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Spatial Variation In Functional Indicators For Non-Wadeable Streams

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Spatial Variation In Functional Indicators For Non-Wadeable Streams

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Table of contents

Table of figures

Executive summary

In order to maintain or improve river ecosystem health, tools for assessing the current ecological state of river ecosystems are needed so the causes of poor health, or the success of rehabilitation efforts, can be measured. In the past, the tools used to measure river ecosystem health have concentrated on structural aspects of the ecosystem (*e.g.* community composition). However, the value of incorporating measurements of ecosystem processes/functions (*e.g.* rates of organic matter decomposition) into regular monitoring programmes is increasingly being recognised.

Rates of organic matter decomposition and ecosystem metabolism (the combination of primary production and ecosystem respiration) appear to have promise as functional indicators of ecosystem health. These indicators were measured at five sites along a continuum of anticipated water quality impacts in the Mangaokewa Stream near Te Kuiti. Strips of cotton cloth and wooden sticks were deployed in three habitat types (edge, bottom and midwater) at each site to determine the amount of small-scale spatial variation in organic matter decay rates. Ecosystem metabolism was estimated using measurements of the natural change in dissolved oxygen concentration at each site over at least a 24 hour period. In addition, invertebrates were collected from wood and stony substrates at each site to determine any differences among sites in traditional stream health indices.

Rates of ecosystem metabolism were low upstream of Te Kuiti, but both gross primary productivity (GPP) and ecosystem respiration (ER) were higher downstream. Rates of GPP were within the range found at reference sites elsewhere. However, rates of ER at the three downstream sites exceeded the criteria that have been suggested for distinguishing between satisfactory and poor ecosystem health.

Rates of wooden stick and cotton cloth decomposition were also highest at the two downstream sites. There were also differences among habitats at individual sites, with slower decay occurring at the stream edge compared with midwater or the river bottom. This suggests that differences in habitat need to be considered when making comparisons of organic matter decomposition among contrasting sites.

Multivariate analyses indicated some differences in the invertebrate community between the upper and lower sites, but these differences were smaller than those found between different substrates (wood versus stone) at the same site. Traditional metrics such as %EPT and MCI did not differentiate between sites or indicate any pattern of cumulative ecological stress downstream.

Given the relatively low number of sites it was difficult to detect statistically significant relationships between the traditional invertebrate-based metrics and either metabolism or organic matter decomposition rates. However, there were trends indicating relationships between wood breakdown rates on the river bottom and the invertebrate metrics. Functional indicators measure a different component of the river ecosystem and relationships among the different types of indicators would not necessarily be expected.

1 Introduction

Recent advances in indicator development have highlighted the value of functional attributes for documenting the health of freshwater ecosystems (Young et al. 2004). Promising indicators include rates of organic matter decomposition and ecosystem metabolism. These attributes have particular relevance for non-wadeable streams where there are issues with scale, ease of sampling, and habitat limitation using conventional biological monitoring techniques.

Last year, Environment Waikato (EW) assisted with a trial of functional indicators for stream health assessment. As an addition to this work, EW included sticks, as well as cotton strips and leaves, in the suite of substrates deployed in five non-wadeable tributaries of Waipa River. Preliminary results of stick weight loss indicate an association with catchment condition (% catchment in native forest), with one site, Mangapu Stream near Otorohanga, being a significant outlier (Young 2006). A major tributary upstream of this site is subject to a range of municipal, industrial and rural discharges, providing the opportunity to assess the utility of functional indicators along a continuum of likely water quality impacts. In addition, variation over smaller spatial scales (within reaches) is of interest to provide a basis for determining the degree of replication required to represent reach-scale conditions.

In this report we describe the results of more intensive deployments/measurement in Mangaokewa Stream (a major tributary of the Mangapu), to determine spatial variation within reaches and longitudinal patterns in relation to discharges. During summer 2005/06, cotton strips and wood sticks were deployed at five sites along the Mangaokewa Stream. Stream metabolism and macroinvertebrate community composition were also measured at these sites during December 2005.

2 Study sites and methods

Five sites were selected for this study (Figure 1). Site 1 was approximately 3 km upstream of Te Kuiti and drained a mixture of agricultural and unmodified land. Site 2 was on the outskirts of Te Kuiti and potentially affected by some industrial activities. Site 3 was located at the northern end of Te Kuiti and potentially influenced by urban runoff. Te Kuiti's sewage is discharged to the Mangaokewa Stream further downstream and approximately 200 m above Site 4. Site 5 was further downstream again and surrounded by intensive farmland.

