Trichoptera, Plecoptera and Acarina were consistently present in lower densities, and Oligochaeta occurred in low numbers in all samples. Rimutaka had a somewhat different community composition to the perennial sites on other streams, appearing more like an intermittent site. This is probably because (due to a lack of more suitable locations) the Rimutaka perennial site was located only 150 m downstream of the intermittent site. During the November survey stream discharge at the perennial site was only 50% greater than at the intermittent site, and during the April survey, surface water at the perennial site was reduced to a thin film, as it was at the intermittent site. By contrast, on other streams, perennial sites were downstream of confluences or on neighbouring streams where discharge was at least 6 times greater than at the corresponding intermittent site (Table 3).

Intermittent sites were dominated by Diptera (mostly Chironomidae) (Fig. 10). Acarina and Crustacea occurred fairly consistently among sites, as did Ephemeroptera, Plecoptera and Trichoptera in lower numbers. Mollusca and Oligochaeta accounted for a significant proportion of the community in some streams, but were almost absent from others. Intermittent sites appeared to be intermediate between perennial and wet sediment sites in terms of their community composition by higher taxa, in particular EPT taxa (Fig. 11) and Diptera.

Wet sediments were dominated by Diptera (mostly Chironomidae), while Acarina and Crustacea occurred fairly consistently in lower numbers (Fig. 10). Other taxa, e.g., Mollusca, Oligochaeta and other non-insects (nematodes+platyhelminthes), were patchy, occurring abundantly in some streams, but in low numbers in others. In these respects, the invertebrate composition in wet sediments was similar to that at the intermittent sites. The main differences between the two habitat types were the greater dominance by Diptera, and the much lower proportion of EPT in the wet sediments (Fig. 11) In the wet sediments, Ephemeroptera were completely absent, and Plecoptera and Trichoptera accounted for >1% of the community on only two streams.

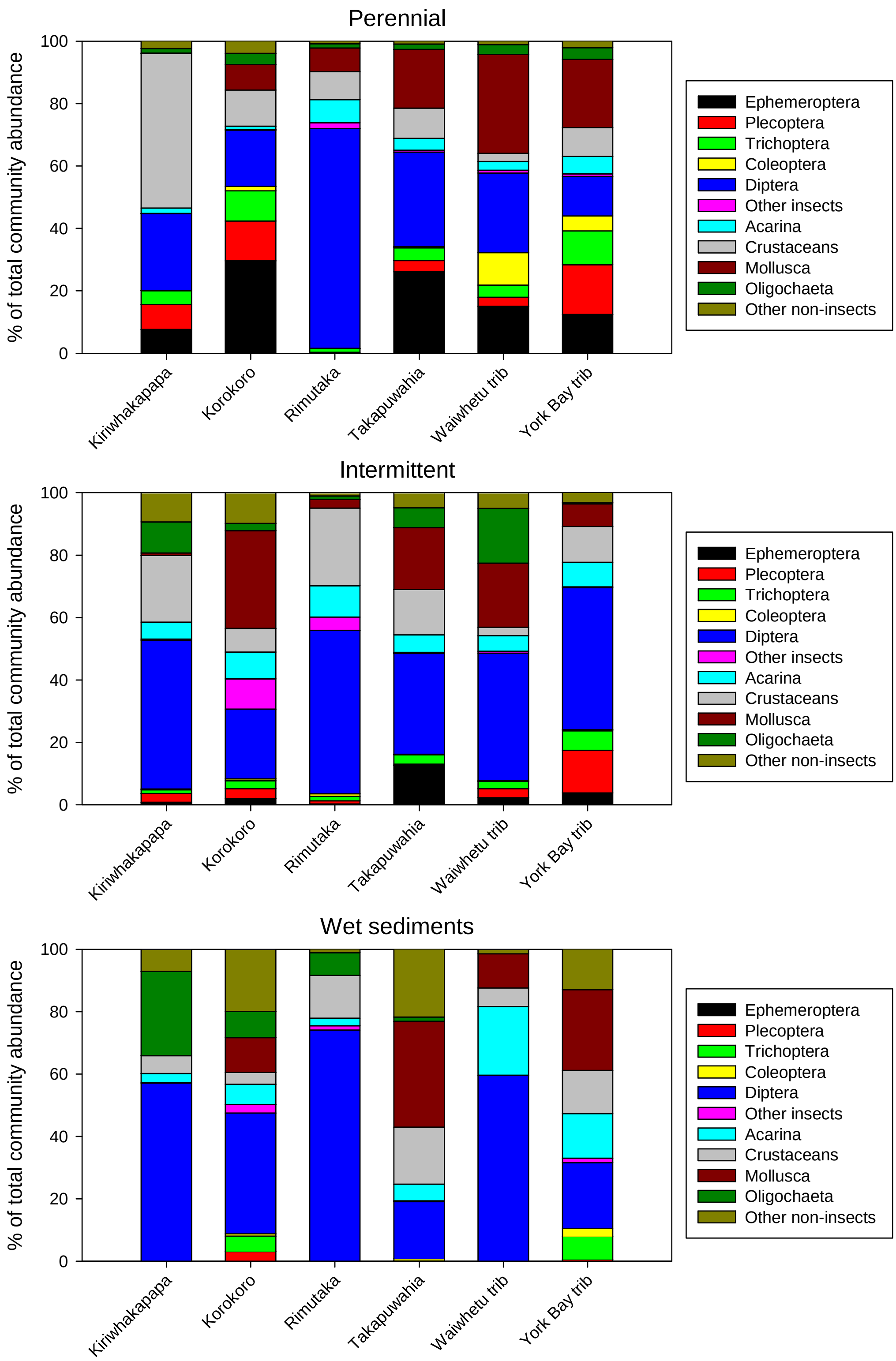

Figure 10: Composition of the invertebrate community in perennial, intermittent and wet sediment sites of the six study streams calculated as percent abundance of higher taxa (orders, classes and phyla).

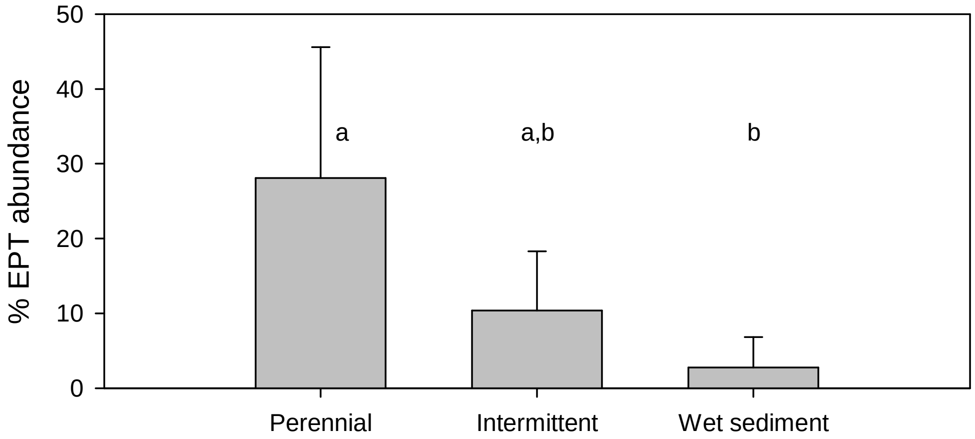

Figure 11: Abundance of EPT (Ephemeroptera, Plecoptera and Trichoptera) as percent of total invertebrate abundance at perennial, intermittent and wet sediment sites. Letters above bars indicate results of Tukey's HSD post-hoc test; bars that share a letter are not significantly different to each other.

