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Invertebrate Drift and Trout Growth Potential in the Taharua and Upper Mohaka Rivers: an Investigation of Effects of Dairy Farming Across Three Seasons



Invertebrate Drift and Trout Growth Potential in the Taharua and Upper Mohaka Rivers: an Investigation of Effects of Dairy Farming Across Three Seasons

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EXECUTIVE SUMMARY

Hawke's Bay Regional Council (HBRC), Hawke's Bay Fish & Game Council and Westervelt Sporting Lodges are concerned that dairy farming in the upper Taharua River catchment may be adversely affecting the trout fishery in that river, and in the Mohaka below the Taharua confluence. Prior to 1987, the predominant land use in the upper Taharua River catchment was low intensity pastoral farming and forestry. Since 1987, 35% of the upper catchment has been converted to dairy farming, with 29% occurring since 1999. Biomonitoring by HBRC has found that the water quality of the Taharua since the dairy conversions has declined. A modelling study conducted by HBRC comparing the contribution of different land uses to nutrient load in the Taharua River catchment suggests that rising nitrogen levels in the Taharua River are the result of recent dairying expansion. There have also been anecdotal reports of a decline in the Taharua and Mohaka river trout fisheries, but few studies to date have specifically addressed this issue. The purpose of this research was to determine whether there was evidence for impaired aquatic invertebrate drift and trout growth potential at dairy-influenced sites in the Mohaka and Taharua Rivers.

This report documents results from three seasonal (summer - February 2009, autumn - April 2009 and spring - December 2009) investigations of invertebrate drift and trout growth potential from the Taharua and Mohaka rivers, and supersedes an earlier report that documented results for summer and autumn. On each occasion an "affected" site in the Taharua River and another in the Mohaka River downstream of the Taharua were compared with an upstream "reference" or un-affected site in the Mohaka.

Macroinvertebrate drift density, biomass and size structure estimates were compared between the sites. Between-site comparisons were also made of predicted gross and net rate of energy intake (GREI, NREI) for drift-feeding trout, using a bioenergetic drift foraging model. GREI and NREI are indices of food availability and growth potential. In order of importance, temperature, food, and water clarity are the three main factors that will influence trout growth. We included the influence of all three of these key variables in our analysis of potential effects of dairy farming.

In autumn and spring we found no significant differences in drift density or biomass between the sites. In summer drift density and biomass at the Taharua site was significantly lower than at the upper Mohaka reference site, with the lower Mohaka intermediary between the two.

We found taxonomic and size structural differences in the drift between sites. On all sampling occasions the upstream Mohaka site had the greatest proportion of EPT taxa. The highest proportion of mayflies occurred at the upstream Mohaka site at dusk in all three seasons (when trout feeding activity is often at its peak). Small invertebrates (3-6 mm), least preferred by large trout, made up a larger proportion (by density and biomass) of the drift in autumn and spring at the sites influenced by dairying inputs (Taharua and downstream Mohaka sites). In all seasons, the upstream Mohaka reference site had the greatest density and biomass of large invertebrates (>6 mm), which are preferred by trout. An exception was in summer where the density, but not biomass, of large invertebrates was highest at the downstream Mohaka site.

In order to interpret GREI and NREI it helps to understand that the feature of invertebrate drift that most influences these indices is size-structured biomass. GREI and NREI will increase with increasing drift biomass and increasing proportion of large invertebrates. Another relevant point is that trout growth is most sensitive to variation in food when water temperatures are highest (late spring through summer), owing to the dependence of metabolism, consumption and growth on water temperature. In summer, predicted GREI and NREI were highest at the upstream Mohaka reference site, followed by the downstream site and Taharua, respectively – mirroring the pattern in aquatic invertebrate drift biomass (and density). In autumn, there was little difference in GREI between any of the sites. In spring the order of sites from highest to lowest GREI and NREI was the same as summer - mirroring the pattern in the proportional contribution of large invertebrates to the spring aquatic drift biomass.

The inclusion of terrestrial invertebrates predictably increased GREI and NREI at each site. Terrestrial drift can be highly variable seasonally, thus accurately assessing the influence of terrestrial drift on trout growth potential is problematical. However, the primary food source for brown trout in the Mohaka and Taharua rivers is aquatic invertebrates - and this food source is subject to effects of dairy farming upstream.

Agricultural land use is often associated with increased turbidity in rivers, which also has implications for visual feeding fishes such as trout. The sensitivity of NREI to turbidity was modelled for a 50 cm brown trout. The modelling showed that drift-feeding trout potentially are very sensitive to reductions in water clarity. Predicted NREI declined with increasing turbidity; the steepest decline in NREI being between 0 to 2 NTU. The minimum (0.31 NTU) and maximum (8.53 NTU) recorded turbidity levels in the Taharua River potentially limit trout growth; reducing NREI by 14% and 152% relative to clear water conditions in summer.

Our results provide evidence for impaired aquatic invertebrate drift and trout growth potential at dairy-influenced sites in the Mohaka and Taharua Rivers in summer and to a lesser extent in spring. However, our results should be interpreted with caution as they are based on only three days sampling over three seasons. Moreover, although our results are consistent with effects expected from dairy farming (enrichment and/or siltation) definitively attributing cause to dairy farming is limited by the absence of a reference site in the Taharua and pre-impact data. Furthermore, there are natural physical differences between the rivers which could contribute to this pattern, including the mobile pumice sand bed in the Taharua in particular and perhaps stable flow. Mobile substrate ought to result in fewer species, fewer EPT taxa and lower densities over most of the bed. Algal proliferation ought to result in smaller invertebrates on the stable substrate remaining (*e.g.* instream debris and submerged riparian vegetation). Bed instability and algal proliferation would themselves be exacerbated by farming. Despite potential confounding factors, our results should be viewed in the context that biomonitoring has shown that water quality has been declining since dairy conversion in the Taharua catchment. Our study complements this effort and reveals the consequences of the current situation (drift and turbidity status) on the growth potential of drift feeding trout in dairy influenced sites.

Assessment of the effects of agricultural intensification on trout populations has been difficult in the past, especially in lowland rivers where water clarity can preclude traditional sampling methods such

as drift diving. However, the bioenergetics foraging model used in this study has proven to be sensitive enough to assess how changes in the drifting food resource available for trout may affect their growth potential, and goes some way to bridging the information gap. Furthermore, the outputs from this model, complement biomonitoring data currently collected by councils to provide a more holistic approach to assessing the cumulative effects of agricultural land use on river ecosystems.

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1. INTRODUCTION

1.1. Background

The upper Mohaka River contains a nationally outstanding trout fishery recognised with Water Conservation Order status. The trout fishery in the Mohaka is dominated by brown trout and has a small, but increasing number of rainbow trout. Only brown trout are present in the Taharua River. Westervelt Sporting Lodges owns land adjacent to the Taharua River, a tributary of the upper Mohaka, and operates an internationally renowned lodge, which is partly dependent on the fishing opportunities available in the Taharua and upper Mohaka rivers. Fish & Game New Zealand recently successfully negotiated access for anglers to the Taharua River through Poronui Station, as a condition of the recent sale of the station to Westervelt Sporting Lodges, opening up a formerly inaccessible fishery. This has added value to the upper Mohaka catchment as an outstanding public fishery.

Agricultural development in the Taharua catchment began in the 1980s with scrub clearance and conversion of land to low intensity sheep and beef farming (Graham Sevicke-Jones, Hawkes Bay Regional Council (HBRC), pers. comm.). By 1999, 6% of the upper catchment had been converted to dairy farming. In 1999, consents were granted for two dairy conversions, including spray irrigation of effluent to land. Dairy farming is now the predominant agricultural land use in the Taharua catchment; there are three large farms that collectively occupy 35% (4,700 ha) of the catchment (John Phillips, formerly HBRC, pers. comm.).

Biomonitoring by the HBRC since the 1999 conversions to dairying indicates that water quality in the Taharua has been declining over time (see Hayes & Hay 2006). In response to rising nitrate levels in the Taharua River (coinciding with the change from sheep and beef farming to dairying), HBRC investigated the likely contributions of different land uses to nutrient load (nitrogen and phosphorus) in the Taharua catchment using a mass balance model. The model outputs indicated that there had been a significant increase in nitrogen loading arising from conversion from sheep and beef to dairying (John Phillips, formerly HBRC, pers. comm.). This study also suggested there was a groundwater lag time of approximately five years in the Taharua catchment, which supports the hypothesis that the recent rising nitrogen levels in the Taharua River were the result of dairy expansion (John Phillips, HBRC, formerly pers. comm.). Lag time is to be confirmed through a planned groundwater aging investigation.

Anecdotal evidence suggests the Taharua trout fishery has declined, and trout size has decreased in this river and the upper Mohaka below the Taharua confluence, since the dairy conversions. Taharua River anglers were included in the 1979 National Angler Survey (NAS). However, low survey respondent numbers (seven anglers) resulted in the Taharua being excluded from a subsequent report on the value of North Island rivers to anglers (Richardson *et al.* 1987). Nevertheless in the 1979 NAS, anglers who fished the Taharua rated the river highly for trout catch rate and size; it had the highest rating of all the rivers sampled for importance of the fishery (4.7 out of 5) (Martin Unwin, NIWA, pers. comm.). By the 1990s, anecdotal reports to Fish and Game indicated that the Taharua was no longer rated highly by

anglers (I. Maxwell pers comm.). Prior to the dairy conversions Poronui Lodge’s guided tourist fishing business was based on the Taharua and upper Mohaka river fisheries (Figure 1). In recent years Poronui fishing guides have ceased operating on the Taharua owing to the decline in the fishery (*i.e.* fewer and smaller fish – pers comm. Eve Reilly, current Poronui Lodge Manager).

HBRC, the Hawke’s Bay Fish and Game Council (HBF&G) and Westervelt Sporting Lodges (formerly Poronui Lodge) are concerned that dairy farming in the upper Taharua River catchment may be adversely affecting the trout fishery in that river and in the Mohaka River below the Taharua confluence.

The present report is the result of a joint initiative by HBRC and HBF&G to address the potential affects on the trout population that may be arising from the dairy development. This report documents results from sampling in summer, autumn and spring 2009, and supersedes an earlier report by Shearer & Hayes (2009).

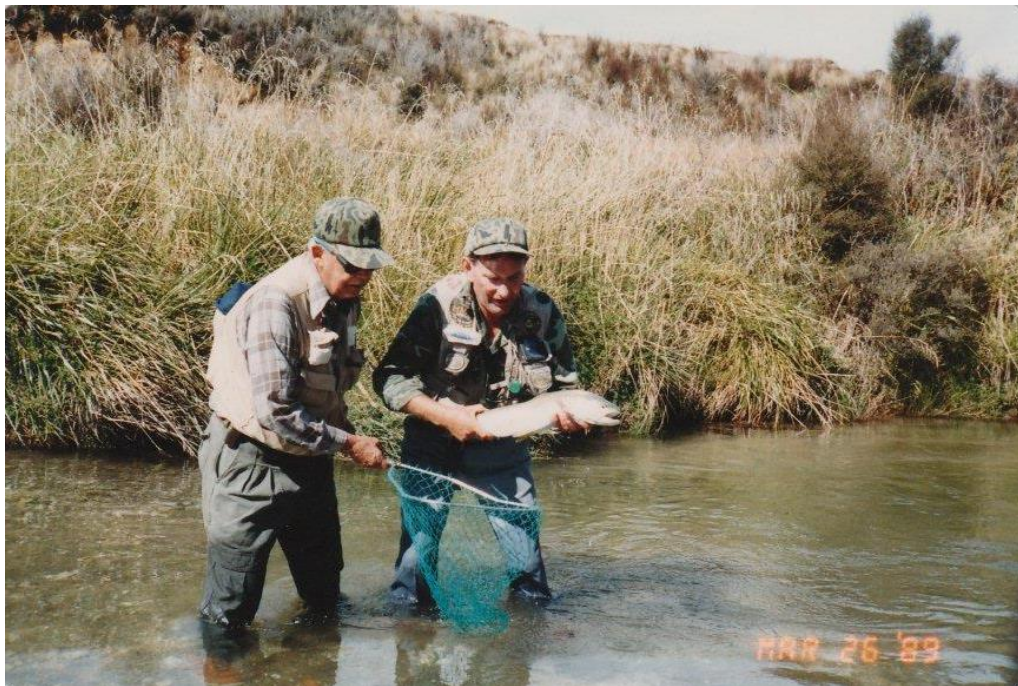


Figure 1. Photo of a fishing guide and his client with typical brown trout caught in the Taharua River prior to the dairy conversions.

1.2. Potential effects of dairying on invertebrate drift and trout fisheries

The dairy industry is among New Zealand’s top export earners (DairyNZ 2009). However, land use intensification associated with dairy farming has the potential to adversely affect a variety of ecosystem services provided by rivers, including trout fisheries. Recent expansion in the number and extent of farm conversions to dairying has generated considerable debate over the environmental effects of dairying, particularly on water quality, river health and New

Zealand's internationally renowned trout fisheries (Young & Hayes 1998; Harding *et al.* 1999; Johnson 2001; Salmon 2001). Understanding the effects of dairying on river health and fish populations is essential to guide water quality standards, consent conditions and regional plan rules, mitigation, and best management practices on-farm.

Potential effects of dairying range from reduction of aesthetic qualities of stream and river systems, to direct effects on the quality of spawning habitats, reductions in water quality and degradation of instream habitat and food resources for juvenile and adult fish. These impacts threaten to reduce domestic and international anglers' participation in New Zealand's trout fishery, which contributes in excess of \$145-230 million *p.a.* to the national economy (Hayes & Hill 2005, based on data in NRB (1991)). New Zealand has an international reputation as a top trout fishing tourism destination, which relies on a clean, green image and extensive opportunities to see and catch large trout in uncrowded, clear rivers and lakes. New Zealand's tourism industry trades on this image as does the agricultural industry. Perceived effects of agricultural intensification on the quality of fishing have been significant (Johnson 2001; Salmon 2001; Jellyman *et al.* 2003), although quantitative data on actual effects on trout ecology and economic effects on the value of the trout fishery is lacking. The high value of New Zealand's trout fisheries and the large perceived effects provides a strong rationale for further investigation of potential effects of dairying on trout. Assessment of the effect of dairying activities on fish populations is also a cost-effective means of assessing river health. Fish are valuable bioindicators of river health given that:

- (i) They are near to the top of food chains, hence respond to deterioration in the structure of the food webs that support them;
- (ii) There is a range of individual, population and community level parameters associated with fish that can be readily measured, interpreted and related to river health; and
- (iii) They represent a significant recreational and economic resource.