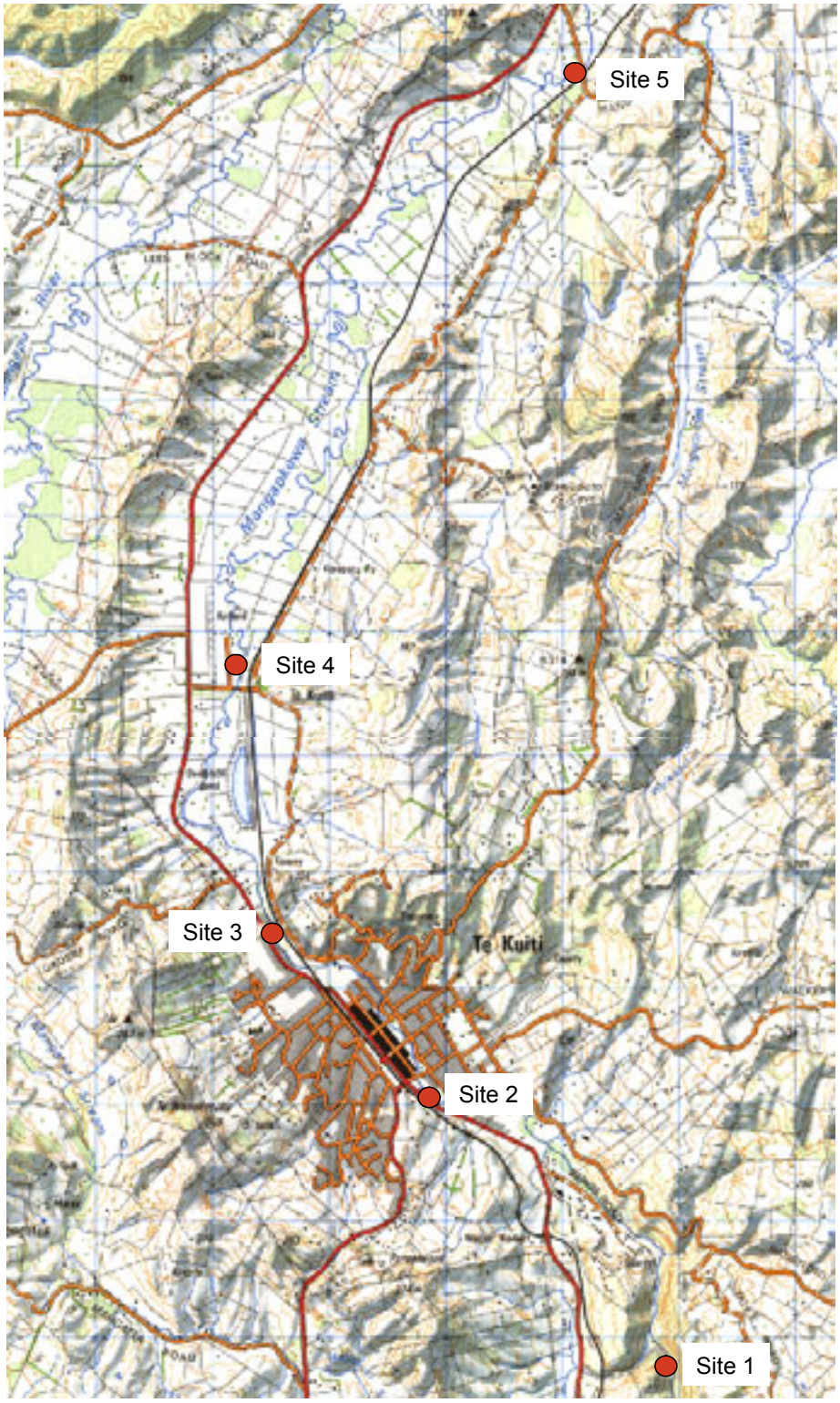

Figure 1 Map showing the sampling sites located on the Mangaokewa Stream.

2.1 Ecosystem metabolism

Ecosystem metabolism, the combination of primary production and ecosystem respiration, was estimated using the single-station open-channel approach which requires measurement of the natural changes in dissolved oxygen concentration at the site over at least a 24 hour period (Owens 1974; Young & Huryn 1996). Oxygen concentration and temperature were recorded once every 10 minutes using an YSI 6920/6000 environmental monitoring system or a Hydrolab Datasonde 4. During measurements, a sonde was deployed at each site in a location as close as possible to the thalweg (central part of the flow). The sondes were secured to the bank or other

suitable solid substrates (*e.g.* tree, bridge pile) using a chain and warratahs. Prior to sampling, the sondes were calibrated in water saturated air. At Sites 1, 2, and 5 the sondes were deployed for 48 hours starting in the afternoon of 12th December 2005, whereas a single sonde was used to measure metabolism at Sites 3 and 4, and transferred from Site 3 to Site 4 in the afternoon of 13th December 2005. Therefore, only 24 hours of data were available from those sites.

While recording oxygen concentrations, photosynthetically active radiation was measured every 15 seconds with a LI-COR quantum sensor and logged every 10 minutes using a LI-COR logger. The sensor was placed on the river bank at Site 2.

An estimate of the average depth of each site was calculated using five measurements of depth at each of five cross-sections spaced out at sufficient regular intervals upstream of the sonde to cover the local variation in channel morphology.

Metabolism values were calculated using the RiverMetabolismEstimator spreadsheet model (version 1.2) developed by Young & Knight (2005). This model uses the following approach to calculate metabolism values. Mean daily ecosystem respiration (ER) and the reaeration coefficient (k) are determined using the nighttime regression method (Owens 1974) which uses only data collected in the dark (< 2 μmol/m^2/s). The rate of change of oxygen concentration over short intervals is regressed against the oxygen deficit (difference between the oxygen concentration at saturation and the observed concentration in the water) to yield:

$$dO/dt = ER + kD \qquad (1)$$

where dO/dt is the rate of change of oxygen concentration (g/m^3/s), ER is the ecosystem respiration rate (g/m^3/s), k is the reaeration coefficient (s^{-1}), and D is the oxygen deficit (g/m^3). The slope of the regression line estimates k while the y-intercept estimates ER (Kosinski 1984).