3.5.4 Community composition: lowest taxonomic units

The perennial, intermittent and wet sediment habitats each had a characteristic community composition that was distinctly different to each other habitat type. Despite the wide geographic separation between the six streams, samples from the different streams were grouped together by habitat type and separated from other habitat types along Axis 1 of the multidimensional scaling plot (Fig. 12). The composition of the intermittent sites was intermediate between that of the perennial and wet sediment sites. The only exception to this overall pattern was the Rimutaka perennial site, which had a community composition intermediate between the intermittent and wet sediment habitats. When the invertebrate density data were transformed to presence-absence or percent composition, similar patterns appeared in MDS plots, indicating that the pattern was not driven only by differences in abundance between species or between sites.

Wet sediment samples were more widely spread than those from intermittent or perennial sites, indicating that community composition was more variable among wet sediment sites. Except for the Rimutaka perennial sample, perennial samples were about as widely spread as intermittent. SIMPER analysis confirmed that with Rimutaka sites removed, average within-group similarity was 67.7% for intermittent sites, 67.8% for perennial sites and 56.9% for wet sediment sites.

Certain taxa (e.g., Chironominae, Ostracoda, Orthocladiinae and *Potamopyrgus*) were present in high densities at all sites, occurring in only slightly higher densities in the wet sediment habitat than in the other habitats. Other taxa (e.g., Acarina, Oligochaeta, Nematoda, Ceratopogonidae, Eriopterini, Hexatomini, *Paradixa*, Tanypodinae, *Zelandotipula*, and Collembola) were more frequently found and/or found in higher densities in wet sediment than in intermittent or perennial sites. Some taxa were frequently found and/or abundant in wet sediment sites but were absent or almost absent from perennial sites (e.g., *Edpercivalia*, *Pseudoeconesus*, *Spaniocercoides*, Dolichopodidae, Thaumelidae, *Zelandotipula* and *Paradixa*).

Perennial sites were characterised by some taxa that were absent from intermittent and wet sediment sites, all of which, except for Lumbricidae and Elmidae, were EPT taxa: *Coloburiscus*, *Zelandoperla*, *Austroclima* and *Nesameletus*. Likewise, intermittent sites were characterised by certain taxa that were absent from wet sediments, almost all of which were EPT taxa: *Zephlebia*, *Deleatidium*, *Neozephlebia*, *Psilochorema*, *Orthopsyche*, *Polyplectropus*, *Spaniocerca*, *Stenoperla* and *Austroperla*. Wet sediment sites were characterised by absence of many taxa that were common at perennial and intermittent sites. Almost all were EPT taxa, but some beetles (Elmidae, Ptilodactylidae and Hydraenidae) also were absent from wet sediments. No mayflies, and only two stoneflies (*Spaniocercoides* and *Taraperla*) were found in wet sediments. Several caddisfly taxa were found, most belonging to the family Hydrobiosidae (*Edpercivalia*, *Hydrochorema* and *Hydrobiosis*), but the only caddisflies in wet sediments with more than 1-2 individuals per sample were *Pseudoeconesus* and *Pycnocentria forcipata*.

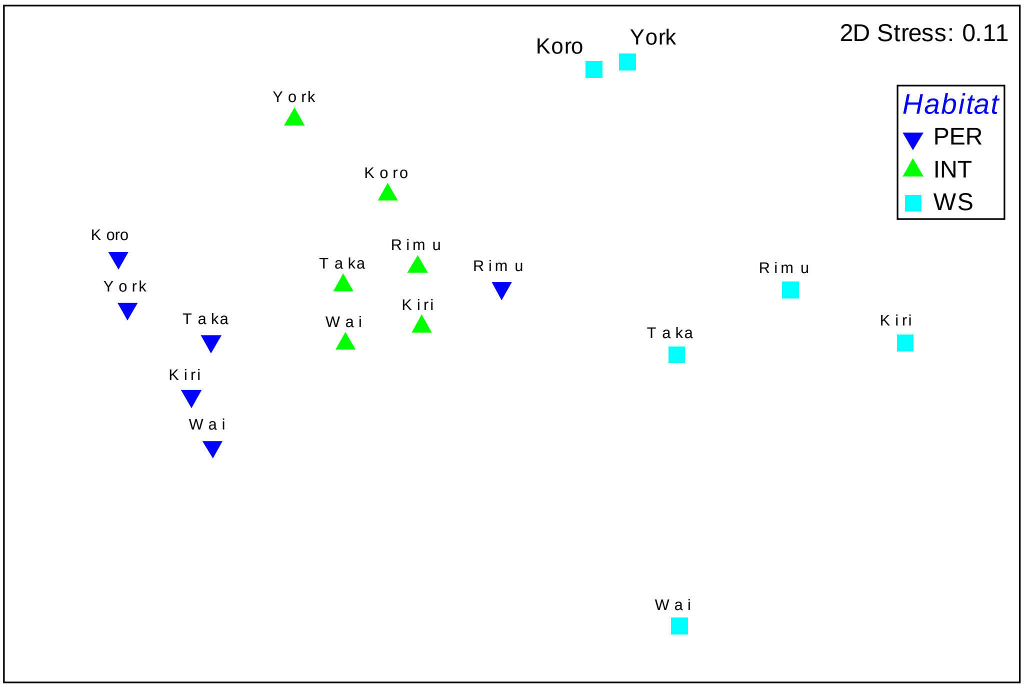

Figure 12: Multi-dimensional scaling plot of community composition (as invertebrate density) in perennial (PER), intermittent (INT) and wet sediment (WS) sites. Stream abbreviations are Kiri (Kiriwhakapapa), Koro (Korokoro), Rimu (Rimutaka), Taka (Takapuwahia), Wai (Waiwhetu), York (York Bay).

3.5.5 Taxa of special interest

Habitat specialists

A number of taxa collected in this study are of particular interest because they are specialists of very small streams and seepages. This means they depend for survival on habitats similar to the headwaters surveyed in this study.

Among the taxa collected in this study, five caddisfly taxa are considered seepage specialists (Collier et al., 2009; B. Smith, NIWA, pers. comm.). These include *Hydrobiosis spatulata*, as well as most species of the genera *Edpercivalia*, *Diplectrona*, *Cryptobiosella* and *Pseudoeconesus*. In this study, three of these taxa were collected only from intermittent and wet sediment sites, while two were found also in the perennial sites. The large, charismatic bush dragonfly, *Uropetala carovei*, found at one intermittent site, is not described as a seepage specialist, but nonetheless appears to be most common near the source of streams (Winstanley and Rowe 1980). For the stonefly genus *Spaniocercoides*, McLellan (1991) gives no habitat notes for *S. philpotti* (the species found in this study) but says the genus includes a seepage specialist and two species that inhabit the hyporheic zone (subsurface gravels beneath stream beds). The latter specialty is thought to be an adaptation to intermittent waters. In this study, *Spaniocercoides* was found only at intermittent and wet sediment sites. The stonefly *Cristaperla fimbria* also tends to inhabit the hyporheic zone (McLellan 2000), thus is well-adapted to survive in intermittent streams. In this study it, too, was found only at intermittent sites.