Trout are opportunistic predators that exhibit varied feeding behaviours and have varied diets. However, drift feeding predominates in moderate to steep gradient rivers because it is energetically most profitable, provided drift rate (drift density x water velocity) is sufficient to support it. Trout feed selectively on large drifting invertebrates because these offer the greatest energy reward for effort (Hayes *et al.* 2000).

Growth and size of drift-feeding trout should be limited by the finite energy availability that is set by the mean drift density for any river (Bachman 1982). The metabolic rate of salmonids increases exponentially with size and water velocity (Brett & Glass 1973; Elliott 1976), whereas the mean supply of drift increases only linearly with water velocity (Elliott 1967; Fausch 1984). Consequently, growth rate must decline with increasing fish size (and therefore age). For a given river, the energy available from drift will limit maximum fish size, unless the trout migrate to more food-rich habitats with favourable water temperature regimes, or are able to switch to prey with greater energy return (*e.g.* fish prey, upon which trout can achieve three times greater growth rate than on an invertebrate diet – Elliott & Hurley (2000)). Faced with increasing energy costs of metabolism, swimming, and feeding as size increases, and with reproductive energy costs, trout must eat larger and larger prey as they age to maintain growth.

If large invertebrates are not well represented in the drift then large trout will be energetically disadvantaged and their growth truncated.

Dairying activities have the potential to alter the aquatic invertebrate food base for trout with positive or negative consequences for growth and carrying capacity, depending on the level of resulting nutrient enrichment. Low to moderate increases in nutrients (enrichment) in low productivity rivers may increase trout growth and abundance by increasing the productivity of their invertebrate food resources. However, a systems tipping point, where further increase in enrichment causes adverse effects is usually unknown.

Nutrient enrichment in rivers can cause proliferations of periphyton (biofilm and algae on the river bed) commonly resulting in a change in aquatic invertebrate community composition, with large, drift-prone taxa (*e.g.* EPT¹ taxa) being replaced by small (chironomids, algal piercing caddis) or non drifting taxa (*e.g.* oligochaetes and snails).

By altering taxonomic and size structure of benthic and drifting aquatic invertebrate communities, dairying has the potential to impair drift-foraging energetics and reduce trout growth rate, thereby favouring small over large trout.

While nutrient enrichment can lead to prolific algal growth, heavy sedimentation (*e.g.* through paddock and steam bank trampling (Parkyn & Wilcock 2004)) can result in smothering of a streambed, thereby reducing numbers of benthic invertebrates and ultimately affecting drift invertebrate densities and taxonomic and size structure (Suren & Jowett 2001). Sediment released as a result of trampling and grazing by stock also reduces water clarity, with adverse consequences for visual feeding trout. Turbid water reduces the foraging efficiency of drift-feeding trout (reduced foraging area and prey capture success) and the subsequent reduction in drift food intake will reduce growth.

Adverse instream effects of enrichment and turbidity on periphyton growth, trout feeding behaviour, growth and abundance will have flow-on effects on angling success and satisfaction.

1.3. Study objectives

The aim of the study was to determine whether there was evidence for impaired aquatic invertebrate drift and trout growth potential at dairy-influenced sites in the Mohaka and Taharua Rivers. Trout feeding and growth potential was investigated with a bioenergetics drift foraging model. The study design involved a spatial comparison of two affected sites, one in the Taharua River and one in the Mohaka below the Taharua confluence, with a reference site in the Mohaka above the confluence.

¹ EPT refers to Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddis flies).

The specific objectives were to:

1. Compare aquatic invertebrate drift density, biomass, taxonomic and size composition among the dairying affected and reference sites;
2. Compare the feeding and growth potential of drift-feeding trout in the three study sites, based on estimated drift density and size composition and water temperature, using the bioenergetics drift foraging model.

2. METHODS

2.1. Study sites

The three study sites were: in the lower Taharua River (above the falls and 1 km above the confluence with the Mohaka), in the Mohaka 0.43 km downstream of the Taharua River confluence, and in the Mohaka 2.40 km upstream of the Taharua River confluence (Figure 2). Map references (mid-point of sampling reaches) of the sites, dates of drift sampling, and flow and mean daily water temperature during sampling are presented in Table 1.

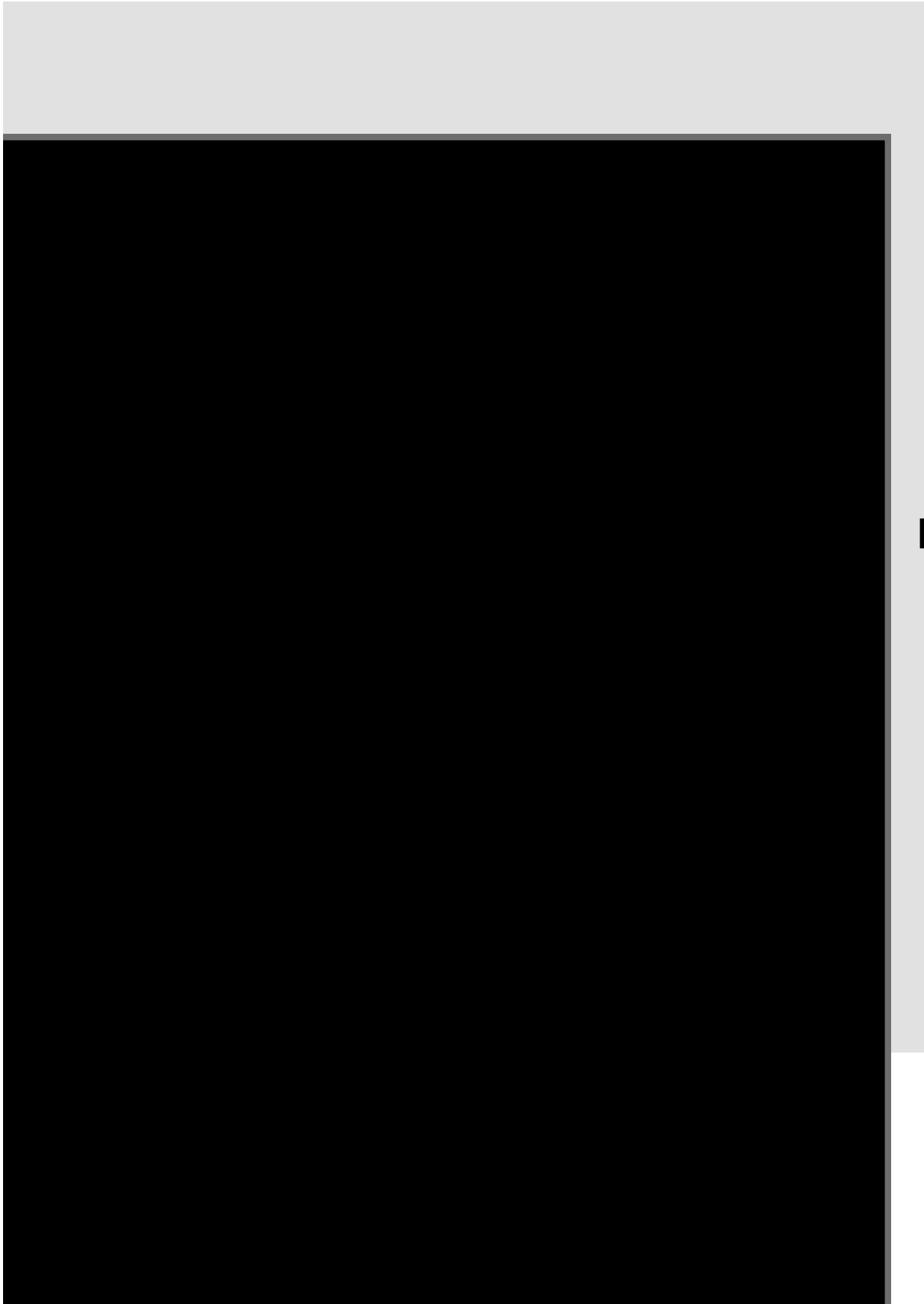


Figure 2. Map of upper Mohaka River catchment and invertibrate drift sampling reaches (● indicates midpoint of sample reach).

The Taharua is a spring-fed river that drains a catchment of 132 km² and flows through a predominately volcanic pumiceous geology (DSIR 1972). A feature of the Taharua River substrate is the predominance of mobile pumice sands. This feature has been pointed out by Hayes & Hay (2006) as precluding excessive growth of periphyton (an indicator of nutrient enrichment in a waterway that can be associated with dairying or landuse intensification). The upper Mohaka River flows through a greywacke/argillite geology with a catchment area of approximately 146 km².

Table 1. Sampling dates, map references, and flow and mean daily water temperature during sampling for the three study sites.

River	Date sampled	Location (Easting, Northing NZMS260)	Flow (m ³ /s)	Daily mean water temperature (°C)
<i>Summer</i>				
Taharua	11 February 2009	2795710, 6231424	2.9	13.3
Mohaka upstream	11 February 2009	2793616, 6231028	3.0	17.3
Mohaka downstream	11 February 2009	2795915, 6230565	6.0 ^a	16.5
<i>Autumn</i>				
Taharua	14-15 April 2009	2795710, 6231424	2.1	10.8
Mohaka upstream	14-15 April 2009	2793616, 6231028	1.6	10.1
Mohaka downstream	14-15 April 2009	2795915, 6230565	3.9	10.3
<i>Spring</i>				
Taharua	17 December 2009	2795710, 6231424	3.7	10.9
Mohaka upstream	17 December 2009	2793616, 6231028	3.4	12.1 ^b
Mohaka downstream	17 December 2009	2795915, 6230565	7.1	12.1

^a A gauging was not undertaken at this site. The flow estimate is derived from adding the Taharua and upstream Mohaka flows together, as no other known sources of water enter the river between these sites and the downstream Mohaka River site.

^b Temperature was not available for this site. The upstream Mohaka temperature shown was derived by fitting a linear regression line to a scatterplot of upstream Mohaka daily temperatures against downstream Mohaka daily temperatures for the period 9-Dec-08 to 23-Apr-09. The resulting regression equation, $y=1.0529x-0.6954$, was used to calculate the missing upstream Mohaka temperature where y = upstream Mohaka temperature and x = downstream Mohaka temperature. The fit of the regression line to the data (*i.e.* r^2) was 0.98.

2.2. Data collection

2.2.1. Water temperature

Water temperature loggers were installed at both sites in the Mohaka on 8 December 2008 and set to log at 30-minute intervals. Temperature in the Taharua River is permanently logged, by HBRC. The mean daily water temperature estimates used for the trout growth modelling covered the period approximately two weeks before and after each sampling occasion (*i.e.* one month).

2.2.2. Invertebrate drift

Sampling was undertaken on three occasions, once in summer (11 February 2009), once in autumn (14-15 April 2009) and once in spring (17 December 2009). On each occasion, invertebrate drift was sampled during the day and dusk at three locations at each of the three sites, with the locations staggered over 1 km. At each location, two drift samplers (0.18 m² in cross-sectional area and with 0.5 mm mesh) were stacked vertically in the water column at approximately mid-depth and at the surface such that terrestrial and adult aquatic invertebrates on the surface film would also be captured (Figure 3).



Figure 3. Example of drift sampler set up.

Allowing for invertebrate width - length relationships, the 0.5 mm mesh retains invertebrates >3 mm (Hayes *et al.* 2000; K Shearer, unpublished data). Samplers were positioned in 0.57-1.15 m deep water in the margins of runs where water velocities were sufficient to keep large drifting invertebrates in suspension. These locations had water velocities within or slightly greater than the suitable range for drift feeding by adult brown trout (Hayes & Jowett 1994).

Given budget limitations, we undertook power analyses to guide the number of drift sample replicates (locations) to balance cost against precision. We conducted a reverse power analyses as described by Quinn & Keough (2002) using drift data from other New Zealand rivers (Shearer *et al.* 2007) where eight drift samplers had been deployed at each site. We plotted minimum detectable effect size against number of replicates and chose a sample size of three (for each site) based on the inflection point of the graphs (*i.e.* the point where the rate of change in the relationship between sample size and precision is greatest, so that incremental increases in precision with increasing sample size begins to decline rapidly).

Daylight and dusk samples were kept separate. February (summer) daylight sampling commenced about 7.20² a.m. and dusk sampling about 7.45 p.m. and ended at about 9.07 p.m., when light level declined to 3×10^{-5} kg/s³ (0.02 lux). In April (autumn), daylight sampling commenced about 7.00 a.m. and dusk sampling about 5.00 p.m. and ended at about 6.33 p.m.³. In December (spring), daylight sampling commenced about 8.30 a.m. and dusk sampling about 7.10 p.m. and ended at 9.21 p.m.

Water velocity was measured within the mouths of the drift samplers with a Marsh McBirney electromagnetic current meter to allow estimation of the volume of water sampled. During daylight sampling, which extended for 11.56 hours in February, 8.49 hours in April, and 10.60 hours in December, water velocity estimates were made at the beginning and end of the sampling period and at irregular intervals during the day. Drift samplers were regularly inspected and the sampler nets washed, by agitation in the river to prevent fine organic matter clogging the mesh. Time and water velocity at the net mouth were recorded before and after washing. Despite net washings, occasional clogging of some samplers was detected (*i.e.* net mouth water velocities declined over some sampling periods). Volumes of water sampled during sampler deployment and redeployment periods (following washing) were estimated from the product of net mouth area, sample duration, and the mean of net water velocities measured at the beginning and end of sampler deployment periods. At dusk, water velocities in samplers were sometimes recorded only at the commencement of sampling (sampling duration was only 1.32–1.95 hours so net clogging did not occur). Drift samples were preserved with 100% ethanol.