The reaeration coefficient and ecosystem respiration rate obtained are then used to determine gross photosynthetic rate over the sampling interval using:

$$GPP_t = dO/dt + ER - kD \qquad (2)$$

where GPP_t is the gross photosynthetic rate (g/m^3/s) over time interval (t). To compensate for daily temperature fluctuation, ER is assumed to double with a 10°C increase in temperature (Phinney & McIntire 1965) while the reaeration rate is assumed to increase by 2.41% per degree (Kilpatrick *et al.* 1989). Daily gross primary production (GPP, g/m^3/day) is estimated as the integral of all temperature corrected photosynthetic rates during daylight (Wiley *et al.* 1990). This analysis gives values of production and respiration per unit volume. An areal estimate is obtained by multiplying the volume based estimates by average reach depth (m) which allows comparison among stations with different depths.

A linear relationship between light intensity and GPP can be attributed to light limitation of primary production, while a non-linear asymptotic relationship suggests that photosynthesis is light saturated and other factors (*e.g.* nutrients, temperature or algal biomass) are limiting GPP (Kirk 1983; Boston & Hill 1991; Steinman 1992). To determine whether photosynthesis was limited by light, 10 minute production estimates were plotted against concurrent surface light measurements.

2.2 Organic matter decomposition

Three different organic substrates were deployed on 12th December 2005 at each site to assess decomposition rates: pre-weighed birch wood coffee stirrer sticks, strips of relatively robust cotton cloth, and lengths of less robust cotton tape. Five replicates of each type of material were deployed in three habitat types (stream edge, stream

bottom and suspended in the water column) to determine the amount of small scale spatial variability in decay rates at a site. The organic substrates were secured using metal stakes and rope and where necessary were weighted down using metal weights.

Both types of cotton were retrieved after 7 days, while the wooden sticks were recovered after 3 months.

For the wooden sticks, decay rates were calculated from the loss in dry mass of the sticks during deployment using the following equation

$$k = -\log_e\left(\frac{W(t_f)}{W(t_i)}\right)/(t_f - t_i) \quad (3)$$

where $W(t_i)$ is the initial dry weight of the sticks and $W(t_f)$ is the dry weight of the sticks remaining after time (t). For the cotton, decay rates were calculated similarly from the difference in tensile strength between material retrieved from the stream versus the tensile strength of a set of control cotton strips that had been soaked in tap water for 1 day. Tensile strength was measured on a commercial tensometer by staff at Landcare Research (Hamilton).

2.3 Macroinvertebrate collection

Invertebrates were collected from wood and stony substrates at all sites where possible (*NB*. only wood was sampled at Site 4). Collections were carried out in flowing water in accordance with national protocols for hard-bottomed (stones) and soft-bottomed (wood) streams (see Stark *et al.* 2001) using a 0.5 mm mesh D-frame net. Samples were preserved in around 70% isopropyl alcohol, and were processed using Protocol P2 (Stark *et al.* 2001) which involves a 200 fixed count and scan for rare taxa using the level of taxonomy described in Collier & Kelly (2004). Differences among sites and in relation to substrate type were explored using (i) Primer-E to carry out a non-metric multidimensional scaling analysis of percent community composition, and (ii) the invertebrate community metrics Macroinvertebrate Community Index (MCI; Stark 1985), and the richness and percent abundance of Ephemeroptera, Plecoptera and Trichoptera (EPT* richness and % EPT*, respectively, with "*" denoting the exclusion of Hydroptilidae which are often found at enriched sites).

3 Results and discussion

3.1 Ecosystem metabolism

Dissolved oxygen concentrations ranged from 75-100 % saturation (Figure 2). As is typically the case, minimum dissolved oxygen concentrations occurred at, or just before, dawn while maximum concentrations occurred in the mid/late afternoon (Figure 2). There was a considerable amount of 'noise' in the data collected from Sites 2, 3 and 4 using the Hydrolab sondes (Figure 2). This short term variability is likely to be related to a lack of precision in the sonde measurements rather than real fluctuations, and can be problematic for the metabolism calculations. Therefore, a moving average smooth with an interval of 4 data points was used to remove this noise from these data sets before calculating metabolism.

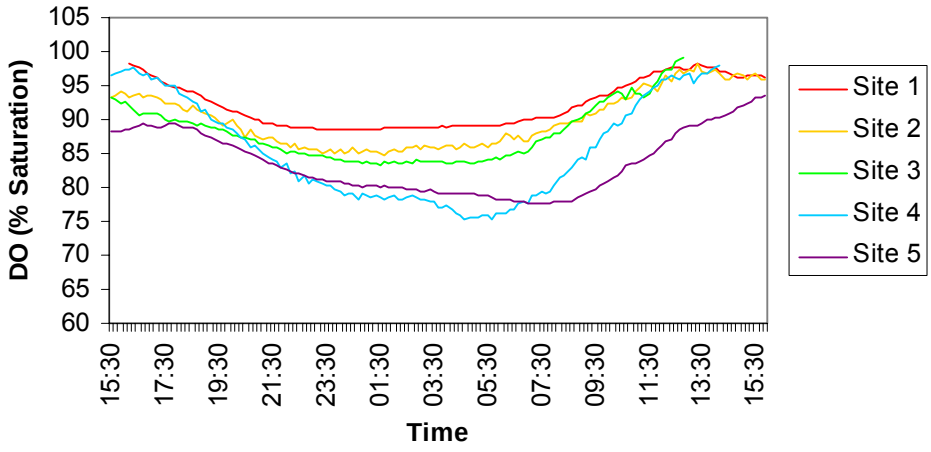

Figure 2 Diel changes in dissolved oxygen at each of the sites on the Mangaokewa Stream.