Another five taxa found in this study are known to inhabit both seepages and small streams. These include the caddisflies *Zelandobius illiesi*, the two most common species of *Polyplectropus* (*P. altera* and *P. aurifusca*), *Triplectidina moselyi* and *Pycnocentria forcipata.* In addition, the lacewing *Kempynus* is a semi-aquatic species that is common in seepages, spray zones and on the wet margins of small streams. However, in this study, all of these taxa were found in perennial sites as well as intermittent and/or wet sediment sites.

Rare or geographically restricted taxa, and new records

A few taxa in this study are of conservation interest due to their rarity or their restricted geographic distribution. Among these are the stonefly *Zelandobius illiesi* (collected at Kiriwhakapapa and York Bay intermittent sites) and the caddisfly *Diplectrona* (collected at various perennial and intermittent sites), which are relatively widespread but uncommon throughout their range. The stonefly *Cristaperla fimbria* (collected at York Bay intermittent) is mostly a South Island species, and may be close to the northern limit of its range in Wellington (McLellan 2000). The stonefly *Spaniocercoides* found in this study was identified as *S. philpotti*. This species is known only from the South Island (McLellan 2006), therefore this collection appears to represent a new record for the North Island. Finally, the caddisfly *Cryptobiosella* sp. (collected at Kiriwhakapapa intermittent and York Bay intermittent) may belong to one of three *Cryptobiosella* species whose distributions include the Wellington area (*C. furcata* from the Tararua Ranges, *C. spinosa* from the Rimutaka Ranges, and *C. hastata* from Coromandel to Westland). The first two of these have highly restricted geographic distributions while all three are known from very few specimens. Therefore, the presence of *Cryptobiosella* in the study sites is of conservation interest regardless of which species it represents.

In addition to these taxa, several others collected in this study had not been collected previously for State of Environment monitoring in the Greater Wellington region (EOS Ecology, unpubl. data). These included the caddisflies *Zelolessica cheira*, *Triplectidina moselyi*, *Pseudoeconesus* sp. and *Edpercivalia* sp., and the neuropteran

Kempynus sp. Among these, *Pseudoeconesus* and *Edpercivalia* are genera with some species listed in Collier (1992) as of particular conservation interest due to their rarity or restricted distributions. It would be worth identifying the specimens collected in this study to species level to determine whether any belong to rare or geographically restricted species.

Overall, rare or geographically-restricted taxa appeared to be more common at the intermittent sites than at wet sediment or perennial sites. York Bay and Kiriwhakapapa appeared to be particularly rich in these taxa.

Forest-dependent taxa

Some of the taxa found in these forested headwaters are considered to be obligate forest stream-dwellers. This means they would be unlikely to survive if forest were removed from around the streams they inhabit. These taxa include *Orthopsyche fimbriata*, *Edpercivalia*, *Triplectidina moselyi*, *Pseudoeconesus*, *Cryptobiosella*, *Diplectrona*, *Hydrochorema crassicaudatum*, *Philorheithrus agilis*, *Nesameletus flavitinctus* and the charismatic *Uropetala carovei* (Winstanley and Rowe 1980, Collier et al., 2009, Winterbourn et al., 2006).

3.5.6 Contribution of headwater habitats to regional biodiversity

In section 4.3.2, "alpha taxon richness", the number of taxa within each sample, was discussed. "Gamma taxon richness" is the number of taxa found among all the samples collected for each habitat type. If alpha richness is low, gamma richness may still be high if each sample has a somewhat different assemblage of taxa.

The relationship between alpha, beta and gamma richness is shown in Figure 13. Alpha richness, the average number of taxa in a single sample, is the value at the left-hand end of each curve. Gamma richness, the total number of taxa collected among all samples, is the value at the right-hand end of each curve. Beta richness, the degree of difference between samples, is shown by the slope of each curve.

In this study, the perennial habitat had both higher alpha and gamma richness than the intermittent habitat. However, perennial and intermittent habitats combined had slightly higher gamma richness than the perennial habitat alone, suggesting that the intermittent habitats add to regional diversity of aquatic invertebrates. This is consistent with the multidimensional scaling plot, which indicates that the community composition among the intermittent sites was somewhat different to that among the perennial sites.

The alpha and gamma richness in the wet sediment habitat were lower than in the other two habitats, and the richness of the intermittent and wet sediment habitats combined was lower than the intermittent habitat alone. However, caution must be exercised in comparing the wet sediments to the perennial and intermittent habitats, due to the smaller habitat area sampled in the wet sediments. The multidimensional scaling analysis indicates that the community composition of the wet sediments was distinctly different to that of the perennial and intermittent habitats, and included some taxa not found in the latter. Also, there were greater differences among streams in the wet sediment habitat than in the perennial and intermittent habitats, indicating high beta diversity. Therefore, although Fig. 13 suggests that the wet sediment sites do not contribute greatly to the regional diversity of aquatic invertebrates, their contribution may be greater than appears.

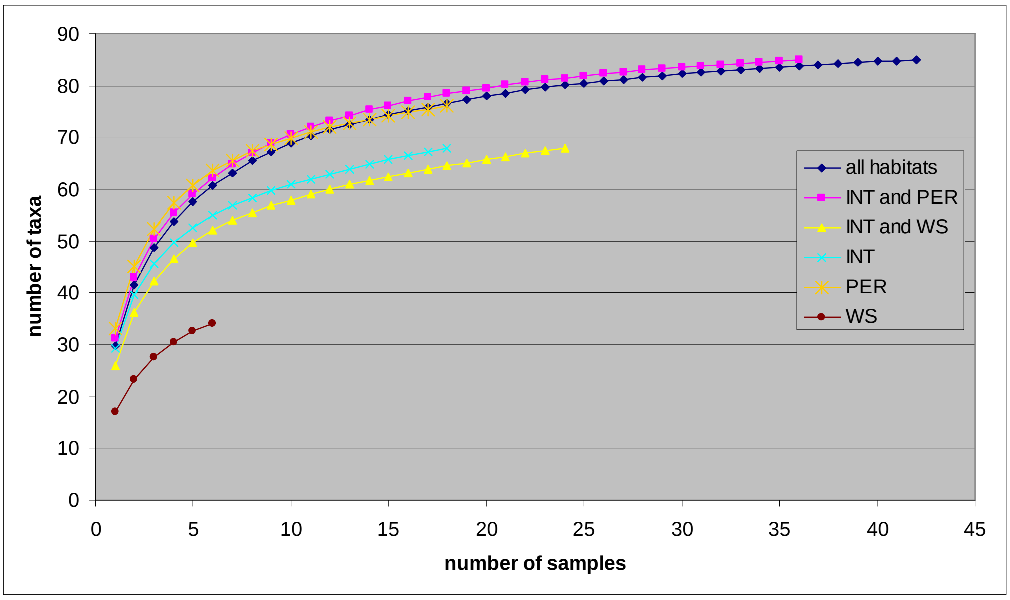

Figure 13: Taxa accumulation curves for each habitat type and combinations of habitat types. Abbreviations are: PER=perennial, INT=intermittent, WS=wet sediments. Note that the curve for wet sediment is not directly comparable to curves for perennial and intermittent habitats due to the smaller sample area in wet sediments (0.062 m^2 vs. 0.4 m^2).