2.2.3. Drift sample processing

A modified version of macroinvertebrate sample processing Protocol P3 (Stark *et al.* 2001) was used for this project. The top and mid drift samples from each location were washed through 2.0 and 0.5 mm mesh sieves to facilitate sample processing. The larger sample portion was placed into a white sampling tray and the smaller into a series of petrie dishes. Animals were then removed from the trays and also placed in petrie dishes. Each petrie dish was placed on top of a 3 x 3 mm grid attached to the baseplate of the microscope. For each sample, invertebrates were sorted into 3 mm body length classes, identified (to species level where practical, or coarser) and counted.

² One of the sampling locations in the Mohaka downstream site started at 9.42 a.m. as a submerged boulder was spotted immediately upstream of the bottom net, so the sampling frame was moved to a better sampling position. The nets at the Mohaka upstream site were started around 8.06 a.m. as this site was the furthest distance from camp.

³ To compare the April with the February and December times add an hour to the former for daylight saving.

2.3. Data analysis and modelling

Brown trout feeding and growth potential was predicted with a bioenergetics based drift foraging model, which required invertebrate drift, water temperature and turbidity information as data input (Hayes 2000; Hayes *et al.* 2000).

2.3.1. Invertebrate drift

For each sampling location, top and mid sampler invertebrate abundance data were combined to provide an estimate of drift through the water column. Size-class specific drift densities (no./m³) for each sample were calculated by dividing numbers of invertebrates per size class by water volume sampled. Dry weights (mg) were calculated for each taxon using length: dry weight relationships from the literature (Sample *et al.* 1993; Towers *et al.* 1994). Overall invertebrate biomass (mg./m³) per sample was calculated by summing density x mean dry weight of the 3 mm size classes. Mean dry weight was a weighted average of all the taxa in each size class. These calculations were automated with Microsoft Excel™ 79 Visual Basic macros.

For trout growth modelling, taxon-specific length-biomass and energy content relationships from the literature were used to estimate mean invertebrate dry weight and energy content for each 3 mm size class in each sample (Cummins & Wuycheck 1971; Sage 1982; McCarter 1986; Sample *et al.* 1993; Towers *et al.* 1994).

Using length-biomass relationships from the literature to estimate biomass is much more cost effective than measuring length-specific dry weights for individual drift samples or establishing length-biomass relationships specifically for the study river. However, it runs the risk of unknown systematic error if length-biomass of invertebrates in the study river is different from that assumed by using literature values. Invertebrate condition can decline in response to competition (Olsen & Watzin 2005) and in response to environmental pollutants (D. Olsen, Cawthron Institute, unpublished data). Therefore, the transferability of literature length-biomass relationships is a relevant consideration requiring research.

Size-class specific drift densities, dry weights and energy content estimated for each location were averaged over the three replicates in each study reach to provide data input to the trout drift foraging model. Gordian worms (commonly referred to as horse-hair worms) were excluded from this analysis because no length-dry weight estimates were available for these long narrow invertebrates and predictions made based on other worms appeared to be gross overestimates, and foraging radii predicted for them by the foraging model were unrealistically large. Unrealistic foraging radii were predicted because the model predicts foraging radius as a function of prey length – for common invertebrate prey which have a length: width ratio of about 4.3 (Hayes *et al.* 2000) whereas gordian worms have a much larger length: width ratio (*i.e.* they are long and thin).

Percent taxonomic and size-class compositions were determined for drift density and biomass from the pooled samples. Drift density and biomass estimates and taxonomic composition were compared between the three sites.

Statistical differences in aquatic drift density and biomass estimates between sites were tested using one-way Analysis of Variance (ANOVA) with Tukey's Honestly Significant Difference (HSD) post-hoc test. Site x seasonal comparisons were undertaken using a two-way ANOVA. Residual plots of the density and biomass data were examined prior to analysis and log₁₀-transformed to improve normality where required. All statistical analyses were undertaken using STATISTICA version 8 (StatSoft, Incorporated, Tulsa OK, USA).

2.3.2. Trout bioenergetics foraging modelling

Gross rate of energy intake (GREI), maximum potential gross rate of energy consumption (GREC_{max}) and net rate of energy intake (NREI) were predicted for drift-feeding brown trout in each site for three, 29-day periods (28 January – 25 February 2009, 26 March – 23 April 2009 and 3 December – 31 December 2009). These periods straddle the drift sampling dates.

GREI is a measure of how much energy a fish can ingest from the available drift. GREC_{max} provides a measure of how much energy a fish can ingest and process over a 24 hour period for a given temperature divided by the number of minutes in 24 hours. The ratio GREI/GREC_{max} is an index of food limitation that estimates how much food trout can obtain from the drift as a proportion of the maximum amount of invertebrate food a fish could eat and digest. Small fish (10–20 cm) tend to have higher values of GREI/GREC_{max} because they can satiate quickly owing to their small stomach volume (*i.e.* large trout are more likely to be food limited). GREI/GREC_{max} may not be proportional to growth because there is an incomplete understanding of whether trout can make use of all the food available during the daytime foraging period given the constraints of food processing (which is temperature dependent) and the choices they make regarding timing of feeding and foraging rate.

NREI is GREI minus the energy costs associated with drift feeding. These costs include the energy a trout expends when intercepting prey and maintaining its position at a focal point while waiting for prey to drift into visual range. NREI is an index of growth potential (*i.e.* it allows relative comparisons of growth potential between sites and times).

Predictions were made using the drift foraging model and maximum consumption equation in the computer programme “Trout_Energetics2” described in Hayes (2000) and successfully tested by Hayes *et al.* (2000). Trout_Energetics2 uses bioenergetics equations developed by Elliott (1976) and Elliott & Hurley (1999).

Foraging models are simplifications of the manner in which fish find and consume their food. They take into consideration factors such as foraging behaviour and swimming speed, prey density and size, and prey capture distance and efficiency and their dependence on water clarity. They comprise a suite of mathematical equations describing functional relationships

between variables relevant to food (energy) intake and energy expended in the course of obtaining food (*i.e.* they estimate prey intake rate (expressed in energy units) and foraging costs).

Hayes *et al.* (2000) coupled the drift foraging model used in the present study with a bioenergetics growth model and successfully predicted whole-lifetime growth of brown trout in the Maruia River. The trout growth model, including GRECmax, is based on Elliott's (1976) and Elliott & Hurley's (1995, 1999) bioenergetics equations and has been rigorously tested in Europe (Elliott 1994; Elliott 2000, Jensen *et al.* 2000; Nicola & Almodóvar 2004). The model performed well over a wide latitudinal and altitudinal temperature range, but underestimated the growth in the coldest rivers with mean annual temperature below 5.1°C. All New Zealand trout streams exceed this temperature threshold.

The foraging model was based Hughes & Dill's (1990) model for drift-feeding salmonids which has been widely used internationally (Appendix 1). Very simply the model estimates how far away a fish of a given size will detect and react to a prey of given size (reaction distance) and, given the prey speed and fish's interception speed, how far the fish will move sideways (or upward) to capture the prey before it is swept past the fish's position (foraging radius). The model then calculates a semicircular foraging area based on the foraging radius (with the fish stationed near the stream bottom). The rate of drift passing through the foraging area is estimated from the drift density and mean column velocity, the latter being estimated from a fish size-dependent optimal swimming speed equation modified by empirical velocity shears over which trout have been recorded feeding (Hayes *et al.* 2000).

The foraging model was operated on a daily time step. Water temperature data, required to drive the model, were obtained from the temperature loggers installed at each site. The 30-minute temperature records were converted to daily means for input to the model. The model was run using site-specific temperature means and standardised temperature regimes (*i.e.* using mean temperature across all sites). The latter factors out temperature from site comparisons allowing the effect of food limitation alone to be isolated.

Invertebrate drift data were summarised as described in Section 2.3.1 for daylight and dusk sampling periods. These data were further summarised to give a combined value for the total diurnal (daytime) foraging period for drift density (no./m³), mean dry weight (g), and mean energy content (calories), for each 3 mm size class, for input to the model. Data from the daylight and dusk sampling periods were combined in a weighted average, based on the proportion of the total daily foraging period represented by each sampling period (*i.e.* daylight and dusk).

The same sets of drift data were used as input to each daily time step modelled – for each day of February, April, and December respectively (*i.e.* there were three seasonal drift data sets per site and only mean daily temperature varied between days within months).

To model drift foraging, “Trout Energetics2” requires the daytime drift foraging period to be estimated. The foraging radius of drift-feeding trout declines with reduction in light intensity (and water clarity). At night the foraging radius will be so small that drift foraging is not energetically profitable. The foraging radius of brown trout is reduced by 50% when light intensity falls to about 0.02 lux (Robinson & Tash 1979), and Hayes *et al.* (2000) used this as the threshold at which drift feeding ceases in their successful test of the model on the Maruia River. Using this same light threshold, we set the drift-foraging period to 15.4 h for the February modelling. This was based on the observed light level recordings taken during drift sampling on the rivers. For the April and December modelling the foraging periods were set to 12.6 h and 16.75 h, respectively.

We confined our modelling to daytime and twilight drift feeding (*i.e.* making predictions of GREI, GRECmax, and NREI for the period of the day during which it was light enough for trout to drift feed at $\geq 50\%$ efficiency (or 0.02 lux)).

GREI/GRECmax and NREI were modelled for seven size classes of trout, progressing in 10 cm length increments from 10 cm to 70 cm.

Table 2. Lengths and weights of trout used in drift foraging modelling. Weights were estimated from a brown trout length/weight regression for the Maruia River (from Hayes *et al.* 2000).

Initial fish length (cm)	Initial fish weight (g)
10	13
20	96
30	304
40	689
50	1298
60	2180
70	3378

The foraging model assumes that fish choose an optimal water column velocity for stationary swimming and maximise their fish and prey size dependent cross-sectional foraging area. We chose modelling options that allowed the fish to further optimise drift foraging energetics by assuming they foraged across both vertical and horizontal velocity differentials (or shears) (*i.e.* foraging from a slow near-bed focal position into the faster water above and laterally) (Hayes 2000). Fish were also assumed to rest when satiated.

Under its standard options, the foraging model restricts prey capture and ingestion to a subset of prey falling within predicted maximum and minimum prey sizes which are limited by mouth gape, foraging cost-benefit relationships, and gill raker spacing (Wankowski 1979; Bannon & Ringler 1986). The maximum prey length available in the drift is not limiting for drift-feeding trout ≥ 10 cm given the restricted size range of most drifting invertebrates. The minimum prey length relationship is: prey length (in mm) = 0.115 x fish length (in cm), equating to 1.2, 2.3, 3.5, 4.6, 5.8, and 6.9 mm for 10, 20, 30, 40, 50, and 60 cm trout,

respectively. The exclusion of invertebrates <3 mm by our drift samplers should have minor influence on predicted energy intake rate and growth even for small trout because it is invertebrates in the 3–9 mm range that usually comprise the greatest biomass in the drift and theoretically can quickly satiate small trout. Small trout (<30 cm) have the greatest growth potential because they are able to eat prey from most size classes available in the drift.

Diet analyses in other New Zealand rivers indicate that trout may feed on smaller prey than the above minimum prey size predictions (*e.g.* Hayes *et al.* 2006). To account for this we relaxed the minimum prey size limit to allow trout ≥ 30 cm to eat prey 3 mm smaller than predicted by the minimum prey size equation (*i.e.* the smallest drift size class retained by our drift samplers (3–6 mm) (*c.f.* Shearer *et al.* 2007). Nevertheless, Shearer *et al.* found that adjusting the drift foraging model to allow larger trout to ingest smaller prey items made little difference to predicted energy consumption and growth, as the energy reward for foraging effort by trout was much less (6.5 times less) for 3–6 mm invertebrates than for larger invertebrates.

Trout food limitation and potential growth predictions for the Mohaka and Taharua River sites were made for the following two invertebrate drift diet scenarios:

1. All drifting invertebrates including aquatic and terrestrial sources;
2. Only aquatic drifting invertebrates.

2.3.3. Water clarity

Water clarity (or turbidity) influences the distance that trout can detect prey items in the drift. This directly affects foraging area and GREI. A reduction in water clarity has most affect on the foraging area of large trout feeding on large invertebrates. For all the modelling runs done on the range of fish sizes described above, we assumed clear water (*i.e.* 0 NTU). We then modelled the influence of turbidity on GREI/GRECmax and NREI for a 50 cm trout for each site; the intention being that these relationships could be used to assess the effect of turbidity recorded in the future.

The foraging model includes an adjustment for turbidity – made by Hayes (2000). This relationship is based on Gregory & Northcote (1993) who reported a log linear decline in reaction distance to invertebrate prey with increasing turbidity for juvenile Chinook salmon. Barrett *et al.* (1992) also found that increased turbidity strongly reduced reaction distances of juvenile rainbow trout to drifting prey items in artificial stream channels. The reaction distance is the maximum distance fish detect and react to prey.

Hughes & Dill's (1990) drift foraging model predicts that reaction distance for a given prey size plotted against fish length reaches an asymptote (Figure 4). For 12 mm prey this asymptote is at approximately 1.4 m. However, the reaction distance to larger prey items is obviously greater (*e.g.* for a 60 cm fish with a 30 mm prey item the reaction distance is predicted to be approximately 3.6 m). The majority of drifting prey eaten by trout in New Zealand rivers is 12 mm or less (because most drifting invertebrates are in this size range).

Given the apparent lack of equivalent empirical data for brown trout, the relationship reported by Gregory & Northcote (1993) for juvenile Chinook salmon, was used by Hayes (2000) to adjust the reaction distance predicted by Hughes & Dill's (1990) model for the effect of turbidity. Based on this adjusted model the reaction distance, at 0.5 NTU (the lowest practical value for comparison), is predicted to be reduced by approximately 50% as turbidity increases to about 10 NTU (Figure 5). The maximum reaction distances to various prey sizes shown in Figure 4 are for the clear water (0.5 NTU) condition. It is possible to approximate the level of water clarity (as measured by black disc) that would be required to maintain reaction distances based on a relationship between NTU and black disc water clarity. A very coarse relationship between black disc and NTU was given for a wide range of rivers by Davies-Colley & Close (1990). However, given the relationship can be river specific, ideally water clarity and NTU relationships should be developed for individual rivers (R Davies-Colley, NIWA, pers comm.).