Rates of GPP were relatively low at Sites 1-3 ranging between just 1.4-1.9 gO_2/m^2/day (Figure 3). However, rates of GPP were substantially higher downstream of the Te Kuiti sewage discharge (Figure 3). Rates of ecosystem respiration were relatively low at Sites 1 and 2, but were higher at Sites 3-5 (Figure 3). The rates of GPP observed in the Mangaokewa Stream are within the range of those found in 'reference' sites elsewhere and would be considered healthy using the criteria suggested by Young et al. (2004). In contrast, the rates of ER at Sites 3-5 exceeded the criterion of 10 gO_2/m^2/day that was suggested for distinguishing between sites with satisfactory and poor river ecosystem health (Young et al. 2004).

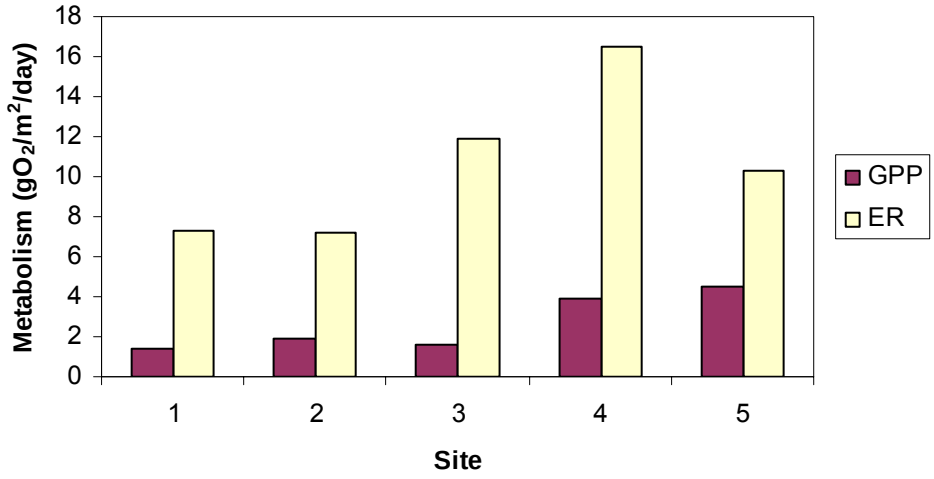

Figure 3 Rates of gross primary production (GPP) and ecosystem respiration (ER) for the five sites along the Mangaokewa Stream. Sites with rates of GPP above 8 gO_2/m^2/day or ER above 10 gO_2/m^2/day are considered to have poor ecosystem health using the criteria from Young et al. (2004).

The balance between GPP and ER is a useful measure of the sources of energy driving a stream ecosystem. If GPP equals or exceeds ER then organic matter produced within the system is probably supporting the food chain, whereas if ER greatly exceeds GPP then organic matter from upstream or the surrounding catchment is being used to maintain the ecosystem. At all sites, ER was much higher than GPP indicating that the ecosystem in the Mangaokewa Stream is primarily driven by organic

matter from upstream or the surrounding catchment (Figure 4). This could include organic matter from natural origins (*e.g.* tree leaves, wood, dissolved organic carbon) and also organic pollutants, such as the discharge from the Te Kuiti sewage plant.

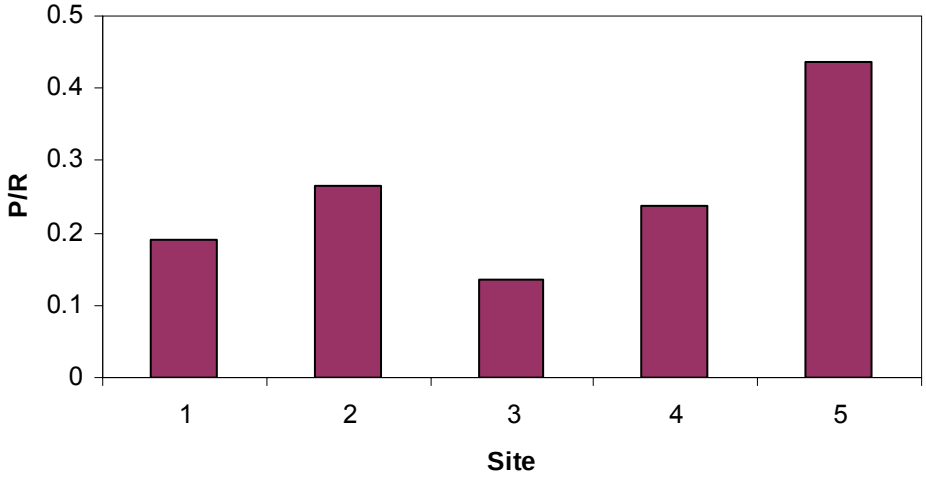

Figure 4 The balance between GPP and ER at each of the sites along the Mangaokewa Stream.