4. Summary of results

1. At the sites labelled "intermittent", surface water on all six of the study streams was reduced to (at most) a thin film in April 2010. Four of the six study streams showed signs of intermittency (loss of surface water flow) at times between November 2009 and April 2010. On one stream, surface flow was lost for only two days, but on the other three, flow ceased for two weeks or more. However, on two of these streams, bed sediments up to the channel head (as defined in November) remained wet even when surface flow had stopped.

2. Based on data from nearby flow and rainfall monitoring sites, stream flow in both spring and autumn is likely to have been below average at all sites, but heavy rains are likely to have increased flows at some sites during January, which is usually the driest month. Therefore, surface water flow may not cease every summer at these sites, but may cease for longer during some summers.

3. Spot measurements of water physicochemical parameters and the heavy shading by riparian vegetation suggested that water temperature and pH are unlikely to limit the invertebrate fauna able to inhabit these perennial or intermittent sites. Oxygen may become limiting during summer in isolated pools where decaying leaves accumulate, but not where water flow persists.

4. The density of aquatic invertebrates was very similar in intermittent and perennial habitats, but significantly higher in wet sediments, though the sampling method was different in the wet sediments.

5. Alpha (per-sample) richness of aquatic invertebrates and of EPT taxa was slightly higher in perennial than intermittent habitats. In wet sediments, invertebrate richness was comparable, but EPT richness appeared to be somewhat lower than in the habitats with surface water.

6. Perennial, intermittent and wet sediment habitats each had a distinct invertebrate composition. The composition of each sample was more similar to others of the same habitat type than to others on the same stream, despite the large geographic distances between streams.

7. Wet sediment habitats were characterised by a higher proportion of Diptera (mostly Chironomidae and Tipulidae) and lower proportions of EPT taxa

(including absence of Ephemeroptera) than the other habitat types. The community at perennial sites had relatively even percentages of Diptera, Ephemeroptera, Crustacea and Mollusca, and had some EPT taxa that were absent from other habitat types. The composition of intermittent sites was intermediate between those of wet sediments and perennial sites.

8. Patterns of taxon richness between streams suggested that intermittent sites may add to the landscape-level biodiversity of aquatic invertebrates in Wellington region. However, it was not clear whether the wet sediment sites also contribute to regional biodiversity.

9. Five caddisfly taxa found in this study are seepage specialists, another five are known mainly from seepages and small streams, and the giant bush dragonfly, *Uropetala carovei*, appears to show affinity for stream sources. Two uncommon caddisfly taxa and one taxon with a highly-restricted distribution were found, and one stonefly species was recorded for the first time in the North Island. Ten taxa found at these sites are considered obligate forest-dwellers, showing the importance of native forest around headwater streams for maintaining a diverse invertebrate community characteristic of undisturbed sites.

5. Recommended methods for ecological assessment of intermittent streams in Wellington

5.1 Importance of reference sites

Very little data has been collected on aquatic invertebrate communities of headwater streams and their spatial and temporal patterns. Until a general understanding has developed of the communities expected in such streams, it is important that each test site is referenced to a comparable site in native forest. As data accumulate on such reference sites, regular spatial and temporal patterns may emerge that reduce the need for further reference site sampling. At that point, a reference site database may provide sufficient comparative data for test sites.

In this study community composition did not vary greatly with geographic distance, suggesting that it may not be critical for reference sites to be very close to test sites. Therefore, if reference sites close to the test sites are hard to find, the current data suggest that it is preferable to use reference sites some distance away from the test sites rather than those that are geographically close but differ in terms of hydrological regime or physical habitat. However, because species distributions typically show some spatial pattern, and rainfall and stream flow patterns vary geographically, it is recommended that reference sites be as close as possible to test sites, for reasons described below.

For some stream types, e.g., lowland, low-gradient streams, it may be difficult to find comparable reference sites in native bush. In this case, if the test site has similar physical habitat (in particular, stream bed particle size) to a steeper-gradient reference site, the steep reference site may be appropriate to use. If the test site is soft-bottomed, it may be appropriate to use reference site data from Auckland (Parkyn et al., 2006a) or Waikato (Parkyn et al., 2006b, Storey et al., 2009). These options will have to be judged on a case by case basis.

5.2 Selecting and describing appropriate sites

Current knowledge of headwater and intermittent streams indicates that the benthic invertebrate community depends strongly on certain aspects of water flow. First, the community varies with water width and depth, particularly when depth is very low; wet sediments and seeps can harbour a distinct invertebrate community (e.g., Collier et al., 2009). Therefore, it is very important to measure water width and depth of the study streams, and to include both wet sediment and flowing water habitats in a survey. Second, the invertebrate community varies with the relative length of wet and dry periods. Therefore it is important to describe whether, and for how long, water flow ceases during the year. Ideally, this should be described by deploying water loggers for up to one year, including the driest period of the year. If this is too time- or labour-intensive, flow intermittency of each site can be characterised by measuring, relative to a fixed marker, the length of stream with surface water at two times of year – once during the wet period of the year (July-October) and once during the driest period (February-April). Because rainfall and stream flow vary from year to year, it is also important to note whether the year of measurement was drier, wetter or similar to average rainfall.

Reference sites should be chosen that are as similar as possible to the test sites in terms of water width and depth, and the timing and length of the dry period. The latter may be difficult to ensure until the sites are well known. But the chance of finding comparable sites can be improved if reference and test sites are both a similar distance downstream of the channel head and on streams with similar geology, topography and aspect. Sampling at more than one location along the length of each stream also would improve the chance of sampling comparable sites. Finally, because of year-to-year variability in stream flow, the reference sites should be sampled in the same year as the test sites.

In sites with limited riparian vegetation, or those where fallen leaves accumulate in slow-flowing areas, water physicochemical parameters may become limiting for aquatic invertebrates. However, oxygen and temperature typically become critical during summer, oxygen during the night and temperature in mid-afternoon. Therefore, to capture the critical values of these parameters, they must be logged over at least one 24-hour period or measured at dawn and mid-afternoon in summer. Since invertebrate sampling typically will be done in daytime during cooler months, note that measurements of water physicochemical parameters are not likely to capture critical peaks and troughs. Recording other site details, such as the amount of instream algal and macrophyte growth, leaf litter accumulation, and riparian shading, may be more useful than direct water physicochemical measurements for estimating whether water parameters may limit certain invertebrate taxa during critical periods.

5.3 Sampling and sample identification

The power of a statistical test relates to the chance of finding a statistically significant difference between “treatments” (e.g., land-uses, sites, etc.) if in fact there is a biologically significant difference between them. For most ecological studies, a power of 0.8, i.e., an 80% chance of detecting this real difference, is considered sufficient.