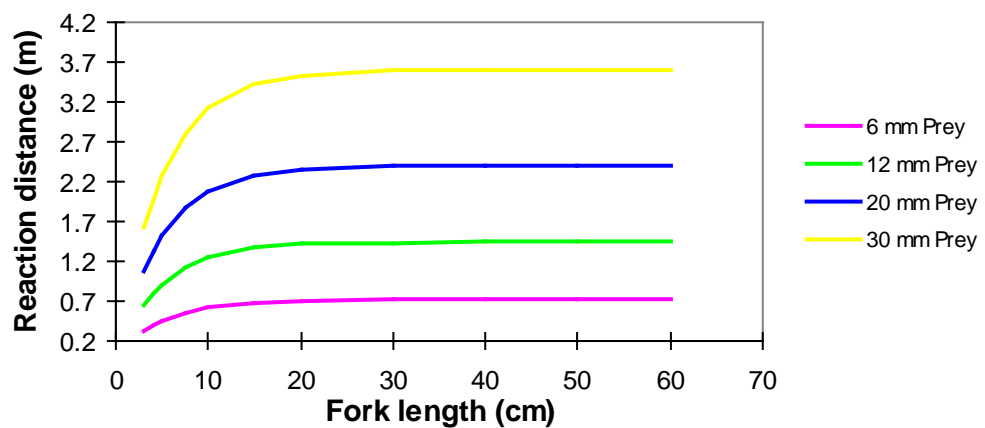


Figure 4. Reaction distance to drifting invertebrate prey relative to fish size, based on Hughes & Dill's (1990) drift foraging model, for a range of sizes of invertebrate prey.

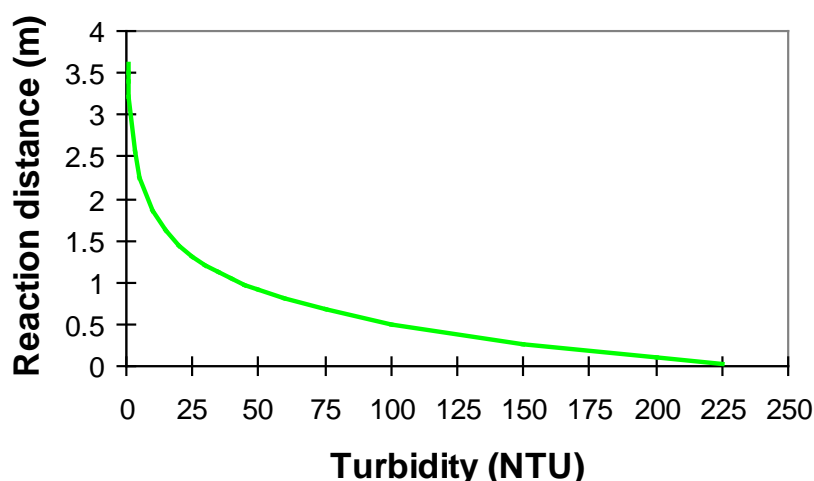


Figure 5. Attenuation of the predicted reaction distance of a drift foraging salmonid with increasing turbidity. Based on Hughes & Dill's (1990) foraging model predictions (for a 60 cm trout with 30 mm prey), modified by the NTU versus reaction distance relationship from Gregory & Northcote (1993).

3. RESULTS

The results section is confined to aquatic drift analysis and trout drift foraging modelling. Results for aquatic and terrestrial drift are presented in Appendices 2-5, 7 and 8.

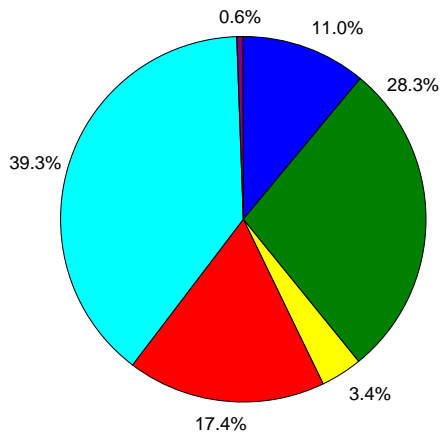
3.1. Aquatic invertebrate drift February 2009 (summer)

Thirty-three aquatic invertebrate taxa were identified from the Taharua River day drift-samples and 19 from the dusk samples (Appendices A2.2, A2.3). Nineteen aquatic taxa were found in common between the day and dusk samples. Beetles, caddis flies and true flies were the most common day drifting invertebrate groups (85% by density), with beetles, caddis flies, true flies and mayflies contributing almost a quarter each to the dusk drift (Figure 6). The elm mid beetle (larvae and adults) was the most abundant drifting invertebrate, contributing 37.8% and 23.7% to day and dusk respectively. The stony-cased caddis *Pycnocentria* was the next most abundant invertebrate in the day drift and caddis fly adults in dusk drift (6.7% and 16.8% respectively).

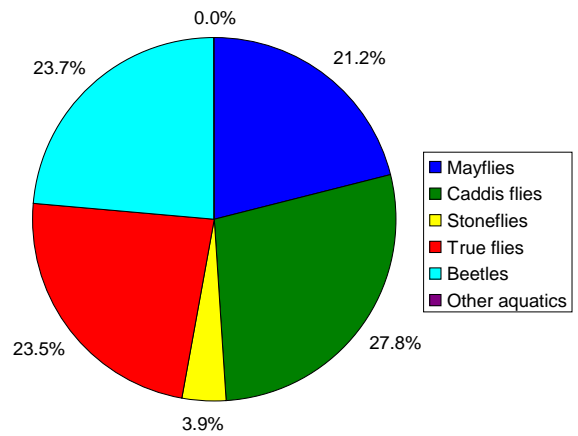
Twenty-four taxa were found in the upstream Mohaka River day drift samples and 21 at dusk. More taxa were found at the downstream Mohaka site: 36 and 29 for day and dusk (Appendices A2.4 - 7). Caddis flies and beetles were the most common day drifting invertebrate groups at the upstream Mohaka site (96.3%), with caddis flies and mayflies contributing 81.9% to dusk drift (Figure 6). At the downstream Mohaka site, caddis flies and beetles were predominant during the day (82.2%) and caddis flies and mayflies (61.2%) during

dusk; however true flies also formed a significant portion of the downstream Mohaka drift during day and dusk (Figure 6). Caddis flies were the most common aquatic invertebrate collected at both sites in the day and dusk, with mayflies contributing a higher proportion to dusk than day drift. The cased caddis fly *Beraeoptera* was the most abundant day drifting invertebrate in the Mohaka, contributing 79.4% and 52.2% to day drift at the upstream and downstream sites, respectively. In the dusk samples, adult mayflies and caddis flies contributed to over 40% of the drift at the upstream sites followed by *Beraeoptera* with 11.4%. By contrast, at the downstream site Elmidae (larvae and adults) and *Beraeoptera* were most abundant in the drift contributing approximately 14% each, followed by adult caddis flies and mayflies (11.8% and 9.1% respectively).

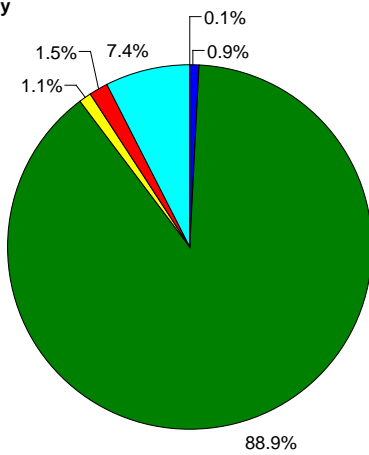
Taharua Day



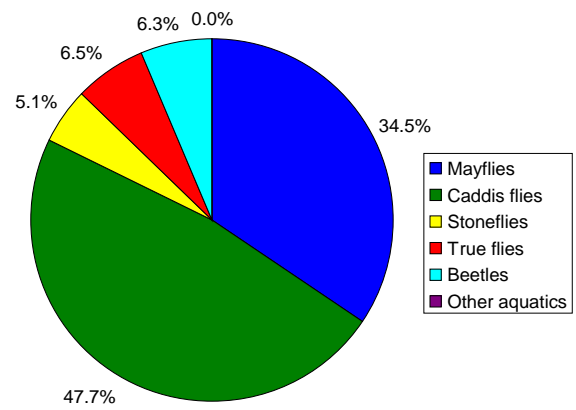
Taharua Dusk



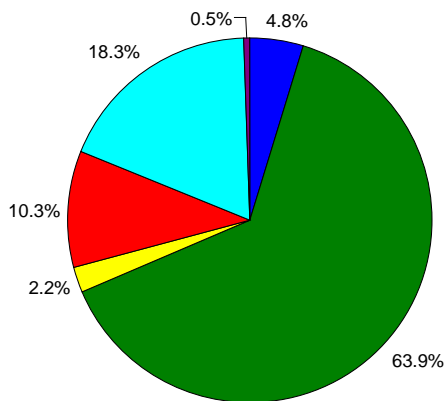
Mohaka US Day



Mohaka US Dusk



Mohaka DS Day



Mohaka DS Dusk

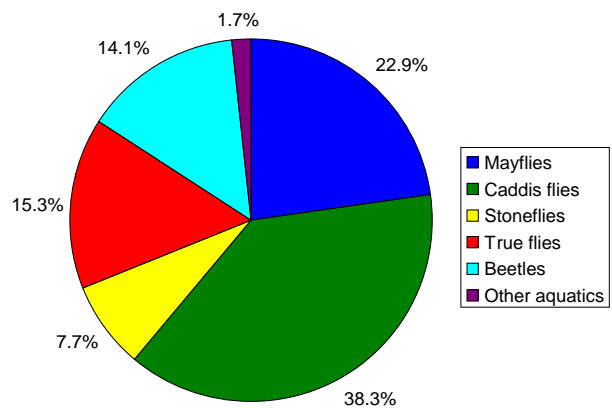


Figure 6. Percentage composition by density of main aquatic invertebrate groups in February 2009 day and dusk drift samples from the Taharua and Mohaka rivers.

Taxa that are generally associated with high algal biomass such as algal piercing caddis (*Oxyethira*) and chironomid fly larva were more abundant in the drift of the dairying-influenced sampling sites (Taharua and downstream Mohaka sites) (Appendices A2.2 – A2.7). The overall contribution of these animals to the drift at these sites may be underestimated due to the exclusion of invertebrates in the 3 mm size class by our drift samplers. The 3-6 mm size class had the highest drift densities and biomass at all sampling sites (Table 3). Our experience from sampling other rivers is that invertebrates <3 mm are the most abundant in the drift, but make a comparatively minor contribution to total biomass. Moreover, the foraging model predicts that invertebrates <3mm will be ignored as prey by trout >20 cm.

Daytime⁴ aquatic drift density and biomass was highest at the upstream Mohaka site and lowest at the Taharua site (Table 4). ANOVA revealed a significant difference between sites (Density $F_{2,6} = 19.921, p = 0.002$; Biomass $F_{2,6} = 9.962, p = 0.012$). A Tukeys HSD test indicated that the density estimates at both Mohaka River sites were significantly higher than the Taharua site ($p < 0.05$) but were not different from each other. Biomass was significantly higher at the upstream Mohaka site than the Taharua ($p < 0.05$), but similar to the downstream Mohaka site.

Although there were proportionately more small invertebrates (3-6 mm) least preferred by adult trout, at the upstream Mohaka site (Figure 7), in the context of trout growth potential, this was compensated by high biomass (and density) (Tables 3 and 4; Figure 13). The biomass of the larger size classes (> 9mm), and their relative contribution to overall biomass, was highest at the two Mohaka sites (Figure 7). These larger size classes have a large influence on trout growth potential.

Table 3. Mean daytime drift density and biomass (\pm standard error) for each 3 mm size class of aquatic invertebrates in the Taharua and Mohaka rivers (February 2009). “-“ indicates no animals were found in this size class.

Size class midpoint (mm)	Taharua		Mohaka US		Mohaka DS	
	Density (no./m ³)	Biomass (mg/m ³)	Density (no./m ³)	Biomass (mg/m ³)	Density (no./m ³)	Biomass (mg/m ³)
4.5	0.340 (0.080)	0.297 (0.044)	2.061 (0.442)	0.863 (0.180)	1.052 (0.158)	0.549 (0.058)
7.5	0.043 (0.021)	0.070 (0.044)	0.083 (0.019)	0.116 (0.023)	0.085 (0.012)	0.110 (0.021)
10.5	0.005 (<0.001)	0.006 (<0.001)	0.007 (0.002)	0.031 (0.003)	0.008 (0.002)	0.022 (0.004)
13.5	0.001 (0.001)	0.001 (0.001)	-	-	0.001 (<0.001)	0.001 (0.001)
16.5	0.001 (0.001)	0.002 (0.002)	0.001 (0.001)	0.007 (0.007)	<0.001 (<0.001)	<0.001 (<0.001)
19.5	-	-	-	-	0.001 (0.001)	0.006 (0.006)

⁴ In this report ‘daytime’ refers to the day and dusk sample results combined.

Table 4. Mean aquatic invertebrate daytime drift density and biomass (\pm standard error) for all size classes combined in the Taharua and Mohaka rivers (February 2009).