Although there is considerable scatter in the data, light-saturation of photosynthesis was evident to some extent at all the sites with little or no increase in maximum instantaneous rates of GPP as light intensities increased above 750 µmol/m^2/s (Figure 5). A possible exception to this could be Site 3, which had such a large amount of scatter that it is difficult to determine if the relationship was linear or asymptotic. Light saturation of photosynthesis is relatively common in streams of this size, and suggests that other factors, such as nutrient availability or algal biomass, are limiting production rates at high light intensities (Young & Huryn 1996, 1999; Uehlinger *et al.* 2000).

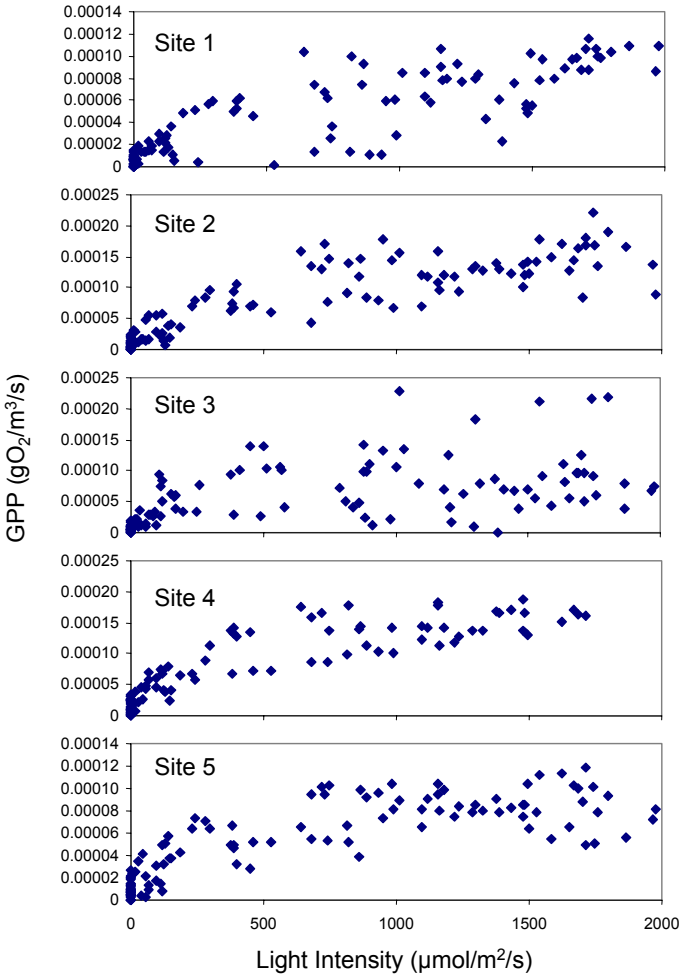

Figure 5 Plots of light intensity versus instantaneous rates of GPP at each of the sites on the Mangaokewa Stream.

3.2 Organic matter decomposition

3.2.1 Wooden Sticks

At the end of 90 days immersion, the remaining sticks had between 38% and 86% of initial dry weight remaining. Several sets of sticks were not recovered, mostly from edge habitats because of a combination of factors such as being swept out of the water, burial by bank slips, and loss in overgrown vegetation. Two sets of sticks at Site 3 were buried under streambed substrates at the time of removal; these had the lowest breakdown rates recorded and were not included in subsequent statistical analyses.

There was a significant interaction effect for decay coefficients (*-k*) between site and habitat type (ANOVA, $P < 0.001$), indicating variable habitat responses at the different sites. A significant effect of habitat was found at Site 2 where mid-water sticks were lost and breakdown was slower on edges than on the stream bottom, and at Site 4 where edge sticks were not recovered and breakdown was faster in mid-water than on the bottom (Figure 6).