In the present study, three replicate samples of 0.4 m^2 each were taken at intermittent and perennial sites. Based on the variability in metrics such as %EPT and total richness between replicates and streams in this study, and between land use types in comparable studies (e.g., Storey et al., 2009), I estimate that four replicate samples of 0.25-0.3 m^2 each should be sufficient to detect ecologically significant differences between a reference intermittent or perennial site and one with some human impact. Four 0.3 m^2 samples will give greater statistical power than three 0.4 m^2 samples while requiring little more sampling or processing effort. For the wet sediment habitat, there are no data for within-site variability, but based on the variability of the intermittent and perennial sites, I expect that four replicate "scrape" samples of 10 cm diameter each will be sufficient to detect biologically significant differences between sites.

Headwater streams tend to harbour a higher proportion of small invertebrate taxa (particularly Diptera) than larger streams. Samples in the current study contained more small animals than most State of Environment monitoring samples (Alex James, EOS Ecology, pers. comm.) Therefore I would recommend using a sampling net with mesh size of 0.25 mm. A mesh size of 0.5 mm could be used provided it is recognised that in using the larger mesh size, a higher proportion of animals will be missed in headwater stream samples than in most SOE monitoring samples.

In this study we identified many of the insect taxa to species level. This is recommended to answer research questions about the biodiversity values of headwater streams. However, for resource consent applications, genus-level identifications should be sufficient.

Invertebrate densities can be very high in headwater streams, leading to long sample processing times if full counts are used. If the Index of Biological Integrity is used to compare reference and test sites, quantitative counting methods will be required. However, sample sorting effort can be reduced by using a fixed count (first 200 individuals) followed by a scan for rare taxa (Protocol P2, Stark et al., 2001).

5.4 Time of year

In an intermittent stream, the benthic invertebrate community changes as invertebrates recolonise the stream habitat during the first few months after water flow resumes in autumn (Storey and Quinn, 2008). Therefore, study and reference sites should be sampled not less than three months after flow resumes (10-year average river flow data suggest headwater streams are likely to resume flow in late April or May), and before drying begins (probably around December, in an average year).

5.5 Assessment of macroinvertebrate community health

Little is known of the spatial and temporal patterns in invertebrate communities inhabiting headwater and intermittent streams. However, it is known that such streams have higher proportions of Diptera and non-insects, and lower proportions of EPT taxa, than larger, perennial streams. For these reasons, the normal scoring ranges for standard assessment metrics such as the Macroinvertebrate Community Index (MCI) are unlikely to be appropriate (although such metric scores may still be used in relation to reference site scores, as in the Index of Biological Integrity, below).

Assessment of the macroinvertebrate community health of headwater and intermittent streams must incorporate comparison with a reference site. A suitable metric is the Invertebrate Index of Biotic Integrity (IBI), based on the method of Plafkin (1989) and modified for New Zealand streams by Quinn et al., (2009). The invertebrate IBI is actually a multi-metric, combining taxon richness, QMCI, %EPT density, EPT richness, community loss index (a metric that assesses the proportion of taxa in common between reference and test sites) and the proportion of "shredder" invertebrates in the community. For each of these metrics, the IBI calculates a score as a percentage of the value at the reference site then combines the percentages to give a single overall percentage score. Ranges of final scores are defined as unimpaired, slightly impaired, moderately impaired or severely impaired. I recommend using the method as described in Quinn et al., (2009), outlined in Appendix 1. However, it is important to note that because there are fewer EPT taxa in headwater and intermittent streams, %EPT, EPT richness and QMCI scores for headwater reference sites will be lower than for reference sites in larger streams (see Table 8, Appendix 1). Therefore these metrics will be less sensitive indicators of habitat degradation in headwater streams than in larger streams.

5.6 Assessment of ecological value

The above method may be used to assess ecological health. In order to assess the ecological value of headwater streams (i.e., the benefits they provide to the wider stream network), a variety of ecological functions should be considered, including hydrological, biogeochemical, habitat provision and biotic functions. A suitable tool that assesses ecological functions is the Stream Ecological Valuation (SEV; Rowe et al 2008). SEV has been applied successfully in very small headwater streams (Storey et al., 2009), though it was noted that native forest reference sites did not score highly for all functions. In particular, the lack of flood plains in headwaters reduced the scores of three functions. Therefore, as with measures of ecological health, SEV assessments for test sites must be reported alongside assessments for reference sites.

SEV has not been validated for intermittent sites, therefore, I advise caution in using it for sites that go dry seasonally.

6. Recommendations for further research

This brief study has shown that headwater and intermittent streams in Wellington region have distinct aquatic invertebrate communities, including some uncommon taxa. Smith (2007) and Collier et al., (2009) found at similar sites in Hamilton that a large number of insect taxa missed by benthic sampling could be collected as adults using light traps. Therefore, to better assess the biodiversity values of Wellington headwater streams, I recommend sampling these sites again using light traps.

This study has given a “snapshot” view of invertebrate communities in headwater streams at a single point in time. To better characterise the seasonal and year-to-year variability in these headwater streams, I recommend repeating the sampling during summer low-flows as well as during winter, and in drier and wetter years. Data on the temporal changes in invertebrate communities will provide context for interpreting the results of one-off surveys conducted for resource consent applications.

In order to understand the impacts of land use change on biodiversity values, I recommend sampling headwater streams in different land-use types, for example, open pasture, urban, and sites protected by riparian vegetation buffers.

Finally, note that intermittent reaches may occur on higher-order streams as well as in headwaters. Higher-order intermittent streams are subject to different ecological processes from intermittent headwaters (Storey and Quinn 2008), therefore are expected to have difference biological values and ecological dynamics. I recommend these reaches as worthy of a separate study.

7. Acknowledgements

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9. Appendix 1: Site locations and photographs