	Density (no.m ³)	Biomass (mg.m ³)
Taharua	0.39 (0.10)	0.38 (0.09)
Mohaka upstream	2.15 (0.46)	1.02 (0.19)
Mohaka downstream	1.15 (0.15)	0.69 (0.04)

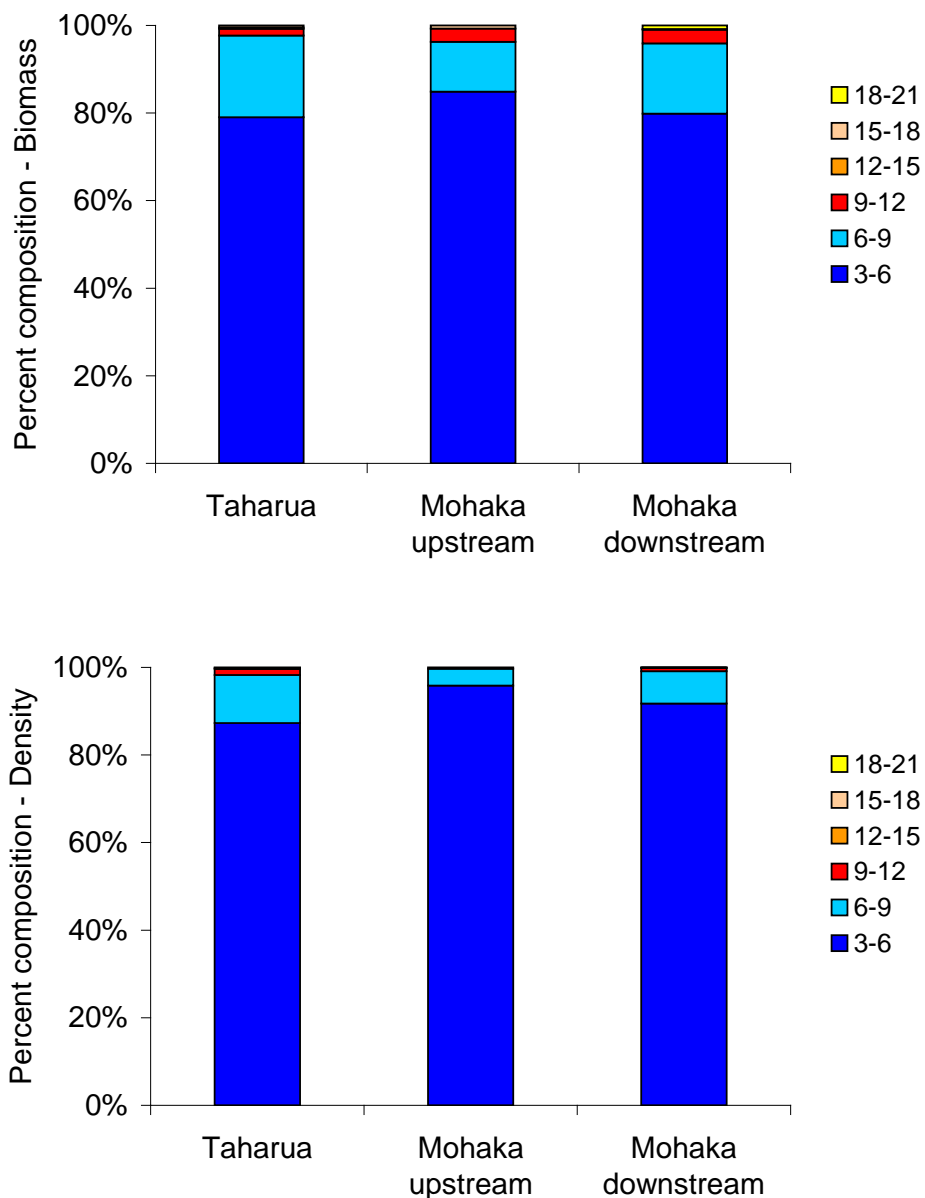


Figure 7. Percent composition by density (bottom) and biomass (top) of each 3 mm size class in aquatic drift (daytime only) from the Taharua and Mohaka rivers (February 2009).

3.2. Aquatic invertebrate drift April 2009 (autumn)

Twenty-five aquatic invertebrate taxa were identified from the Taharua River day drift samples and 22 from the dusk samples in April (Appendices A2.8, A2.9). Eighteen aquatic taxa were found in common between the day and dusk samples. Caddis flies, true flies and mayflies were the most common day drifting invertebrate groups contributing 93.5% of day drift and 92.6% of dusk drift (Figure 8). Caddis flies contributed almost half, and true flies a quarter, of the day and dusk drift density. The stony-cased caddis fly *Pycnocentria* was the most abundant day and dusk drifting invertebrate (33.2% and 27.6% respectively) with the mayfly larva of *Deleatidium* next most abundant in the day drift (11.6%) and the sandfly larva *Austrosimulium* (11.5%) in the dusk drift.

Similar numbers of aquatic taxa were found at the Taharua and upstream Mohaka River drift samples (24 and 14 for day and dusk). More were found at the downstream Mohaka site, (27 and 23 for day and dusk respectively) (Appendices A2.10-A2.13). Caddis flies and stoneflies were the most common day drifting invertebrate groups at the upstream Mohaka site (75.4%), with mayflies, true flies and caddis flies contributing 85.7% to the dusk drift (Figure 8). At the downstream Mohaka site, the true flies contributed over a third of the day and dusk drift, and caddis flies just under a quarter (Figure 8). There was a much stronger presence of true flies at the downstream Mohaka site followed by the Taharua and lastly the upstream Mohaka site. Mayflies contributed a higher proportion to the dusk than day drift at both Mohaka sites, while stoneflies showed the opposite trend. The true fly larvae Orthoclaadiinae was the most abundant drifting invertebrate in the downstream Mohaka site, contributing 25% to day and dusk drift. The stonefly *Zelandoperla* was the next most abundant day and dusk drifting invertebrate at the downstream site. At the upstream Mohaka site, the cased caddis fly *Beraeoptera* was the most abundant day drifting invertebrate (35.4%) closely followed by *Zelandoperla* (22.8%), with the latter the most abundant drifting invertebrate in the dusk samples (12.6%) followed by *Beraeoptera* (12.1%).

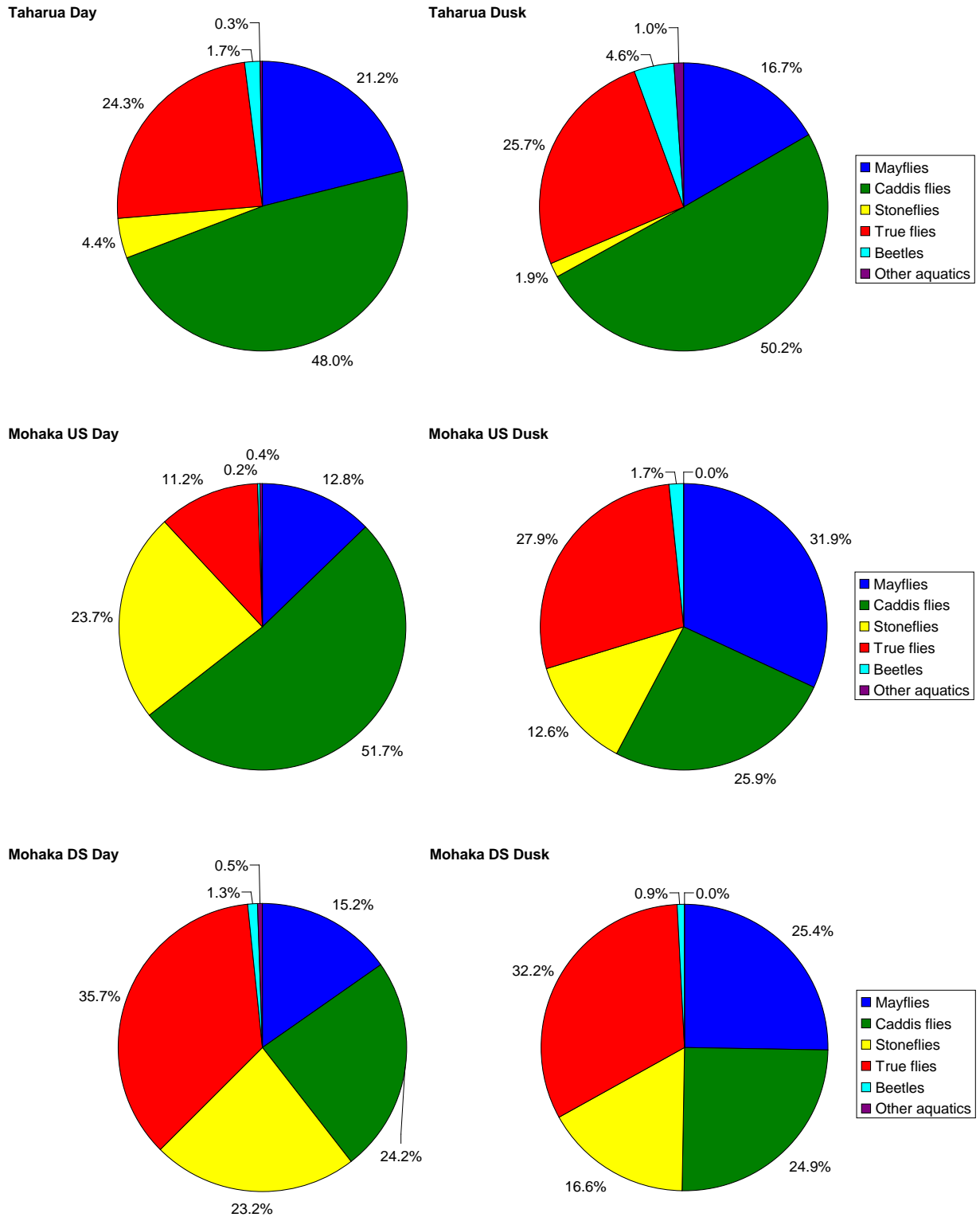


Figure 8. Percentage composition by density of main aquatic invertebrate groups in April 2009 day and dusk drift samples from the Taharua and Mohaka rivers.

Overall density and biomass of aquatic invertebrate drift was highest at the downstream Mohaka site. However, ANOVA revealed there that there were no significant differences between sites (Density $F_{2,6} = 2.897$, $p = 0.132$; Biomass $F_{2,6} = 1.076$, $p = 0.399$) (Tables 5 and 6).

The relative contribution of small invertebrates (3 – 6 mm) (least preferred by adult trout) to biomass was highest at the downstream Mohaka site and lowest in the Taharua (Figure 9). However, in the context of trout growth potential, the high proportion of small invertebrates at the downstream Mohaka site was compensated by a higher proportion of very large invertebrates (> 12 mm). Nevertheless these differences in size structure are minor – as were the differences between sites in overall density and biomass.

Table 5. Mean daytime drift density and biomass (\pm standard error) for each 3 mm size class of aquatic invertebrates in the Taharua and Mohaka rivers (April 2009). “-“ indicates no animals were found in this size class.

Size class midpoint (mm)	Taharua		Mohaka US		Mohaka DS	
	Density (no./m ³)	Biomass (mg/m ³)	Density (no./m ³)	Biomass (mg/m ³)	Density (no./m ³)	Biomass (mg/m ³)
4.5	0.311 (0.091)	0.114 (0.024)	0.275 (0.041)	0.162 (0.030)	0.570 (0.021)	0.317 (0.017)
7.5	0.085 (0.038)	0.135 (0.053)	0.047 (0.022)	0.085 (0.046)	0.044 (0.023)	0.061 (0.032)
10.5	0.009 (0.004)	0.020 (0.010)	0.011 (0.005)	0.031 (0.021)	0.010 (0.006)	0.018 (0.009)
13.5	-	-	0.002 (0.001)	0.003 (0.002)	0.001 (0.001)	0.002 (0.001)
16.5	-	-	-	-	0.001 (0.001)	0.004 (0.004)
22.5	-	-	-	-	0.001 (0.001)	0.003 (0.003)

Table 6. Mean aquatic invertebrate daytime drift density and biomass (\pm standard error) for all size classes combined in the Taharua and Mohaka rivers (April 2009).

	Density (no.m ³)	Biomass (mg.m ³)
Taharua	0.41 (0.13)	0.27 (0.06)
Mohaka upstream	0.34 (0.05)	0.28 (0.09)
Mohaka downstream	0.63 (0.04)	0.40 (0.06)

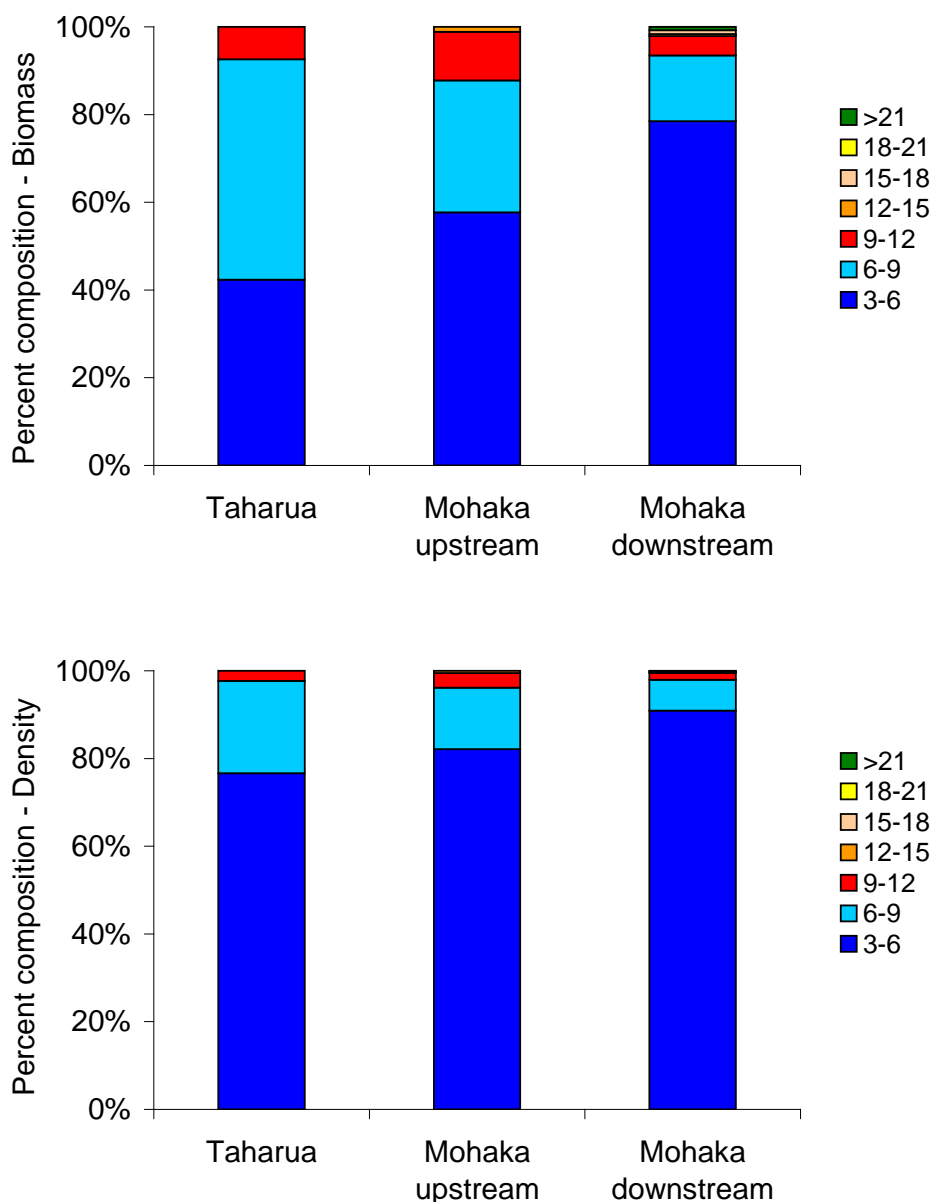


Figure 9. Percent composition by density (bottom) and biomass (top) of each 3 mm size class in aquatic drift (daytime only) in from the Taharua and Mohaka rivers (April 2009).