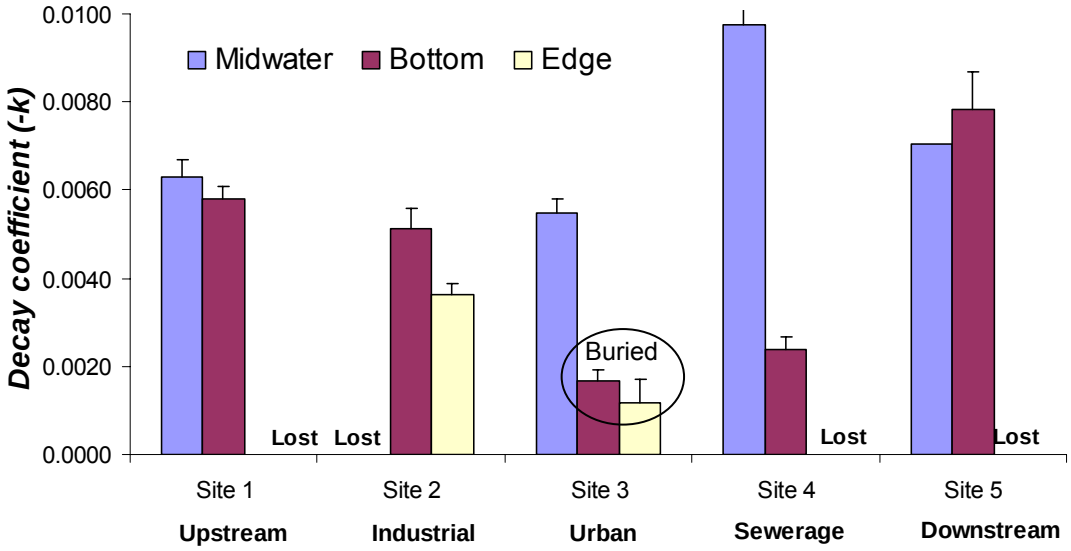

Figure 6 Decay coefficients for sticks submerged for 90 days in three habitat types at 5 sites on Mangaokewa Stream.

3.2.2 Robust Cotton Cloth

The tensile strength of the control cotton strips ranged from 35-48 kg. The rates of cotton strip strength loss were very high at all the sites and particularly at Sites 4 & 5 where the strength was less than the detectable limit of the tensometer (5 kg) after 7 days in all habitats (Figure 7). There was a significant difference in strength loss rates among habitats at Sites 1 and 2 where strength loss was slower at the stream edge than in midwater, or on the bottom (Figure 7; nested ANOVA, $F = 7.181$, $P < 0.0001$). This difference among habitats indicates that strength loss rates are habitat dependent and therefore results from one habitat at a site can not be directly compared with rates from different habitats at another site.

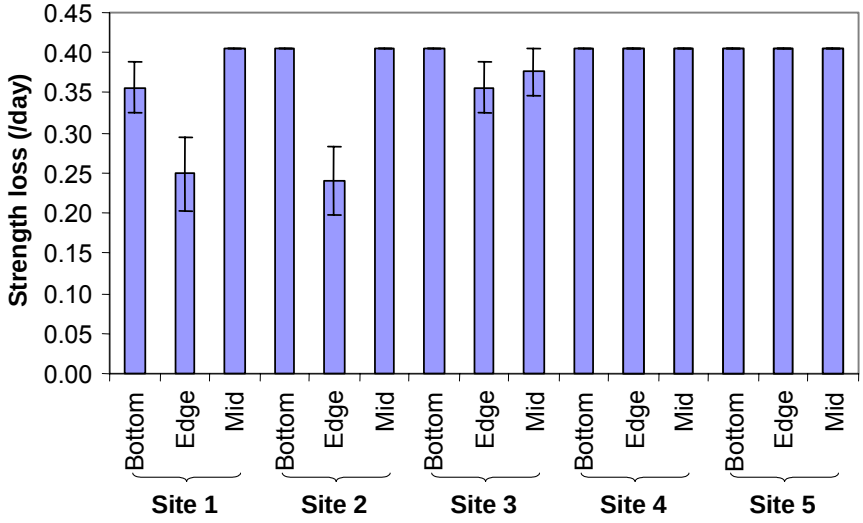

Figure 7 Cotton strip strength loss coefficients (±SE) in different habitats at each of the sites in the Mangaokewa Stream.

3.2.3 Less Robust Cotton Tape

Cotton tape has a consistent width, which removes some of the variability associated with using strips of cotton cloth, which may vary slightly in width. The original Shirley Soil Burial test fabric that has been widely used in the past, but is no longer being

manufactured, had coloured threads woven into the cloth to resolve this problem (Young 2006).

The tensile strength of control lengths of the cotton tape ranged between 37-44 kg. However, after 7 days the tensile strength of the cotton tape from all habitats at all sites was below the detection limit of the tensometer (<5 kg). Therefore, it was impossible to make any comparisons among sites or habitats using this material.

The rate of tensile strength loss of this material was surprisingly fast. The results from the more robust material also suggest that cotton decomposition is fast at these sites and faster than that observed using Shirley Soil Burial Fabric at all sites, except one, during previous trials at a range of sites throughout New Zealand (Young 2006).

3.3 Invertebrate communities

The non-metric multidimensional scaling analysis suggested that the effect of substrate was greater than spatial differences for Sites 1-3 where there was little difference in terms of community composition for wood faunas in particular (Figure 8). However, community composition at Sites 4 and 5 downstream of the sewerage discharge did appear different to the other sites. However, the three invertebrate community metrics examined did not clearly differentiate among sites or indicate any pattern of cumulative ecological stress downstream (Figure 9).