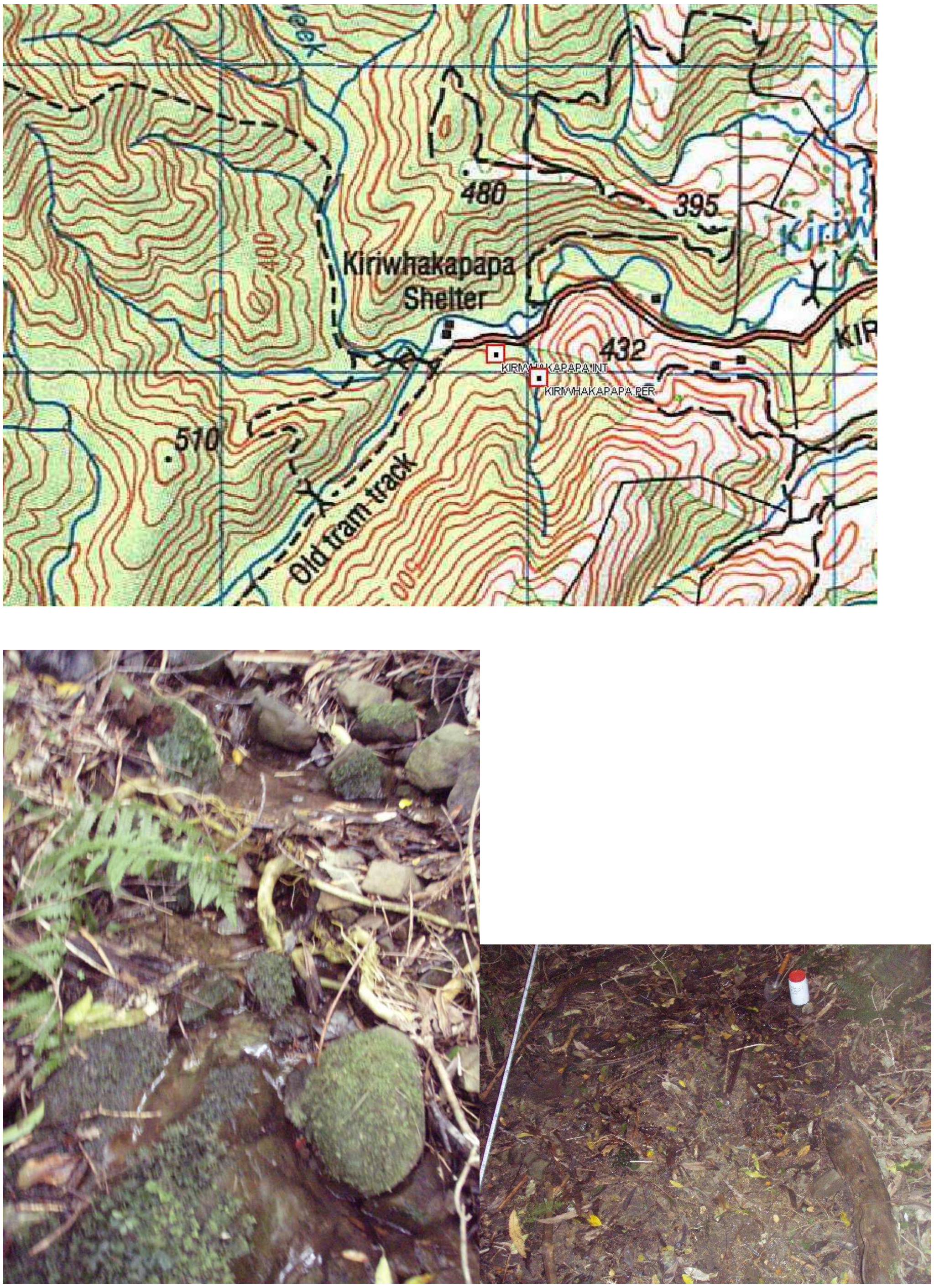

Figure 1: Kiriwhakapapa: locations of intermittent and perennial sites (top) and photos of intermittent and wet sediment sites in November (bottom).

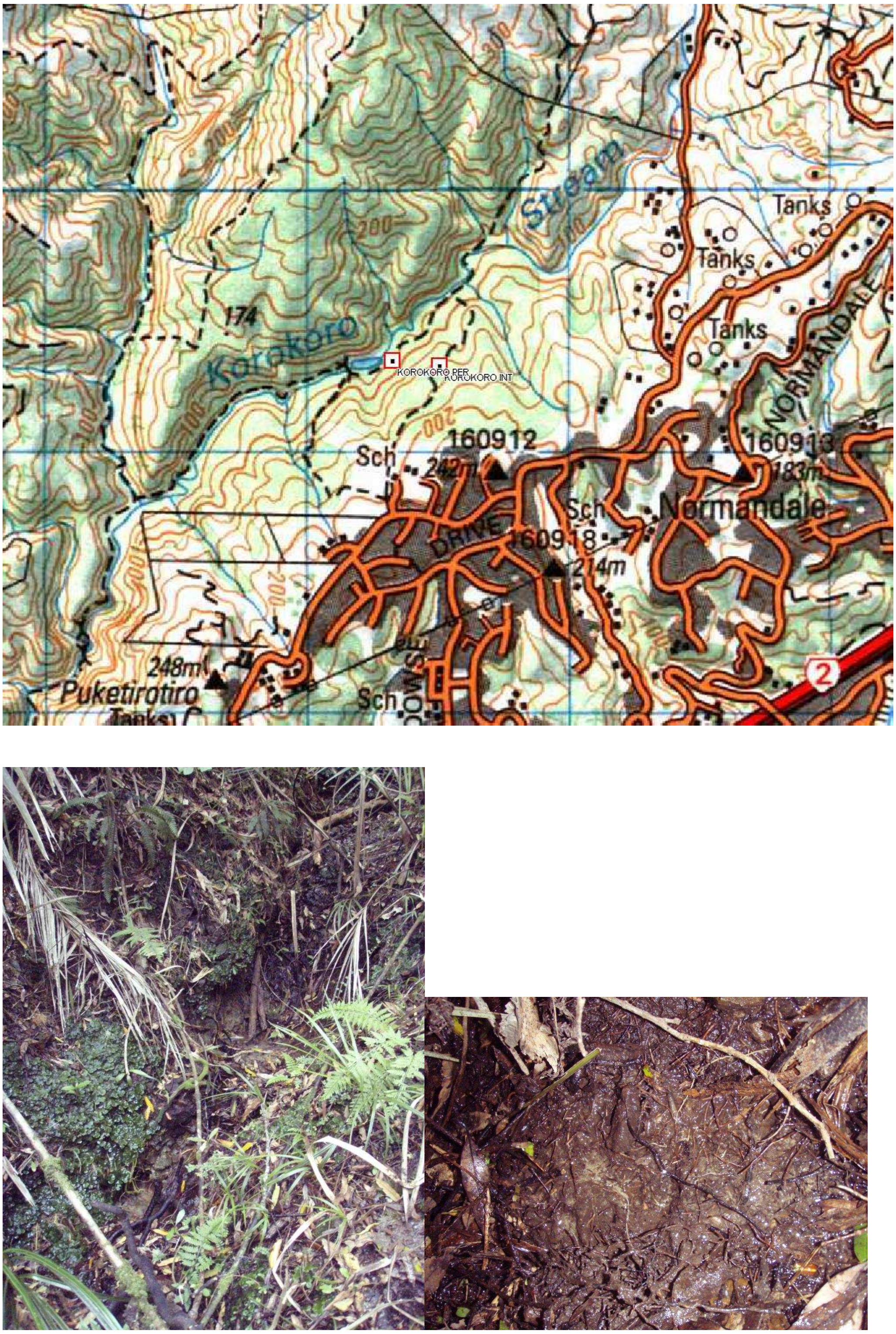

Figure 2: Korokoro: locations of intermittent and perennial sites (top) and photos of intermittent and wet sediment sites in November (bottom).