3.3. Aquatic invertebrate drift December 2009 (spring)

Twenty-seven aquatic invertebrate taxa were identified from the Taharua River day drift samples and 19 from the dusk samples (Appendices A2.14, A2.15). Fourteen aquatic taxa were found in common between the day and dusk samples. Caddis flies, stoneflies and beetles were the most common day drifting invertebrate groups (89.7% by density), with caddis flies, beetles and stoneflies contributing to the dusk drift (85.7% by density) (Figure 10). The stony-cased caddis fly *Pycnocentria* was the most abundant day drifting invertebrate contributing

22.7%, while elmids (larvae and adult) were the most abundant drifting animal in the dusk (36.7%). The cased caddis *Beraeoptera* was the next most abundant invertebrate in the day drift and *Pycnocentria* in dusk (20.0% and 14.0% respectively).

Similar numbers of aquatic taxa were found at the Taharua and upstream Mohaka River drift samples (27 and 19 for day and dusk) (Appendices A2.16-A2.19). More taxa were found at the downstream Mohaka site, (30 and 26 for day and dusk respectively). Caddis flies and mayflies were the most common day and dusk drifting invertebrate groups at the upstream Mohaka site (84.6% and 93.5% respectively) (Figure 10). At the downstream Mohaka site, caddis flies contributed 63.3% and 40.8% to the day and dusk drift, followed by beetles (15.3% day and 25.5% dusk); however stoneflies also formed a significant portion of the downstream Mohaka drift during day and mayflies during dusk (Figure 10). The presence of true flies in the downstream Mohaka (and Taharua) drift was much lower in December than in April or February, but still higher than was found at the upstream Mohaka site. The cased caddis *Beraeoptera* was easily the most abundant drifting invertebrate in the downstream Mohaka site, contributing to over half of the day drift and a third of the dusk drift. The beetle Elmidae was the next most abundant day and dusk drifting invertebrate at the downstream site (14.9% and 24.5% respectively). At the upstream Mohaka site, the cased caddis fly *Beraeoptera* was the most abundant day drifting invertebrate (36.0%) followed by *Deleatidium* (17.8%), with mayflies adults the most abundant drifting invertebrate in the dusk samples (30.6%) followed by *Beraeoptera* (23.9%).

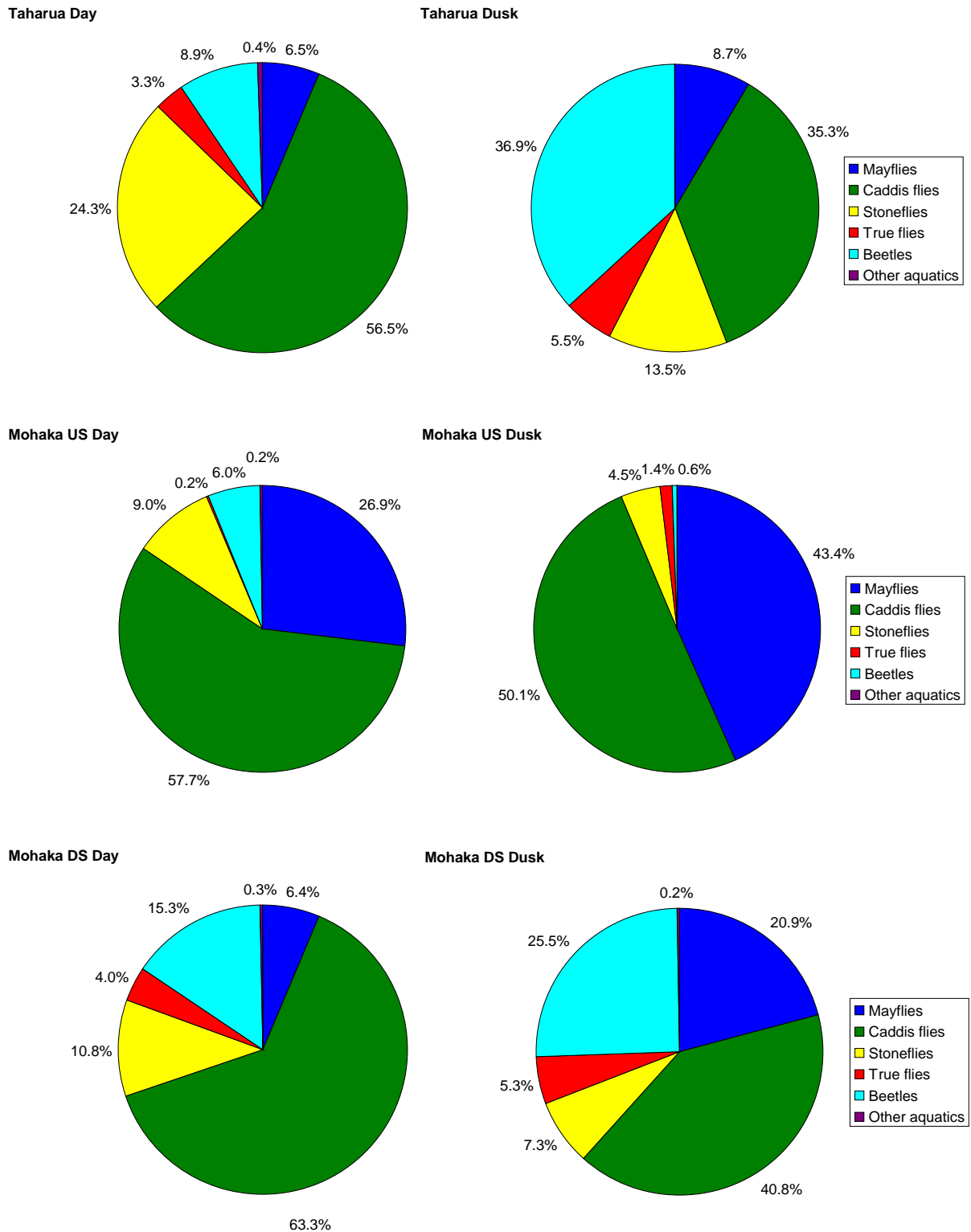


Figure 10. Percentage composition by density of main aquatic invertebrate groups in December 2009 day and dusk drift samples from the Taharua and Mohaka rivers.

In December, drift densities and biomass were lowest in the Taharua and highest at the downstream Mohaka site (Table 7 and 8). These “differences” were not statistically significant (Density $F_{2,6} = 3.983$, $p = 0.079$; Biomass $F_{2,6} = 1.185$, $p = 0.369$), (Tables 7 and 8).

Nevertheless, there were differences in drift size structure that have some bearing on trout growth potential. Although overall biomass was highest at the downstream Mohaka site, the contribution of large invertebrates (*e.g.* > 9 mm) to biomass was highest at the Mohaka upstream site (Table 7, Figures 11, 13).

The density of the smallest size class (3–6 mm) (least preferred by adult trout) was highest at the downstream Mohaka site and lowest in the Taharua (Table 7). The biomass of this size class, and its relative contribution to overall biomass was highest at the downstream Mohaka site and lowest at the upstream Mohaka site (Table 7, Figure 11, Figure 13). The biomass of invertebrates > 9 mm was also highest at the upstream Mohaka site (Figure 13).

Table 7. Mean daytime drift density and biomass (\pm standard error) for each 3 mm size class of aquatic invertebrates in the Taharua and Mohaka rivers (December 2009). “-” indicates no animals were found in this size class.

Size class midpoint (mm)	Taharua		Mohaka US		Mohaka DS	
	Density (no./m ³)	Biomass (mg/m ³)	Density (no./m ³)	Biomass (mg/m ³)	Density (no./m ³)	Biomass (mg/m ³)
4.5	0.247 (0.064)	0.142 (0.043)	0.292 (0.035)	0.121 (0.006)	0.509 (0.088)	0.281 (0.095)
7.5	0.068 (0.024)	0.104 (0.038)	0.115 (0.020)	0.204 (0.040)	0.083 (0.009)	0.135 (0.010)
10.5	0.011 (0.005)	0.035 (0.016)	0.027 (0.013)	0.125 (0.069)	0.020 (0.003)	0.080 (0.011)
13.5	0.004 (0.002)	0.022 (0.018)	0.005 (0.002)	0.038 (0.022)	0.005 (0.001)	0.014 (0.007)
16.5	0.001 (0.001)	0.002 (0.001)	-	-	0.002 (0.001)	0.015 (0.011)
19.5	-	-	-	-	<0.001 (<0.001)	0.002 (0.002)
22.5	-	-	-	-	0.001 (0.001)	0.004 (0.004)

Table 8. Mean aquatic invertebrate daytime drift density and biomass (\pm standard error) for all size classes combined in the Taharua and Mohaka rivers (December 2009).

	Density (no.m ³)	Biomass (mg.m ³)
Taharua	0.33 (0.09)	0.31 (0.10)
Mohaka upstream	0.44 (0.02)	0.49 (0.13)
Mohaka downstream	0.62 (0.08)	0.53 (0.10)

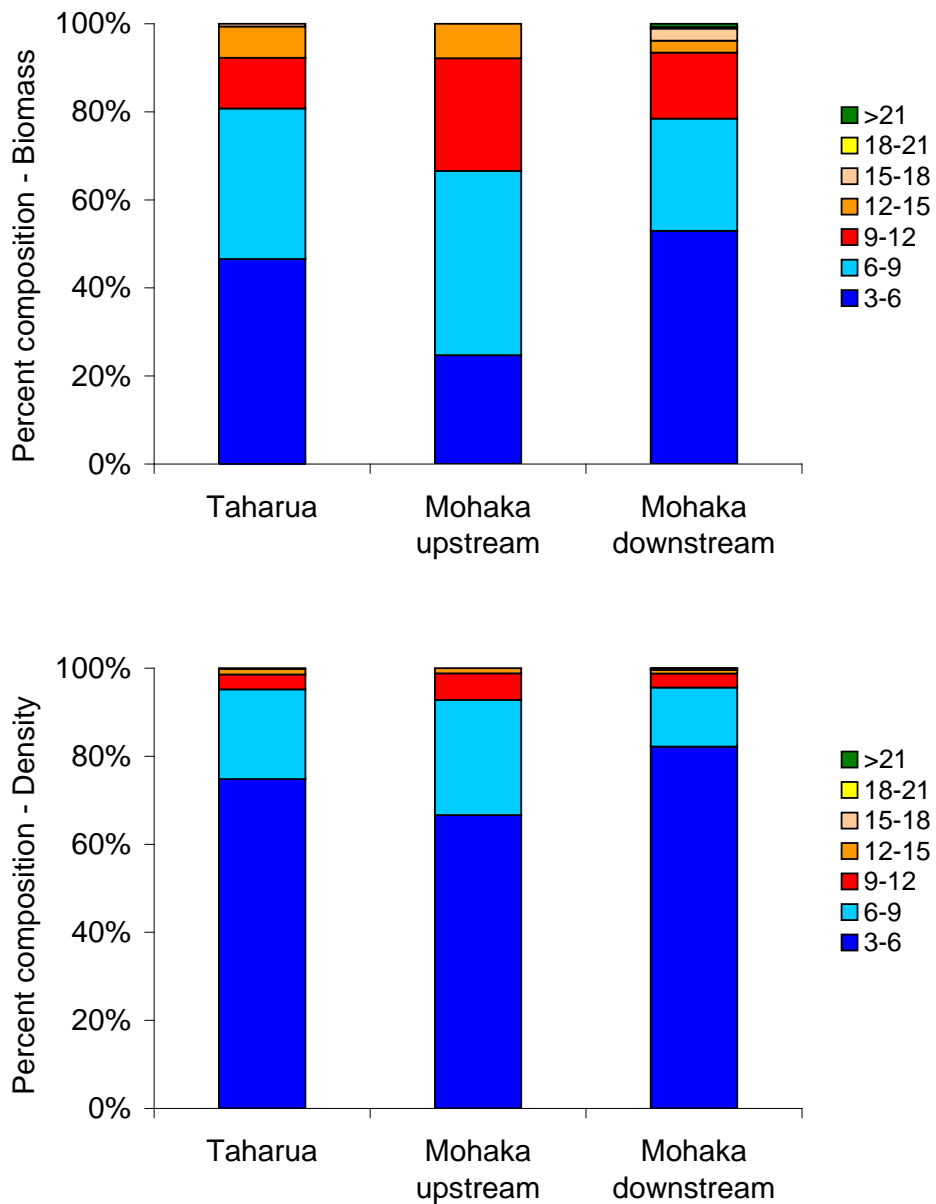


Figure 11. Percent composition by density (bottom) and biomass (top) of each 3 mm size class in aquatic drift (daytime only) in from the Taharua and Mohaka rivers (December 2009).