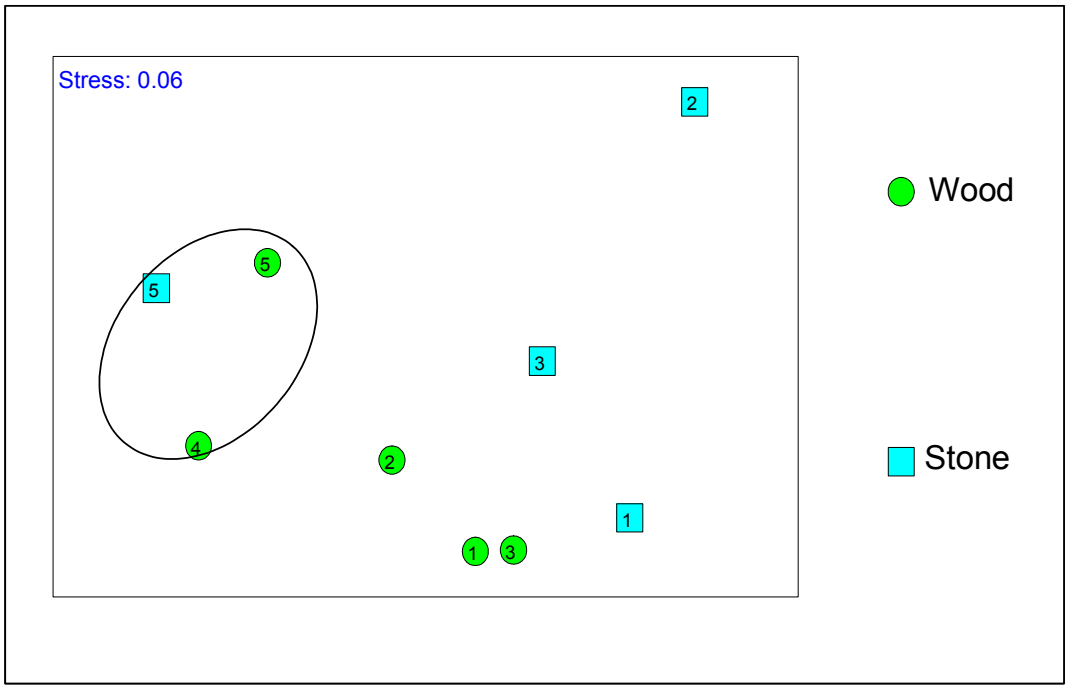

Figure 8 Non-metric multidimensional scaling plot on percent abundance data for macroinvertebrate communities collected from wood or stones at 5 sites (1-5) on Mangaokewa Stream.

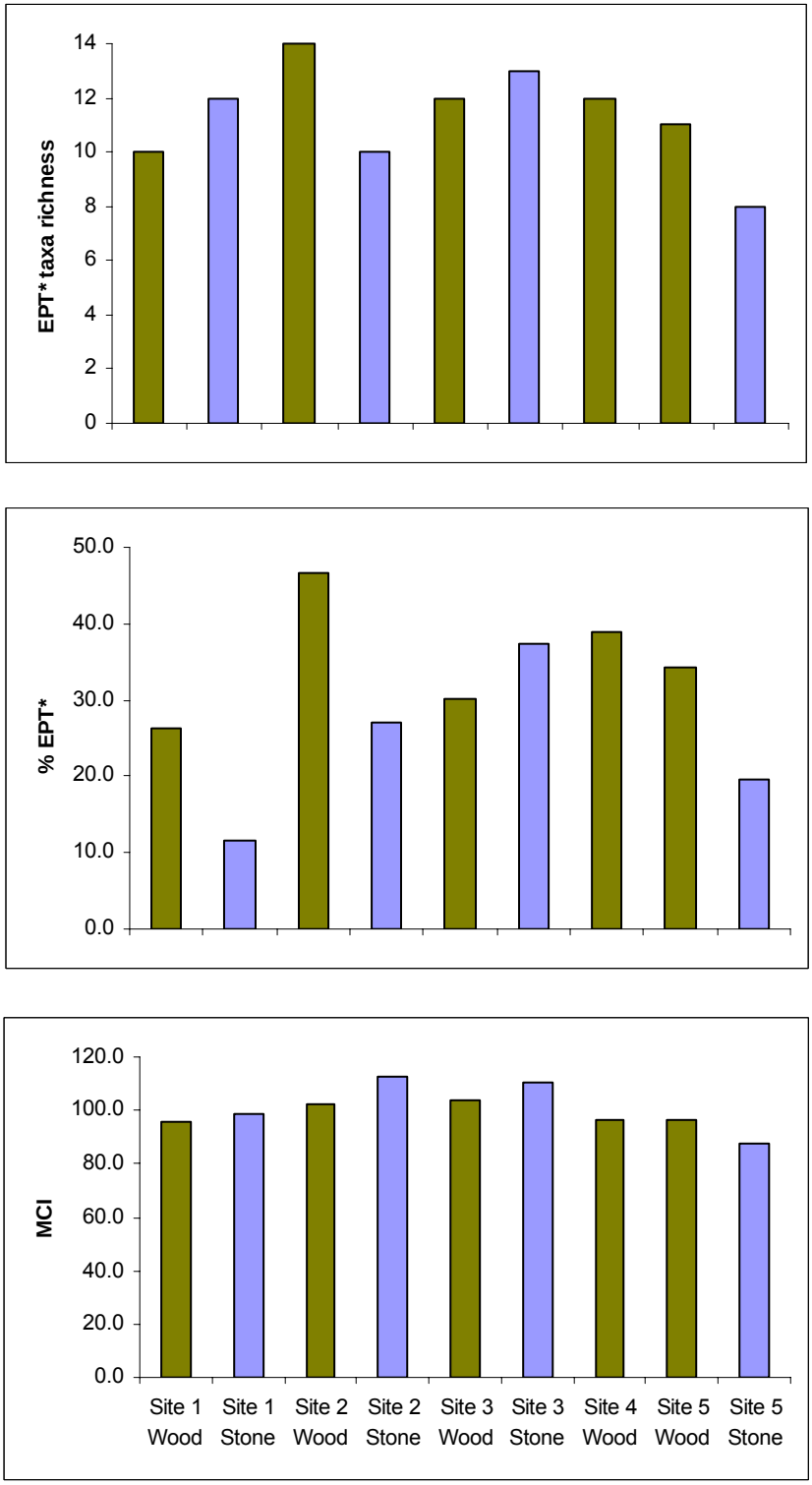

Figure 9 Values for three invertebrate metrics calculated from samples collected on wood or stones at 5 sites on the Mangaokewa Stream.