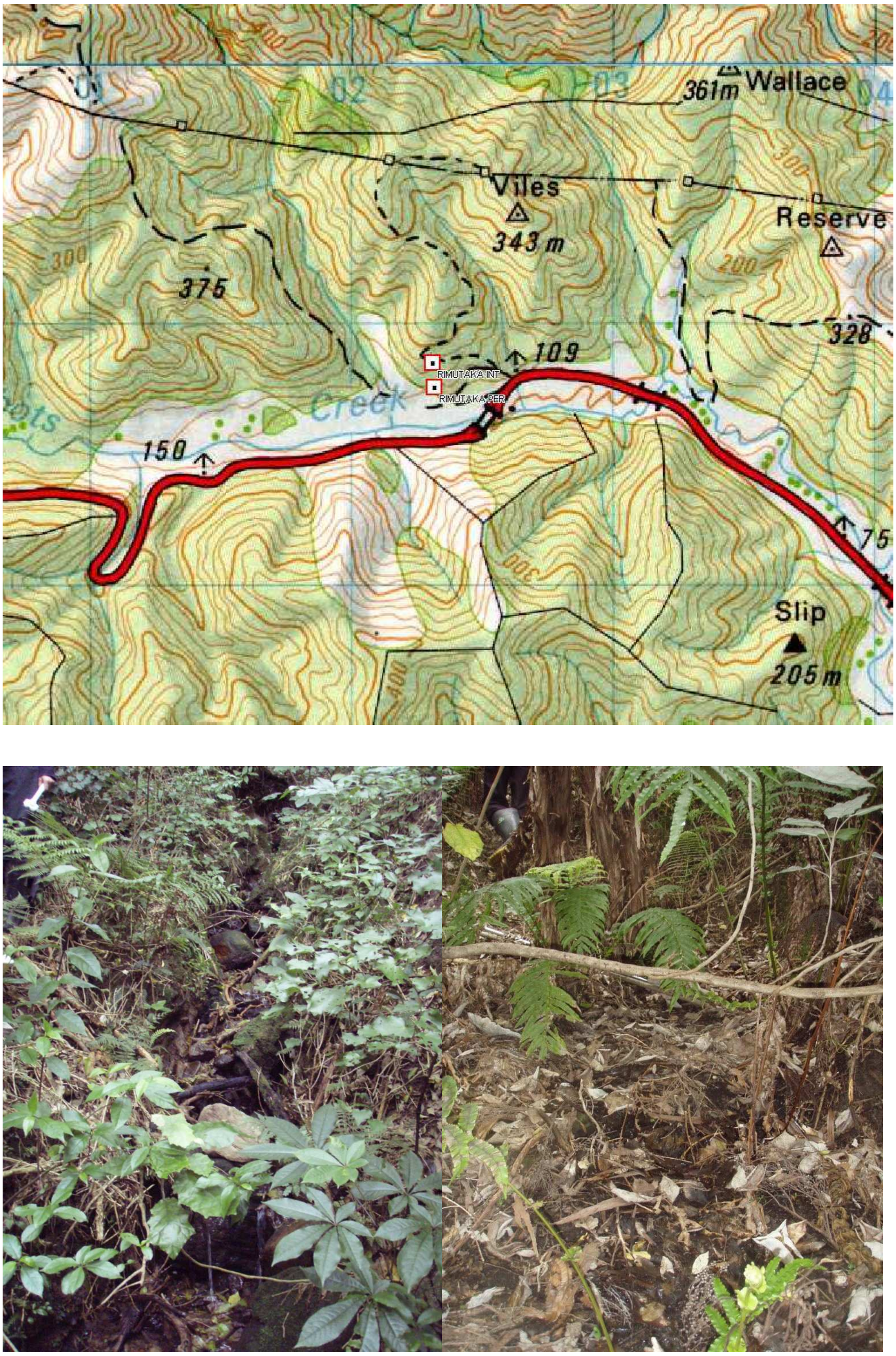

Figure 3: Rimutaka: locations of intermittent and perennial sites (top) and photos of intermittent and wet sediment sites in November (bottom).

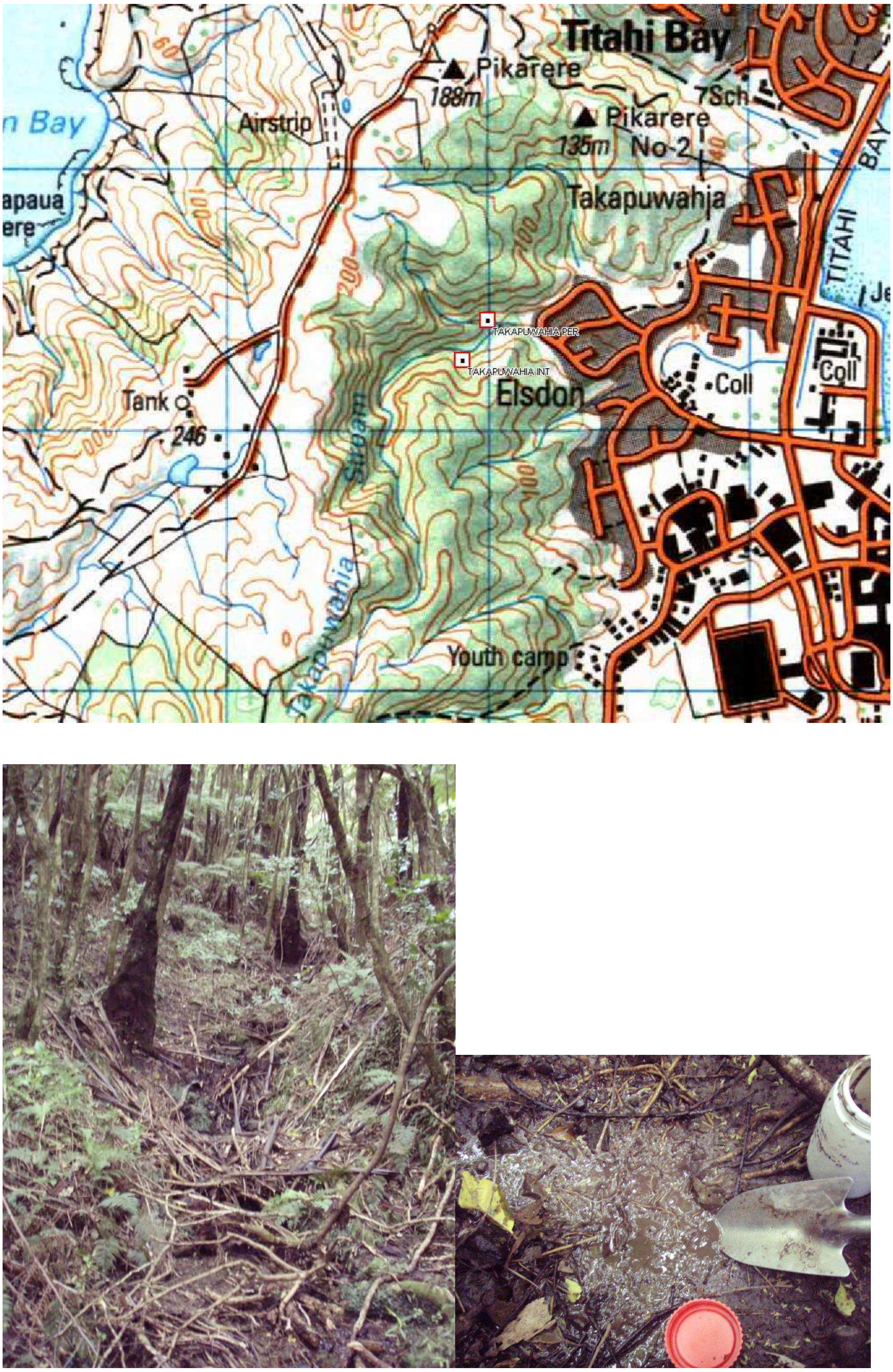

Figure 4: Takapuwahia: locations of intermittent and perennial sites (top) and photos of intermittent and wet sediment sites in November (bottom).

Figure 5: Waiwhetu: locations of intermittent and perennial sites (top) and photos of intermittent and wet sediment sites in April (bottom).