3.4. Seasonal comparison of drift

Caddis flies represented a greater proportion of the drift density and biomass in summer and spring than in autumn at the Mohaka River sites (Figures 6, 8 and 10). Stoneflies showed the reverse trend. Overall densities of stoneflies were generally greatest in autumn followed by spring, then summer (Appendix 2). Some stonefly species, unlike many other aquatic invertebrate taxa, tend to be more active as the seasons get colder *i.e.* hatching occurs in the colder months of the year, which may account for these differences between the seasons. In the Taharua, beetles were more common in summer followed by spring then autumn. In all three seasons true flies represented a greater proportion of the drift in the Taharua and downstream Mohaka site than the upstream Mohaka site (Figures 6, 8 and 10). Drift densities of mayflies were highest in summer at the Taharua and upstream Mohaka sites, although the next highest mayfly densities in the Taharua were collected in autumn, and at the upstream Mohaka site, spring. Mayfly densities were relatively similar between all seasons at the downstream Mohaka site. Elmid beetle densities were highest at the Taharua and downstream Mohaka sites in spring followed by summer: the opposite was true at the upstream Mohaka site. There was very little difference between summer and autumn in stonefly drift densities at the upstream Mohaka site; lower densities occurred in spring. Highest stoneflies densities at the downstream site occurred in autumn followed by spring, while in the Taharua the order of densities from highest to lowest was spring/summer/autumn. True fly densities were higher in summer and autumn than in spring at all sites, and notably higher at the Taharua and downstream Mohaka sites compared to the upstream Mohaka site across all seasons. Caddis fly drift densities were notably higher in the summer drift at the Mohaka sites. The next highest drift densities of caddis flies in the Mohaka River were in spring. In the Taharua, caddis fly drift densities were lowest in summer and highest in spring (Appendices A2.2 - 19).

Overall daytime aquatic drift density was significantly higher in summer than in autumn and spring at the Mohaka sites; particularly at the upstream Mohaka site (Density: site x season interaction, $F_{4,18} = 5.607$, $p = 0.004$, Tukeys) (Figure 12). Daytime aquatic drift biomass was also significantly higher in summer than the other two seasons at the upstream Mohaka site (Biomass: site $F_{2,18} = 6.168$, $p = 0.009$, season $F_{2,18} = 10.319$, $p = 0.001$). However, the interaction between site x season was not as strong for the biomass results compared to the density results (Biomass: site x season interaction $F_{4,18} = 2.697$, $p = 0.064$, Tukeys). This was because the downstream Mohaka site aquatic invertebrate biomass was, in general, statistically similar to the upstream Mohaka and Taharua biomass across the seasons. Drift density and biomass at the Taharua site was relatively similar between seasons in comparison to the greater variability at the Mohaka sites (Tables 4, 6 and 8, Figure 12).

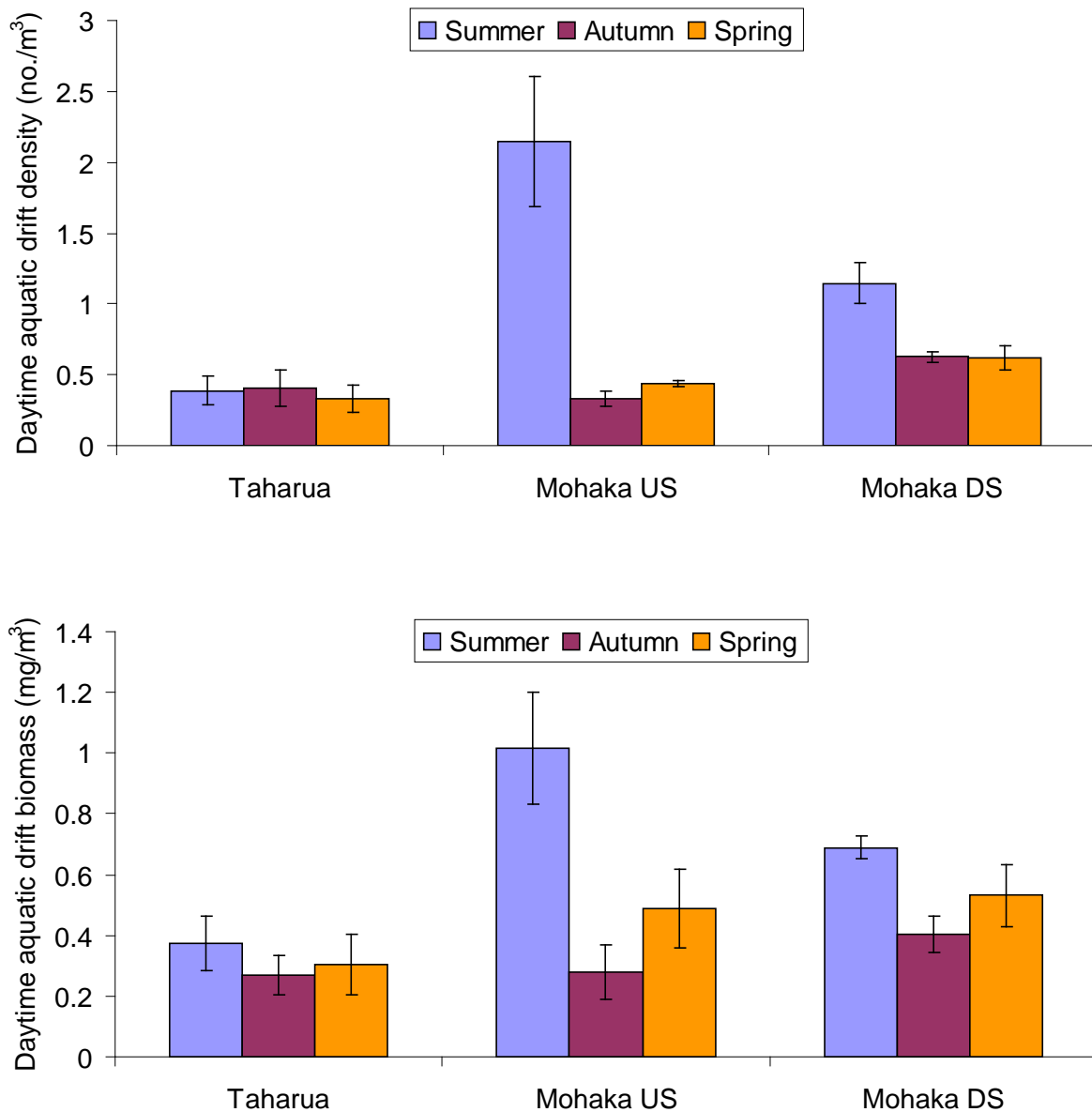


Figure 12. Daytime aquatic drift density and biomass for the Taharua, and upstream and downstream Mohaka sites in summer, autumn and spring. Error bars are standard errors.

In addition to overall biomass the size structure of drift also influences trout growth potential. Small invertebrates dominated the drift at all of the sites, which is typically found in other rivers. However, the prey size fraction >6 mm is much more relevant to trout growth potential than smaller prey. Densities of invertebrates greater than 6 mm were highest in spring followed by autumn and then summer at all sites (Figure 13). The biomass of invertebrates >6 mm was higher in summer than autumn at the two Mohaka River sites, but the reverse applied for the Taharua. At all the sites, the biomass of large invertebrates (>6 mm) was

greatest in spring compared to the other seasons (Figure 13). Small invertebrates dominated the drift at all of the sites, which is typically found in other rivers.

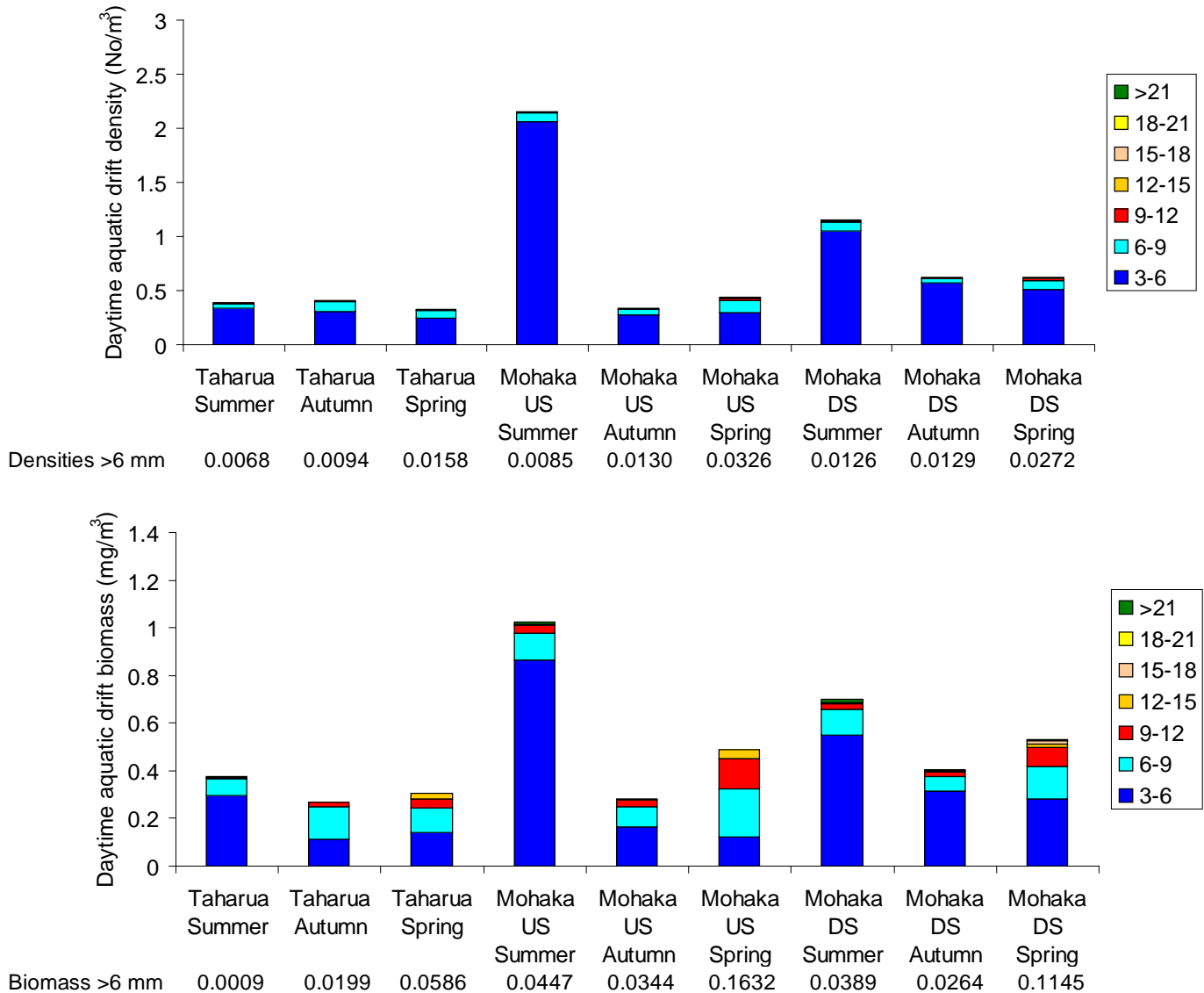


Figure 13. Daytime aquatic drift density and biomass expressed in terms of invertebrate size class for the Taharua, and upstream and downstream Mohaka sites in summer, autumn and spring. Density and biomass for invertebrates greater than 6 mm are given for each site and season below the graphs.

3.5. Trout growth modelling

The GREI and NREI results for summer, autumn and spring are presented in the following sections. These predictions are based on trout being able to forage on only aquatic invertebrates, since this is the component of drift that will be most affected by changes in water quality as a result of dairying activities. The calculation of GREI and NREI in the body

of the report was based on standardised temperature means, as temperature can be a major factor influencing trout growth potential, and we were interested in how changes in food only would influence growth potential. Standardised temperatures were calculated by averaging across the daily site temperatures on each sampling occasion (*i.e.* so the same daily temperature was used for modelling at all three sites).

Seasonal modelling results for GREI/GRECmax and NREI, based on site specific water temperatures, contrasting the influence of aquatic and total (aquatic + terrestrial) drift within rivers are presented in Appendices 3-5). Seasonal GREI and NREI predictions based on site-specific temperatures and only aquatic invertebrate drift between rivers are provided in Appendix 6. Although aquatic drift is the main focus in these results, the terrestrial component of drift can strongly influence trout growth potential in some rivers and seasons. Seasonal predictions of GREI and NREI for total (aquatic + terrestrial) drift based on standardised and site-specific temperatures are provided in Appendices 7 and 8, respectively. Overall, there was very little difference in GREI and NREIs calculated using standardised temperatures compared to site-specific temperatures.

The average site temperature over the February modelling period was 12.6°C in the Taharua, 15.0°C at the downstream Mohaka site, and 15.4°C at the upstream Mohaka site. The average site temperatures in the April modelling period were very similar between sites, ranging from 10.2 to 10.4°C. In December, the average temperature in the Taharua was 11.7°C, and 13.2°C at both Mohaka River sites.

3.5.1. Interpretation of GREI/GRECmax and NREI

Figures 14, 16 and 18 show predicted GREI for drift-feeding trout as a proportion of the maximum potential gross rate of energy consumption (GRECmax). When GREI/GRECmax = 1, then theoretically trout are ingesting all the food that can be physically processed at the modelled water temperature. When this ratio is less than 1, it indicates that trout are food limited.

Predicted NREI for each site is shown in Figures 15, 17 and 19. As trout increase in size, the energy costs of foraging on drift increase because drag is higher and energy return for effort is less. Large trout will also drop the smallest size classes from their diet (partly because they slip through their gill rakers). Hence NREI can be expected to decline as fish grow beyond a certain threshold for the site.

Predicted GREI/GRECmax and NREI at each site was highest for 10 cm fish, as small trout can satiate quickly due to their smaller stomach size and their energy return for foraging effort is relatively high - even when feeding on small prey. Predicted GREI/GRECmax and NREI for each site declined with increasing size, at least after 20 cm. (Figures 14 - 19).

3.5.2. GREI and NREI site comparison for February (summer)

Predicted GREI/GRECmax was lowest at the Taharua site and highest at the upstream Mohaka site for 10 cm trout (Figure 14). This was due to the differences in aquatic invertebrate drift between sites, with the Taharua having the lowest density and biomass in summer and the upstream Mohaka site the highest (Section 3.4). The modelling predicts that in the Taharua River trout >35 cm should be food limited, as indicated by GREI/GRECmax falling below 1 at this size. This threshold was not reached in the Mohaka downstream and upstream sites until trout were greater than about 50 and 60 cm, respectively (Figure 14).

There was an initial increase in NREI for trout between 10-30 cm at all the sites (Figure 15). The reason for this is mainly because the foraging model predicts that the foraging radius usually becomes optimal for fish between 20-30 cm. Trout in this size range are also still able to gain better energetic advantage from feeding on small invertebrate prey compared to larger trout (*i.e.* smaller trout have lower swimming costs (less drag) than large trout, they can get greater energy return for effort from capturing small prey) (Hayes *et al.* 2000). The steeper decline in NREI at each site after trout reach 60 cm in length is a function of the predicted minimum prey size selected by trout as they grow. The foraging model predicts that trout 70 cm in length (the next size modelled after 60 cm) are unable to ingest prey in the 3-6 mm size category. This is because as trout grow the space between the gill rakers increases and smaller prey items pass through instead of being retained.