3.4 Comparison of functional indicators with other measures of stream health

There appeared to be little consistent correspondence between invertebrate community metrics and measures of stream metabolism or the breakdown of sticks in mid-water habitats (Figure 10). However, there were consistent positive relationships between all invertebrate metrics and the breakdown rates of sticks held at the bottom, irrespective of whether they were buried, although none of these relationships was statistically

significant based on the sample sizes available for analysis. Some positive relationships with r_s >0.50 were also found between stick breakdown rates and measures of stream metabolism, but as with the invertebrate metrics none were statistically significant.

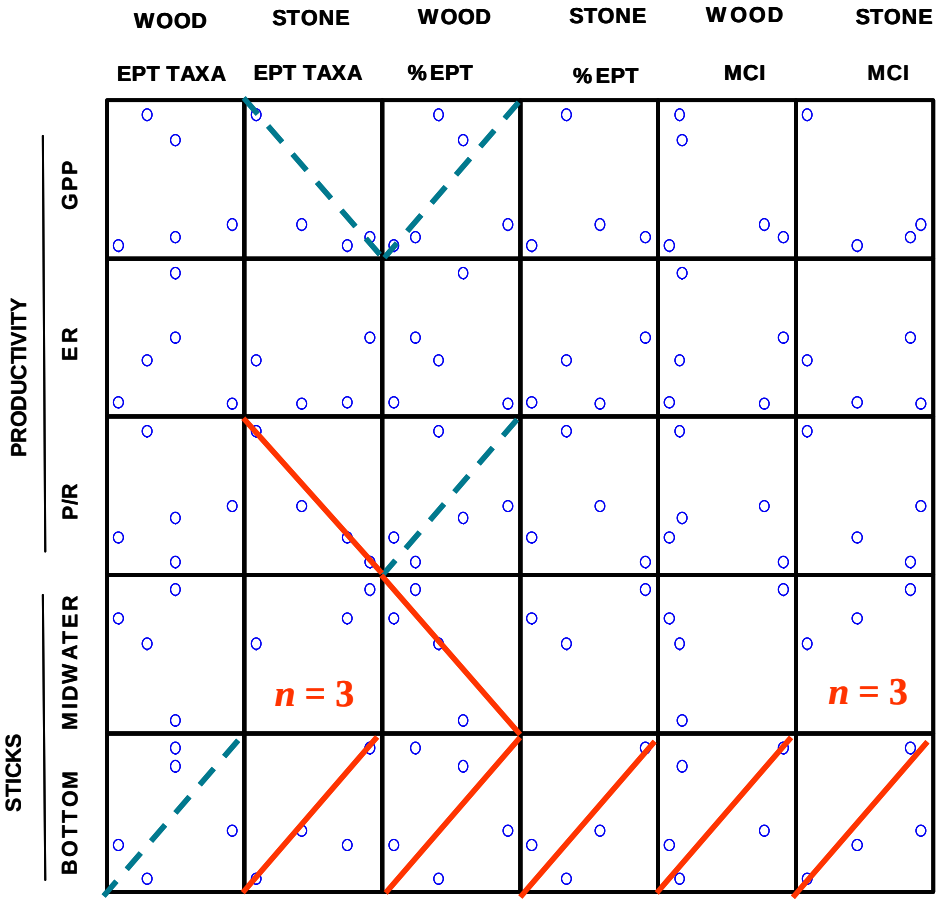

Figure 10 Relationships between macroinvertebrate indicators and measures of stream metabolism and stick decomposition. Dashed and solid lines indicate Spearman correlation coefficient values of 0.50-0.79 and ≥ 0.80, respectively where *n* = 4-5. Stick breakdown data are expressed as % initial dry weight remaining.

4 Summary

Both ecosystem metabolism and organic matter decomposition responded to the continuum of water quality impacts expected along the Mangaokewa Stream suggesting that they could be useful indicators of river health in this system and other rivers that have non-wadeable sections. Rates of GPP, ER and organic matter decomposition were generally higher at the more impacted sites downstream of Te Kuiti. Rates of ER at the three downstream sites were high enough to be indicative of poor ecosystem health. In contrast, traditional invertebrate-based metrics did not differentiate among sites and showed no patterns of cumulative ecological stress downstream.

Small-scale variation in organic matter decomposition rates at each site was observed, with slower decay occurring at the edges compared with midwater or on the stream bottom. This suggests that any differences in habitat need to be considered when making comparisons of organic matter decomposition rates among contrasting sites.

A comparison of these functional indicators with other measures of river health indicated possible relationships between wood decay rates on the stream bottom and the invertebrate metrics. However, functional indicators measure a different component of the river ecosystem and relationships among the different types of indicators would not necessarily be expected.

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