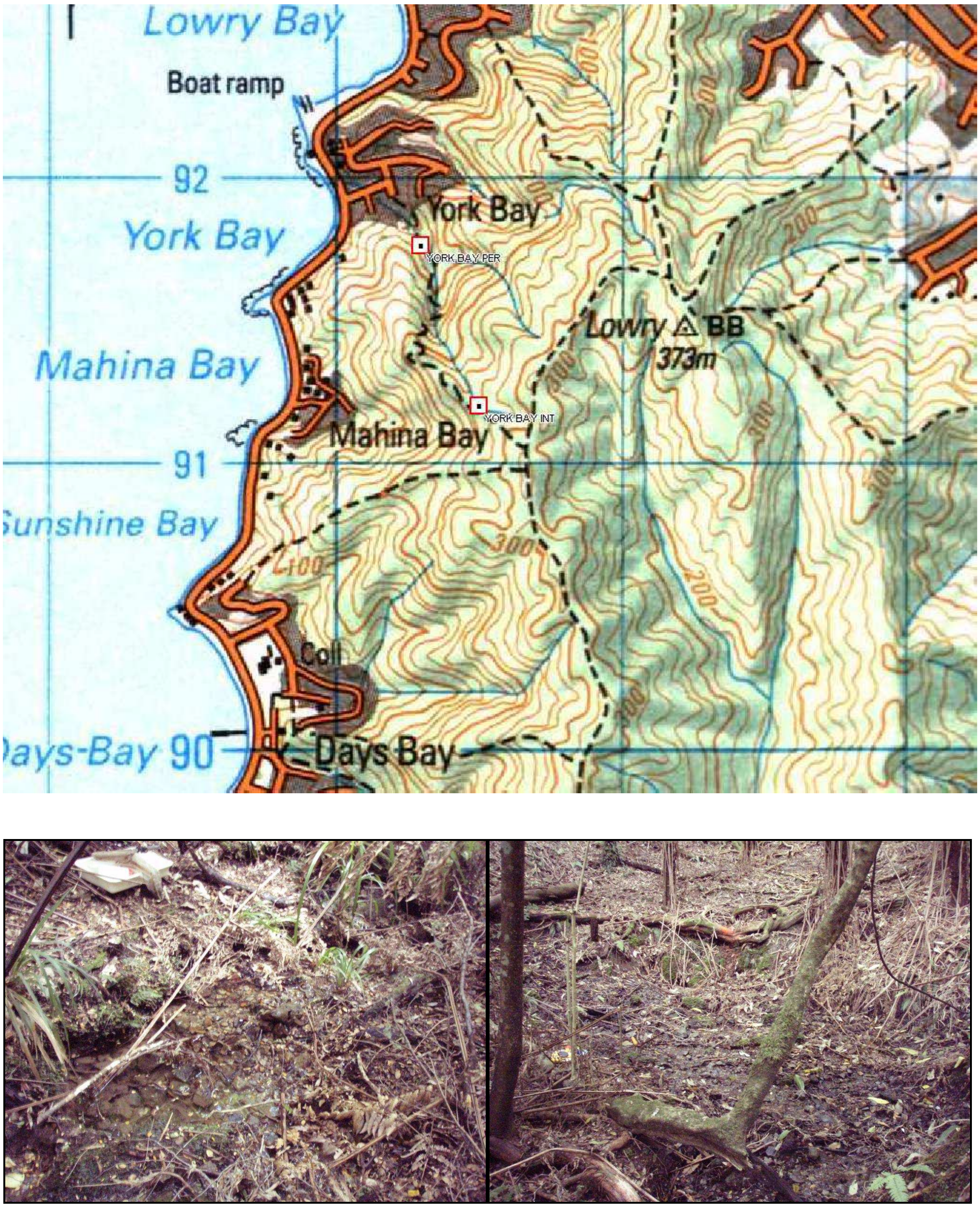

Figure 6: York Bay: locations of intermittent and perennial sites (top) and photos of intermittent and wet sediment sites in November (bottom).

10. Appendix 2 Method for calculating invertebrate Index of Biotic Integrity (IBI)

The invertebrate Index of Biotic Integrity (IBI) is recommended for assessing the ecological health of the invertebrate communities in headwater and intermittent streams. The IBI presented here is derived from Plafkin (1989) and modified as in Quinn et al., (2009).

Six metrics describing different aspects of the invertebrate community are calculated: taxon richness (the number of taxa present in the community), QMCI (quantitative macroinvertebrate community index; Stark 1985, 1993), %EPT density (% of the total invertebrate abundance belonging to insect orders Ephemeroptera, Plecoptera and Trichoptera), EPT richness (number of EPT taxa), % abundance of shredders (invertebrates that feed by shredding coarse particulate organic matter) and CLI (community loss index). CLI is calculated as the number of taxa at a reference site minus the number of taxa in common between the reference and test site, divided by the number of taxa at the test site.

Except for %EPT density, metric scores are converted to percentages by dividing the score at the test site to that at the reference site(s). This is not done for %EPT as it is already a percentage. Metric scores as % of reference site scores are then assigned a value of 0, 2, 4 or 6 according to Table 6. The five values are then combined to give a total value between 0 and 30. These combined scores are again divided by the score at the reference site(s) to give overall % values, which can be reported as percentages or in the categories non-impaired, slightly impaired, moderately impaired or severely impaired according to Table 7.

Scores of these metrics calculated for the native forest sites in this study are given in Table 8.

Table 6: Scoring system for combining the four metrics used in the invertebrate Index of Biotic Integrity. For each metric, a score falling within the range indicated in the corresponding row is given the score (0-6) for that column in bold type at the top of the table. Abbreviations are: QMCI, quantitative macroinvertebrate community index; CLI, community loss index.

Metric	**Biological condition scoring criteria**			
	6	**4**	**2**	**0**
Taxon richness	>80%	60-80%	40-60%	<40%
QMCI	>85%	70-85%	50-70%	<50%
%EPT density	>75%	75-50%	25-50%	<25%
EPT richness	>90%	80-90%	70-80%	<70%
% shredders	>50%	35-50%	20-35%	<20%
CLI	<0.5	0.5-1.5	1.5-4.0	>0.4

Table 7: Scoring system and impairment categories for final IBI scores.

% compared to reference site(s)	**Biological condition category**	**Attributes**
>83%	Non-impaired	Comparable to the best situation expected in an ecoregion. Balanced trophic structure. Optimum community structure (composition and dominance) for stream size and quality.
54-79%	Slightly impaired	Community structure less than expected. Composition (taxon richness) lower than expected due to loss of some sensitive taxa. Percent contribution of tolerant forms increases.
21-50%	Moderately impaired	Fewer species due to loss of most of the sensitive taxa. Reduction in EPT taxa.
<17%	Severely impaired	Few species present. If high densities of organisms, then dominated by a few tolerant taxa.

Table 8: Values for IBI metrics from native forest site.

Metric	Wet sediment	Intermittent	Perennial
Total richness per 0.4 m^2 sample	17.0±3.9	29.4±3.5	33.3±7.0
EPT richness per 0.4 m^2 sample	1.8±2.1	8.8±2.3	13.1±6.1
% EPT abundance	2.7±4.1	10±8.2	27.7±17.3
QMCI	3.9±1.3	3.6±0.5	4.4±0.8
% shredder abundance	1.6±1.6	2.2±1.9	7.0±6.5