Growth potential (NREI) was lowest in the Taharua, highest at the upstream Mohaka site, and intermediate at the downstream Mohaka site. The lower aquatic drift density at the Taharua site in summer was the reason for the low growth potential relative to the Mohaka River sites, as less energy was available for trout growth.

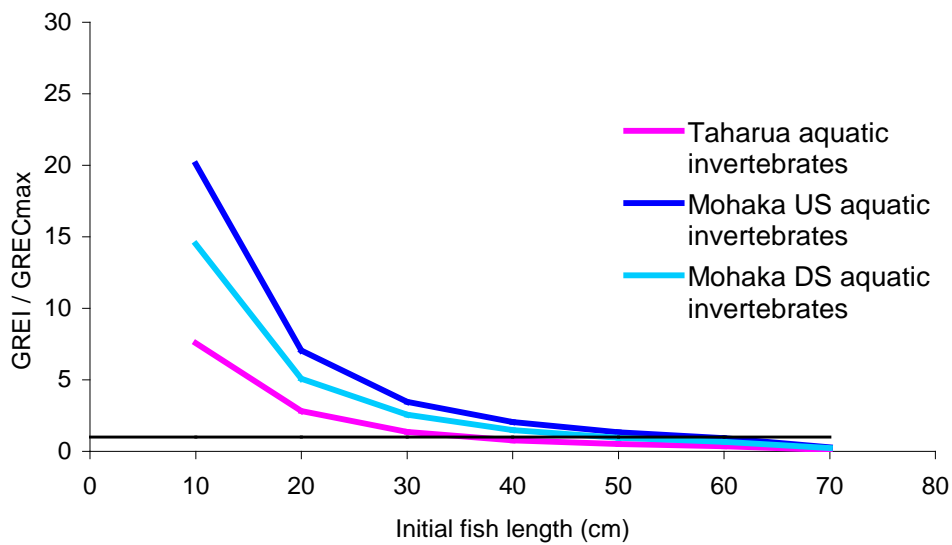


Figure 14. GREI/GRECmax predicted with the drift-foraging model for a range of size classes of brown trout in February 2009 for the Taharua and upstream and downstream Mohaka sites. Solid black line indicates $GREI/GREC_{max} = 1$, below which trout ought to be food limited. Predictions assume the following minimum prey length x fish length relationships: for 10 and 20 cm trout prey length (mm) = $0.115 \times$ fish length (in cm); for trout ≥ 30 cm prey length (mm) = $0.115 \times$ fish length (in cm) - 3 mm.

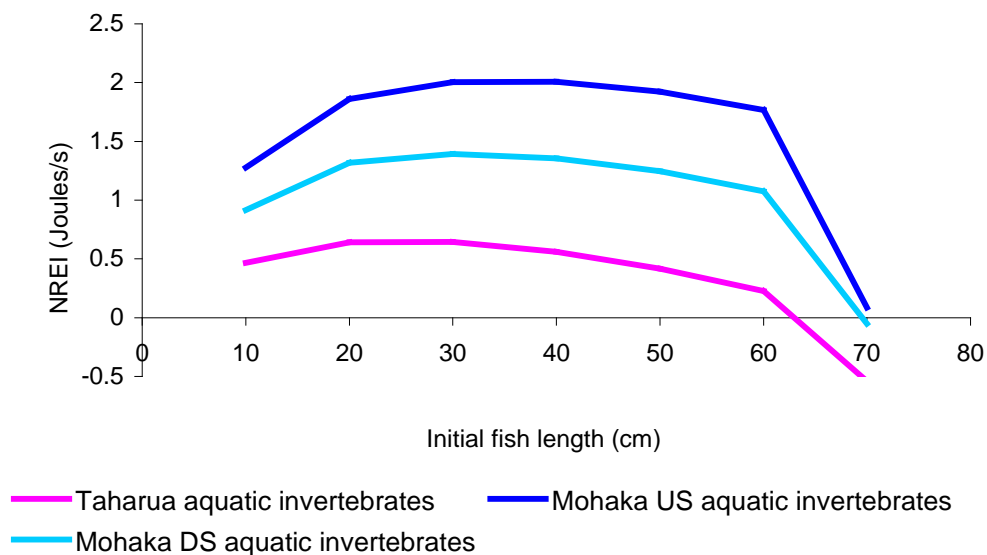


Figure 15. NREI predicted with the foraging model for a range of size classes of brown trout for February 2009 for the Taharua and upstream and downstream Mohaka sites. Predictions assume the same minimum prey length x fish length relationships as described in Figure 14.

Overall, in summer the sites with the greatest predicted food limitation and lowest growth potential were at the two affected sites - the Taharua site, followed by the Mohaka downstream site.

3.5.3. GREI and NREI site comparison for April (autumn)

In autumn, GREI/GRECmax was lowest for 10 cm trout at the upstream Mohaka site and highest at the downstream Mohaka site (Figure 16). However, the magnitude of differences in GREI/GRECmax values between sites in autumn was less than for summer. Drift densities and biomass estimates were more similar between sites in autumn than in summer (see Section 3.4). The model predicted that trout greater than 50 cm would be food limited ($\text{GREI/GRECmax} \leq 1$) at all sites (Figure 16).

NREI increased over the size range 10 to 30 cm, and remained positive over the entire modeled size range at all sites in autumn (Figure 17). In contrast to the summer results, NREI in autumn was lowest at the upstream Mohaka site, highest at the downstream Mohaka site, and intermediate in the Taharua. As for the summer results the differences in aquatic drift density between the sites accounted for the differences between growth potential predictions for each site.

Compared to the summer results the overall difference in NREI between the sites was less in autumn (compare Figures 15 with 17). This was because compared to summer the drift density, size structure and temperatures between the sites were relatively similar in autumn.

In Figure 17, differences in rate of decline in NREI at each site for 70 cm compared with 60 cm trout is a reflection of the relative differences in biomass of the 3-6 mm drift size class at each site. In autumn, the 3-6 mm invertebrate drift size class at the downstream Mohaka site comprised almost 80% by biomass, 58% by biomass at the upstream Mohaka site and 42% by biomass in the Taharua (Figure 9).

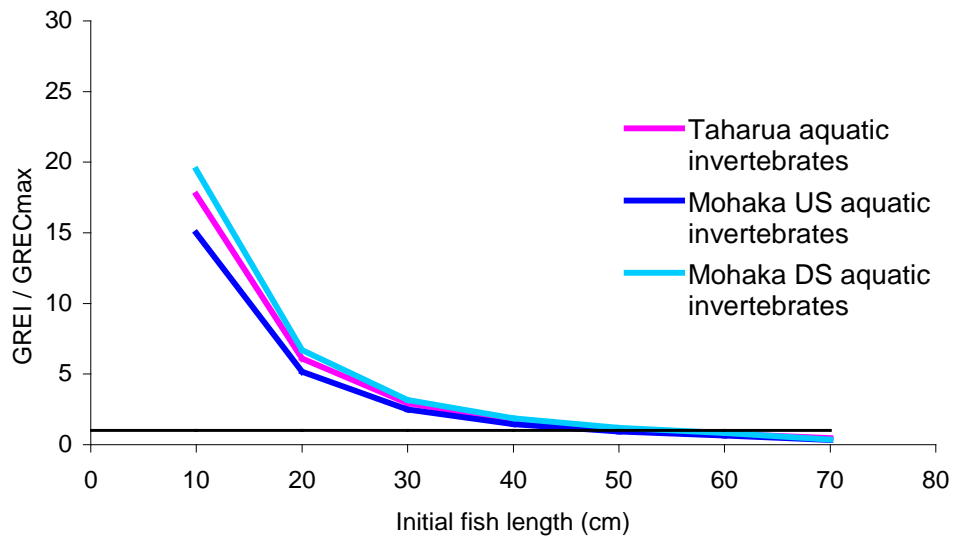


Figure 16. GREI/GRECmax predicted with the drift-foraging model for a range of size classes of brown trout for April 2009 for the Taharua and upstream and downstream Mohaka sites. Solid black line indicates GREI/GRECmax = 1, below which trout ought to be food limited. Predictions assume the same minimum prey length x fish length relationships as described in Figure 14.

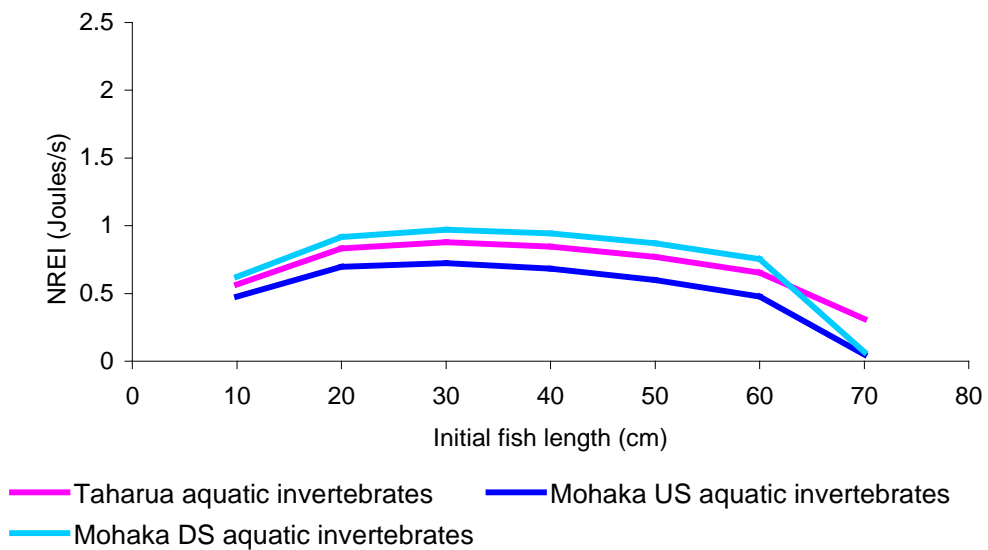


Figure 17. NREI predicted with the foraging and model for a range of size classes of brown trout for April 2009 for the Taharua and upstream and downstream Mohaka sites. Predictions assume same minimum prey length x fish length relationships as described in Figure 14.

3.5.4. GREI and NREI site comparison for December (spring)

In spring, GREI/GRECmax was lowest for 10 cm trout at the Taharua site, compared to the Mohaka downstream and upstream sites, which both had a similar GREI/GRECmax (Figure 16). As seen in the previous seasons, this was due to the comparative differences in aquatic invertebrate density for each site. The magnitude of differences in GREI/GRECmax values was much greater between the Taharua site and the Mohaka sites than was seen in autumn and summer. Although there was little difference in overall drift densities and biomass estimates between the sites in spring, the density and biomass of large (>6 mm) invertebrates in both Mohaka sites was approximately double that of the Taharua (see Section 3.4). The model predicted that in the Taharua trout greater than 45 cm would be food limited (GREI/GRECmax ≤ 1), while trout in both Mohaka River sites would not be food limited until they reached >65 cm (Figure 16).

NREI was positive and increasing for trout between 10 and 30 cm in length at all sites in spring (Figure 17), and continued increasing until about 40 cm at the two Mohaka sites, for the reasons given in Section 3.5.2. The order of NREI predictions in spring were similar to summer, with lowest NREI predicted for the Taharua and highest NREI for the upstream Mohaka site.

There was a much larger difference in NREI between the Taharua and Mohaka sites in spring than in the other seasons (compare Figures 15 and 17 with Figure 19). This was because the drift density of large invertebrates in the Taharua River was considerably lower than the Mohaka sites in spring than in autumn and summer.

Overall drift density was higher at the downstream Mohaka site than the upstream site. However, the NREI at the upstream Mohaka site was higher than at the downstream Mohaka site. The greater density *and* biomass of large invertebrates (>6 mm) at the upstream site again explains this result.

Overall, in spring (as in summer) the sites with the greatest predicted food limitation and lowest growth potential were at the two affected sites - the Taharua site, followed by the downstream Mohaka site.

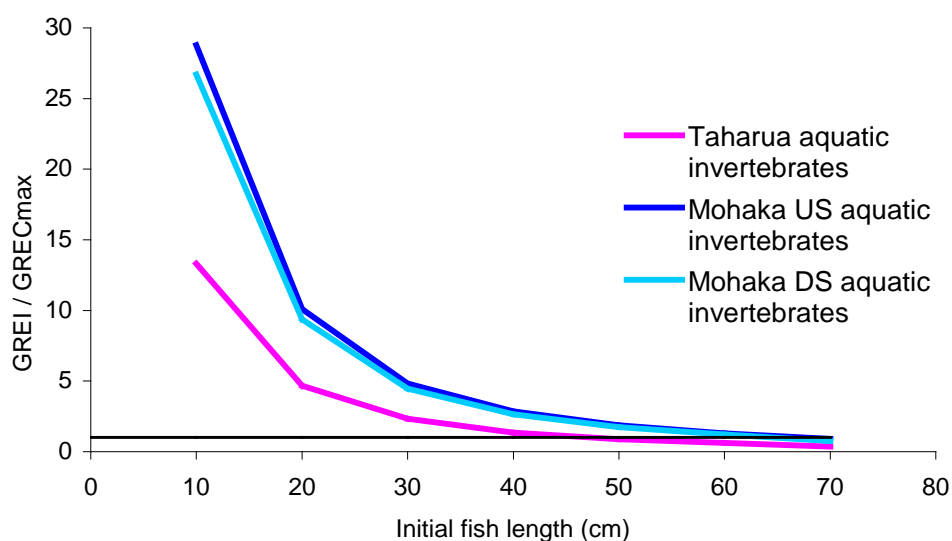


Figure 18. GREI/GRECmax predicted with the drift-foraging model for a range of size classes of brown trout for December 2009 for the Taharua and upstream and downstream Mohaka sites. Solid black line indicates GREI/GRECmax = 1, below which trout ought to be food limited. Predictions assume the same minimum prey length x fish length relationships as described in Figure 14.

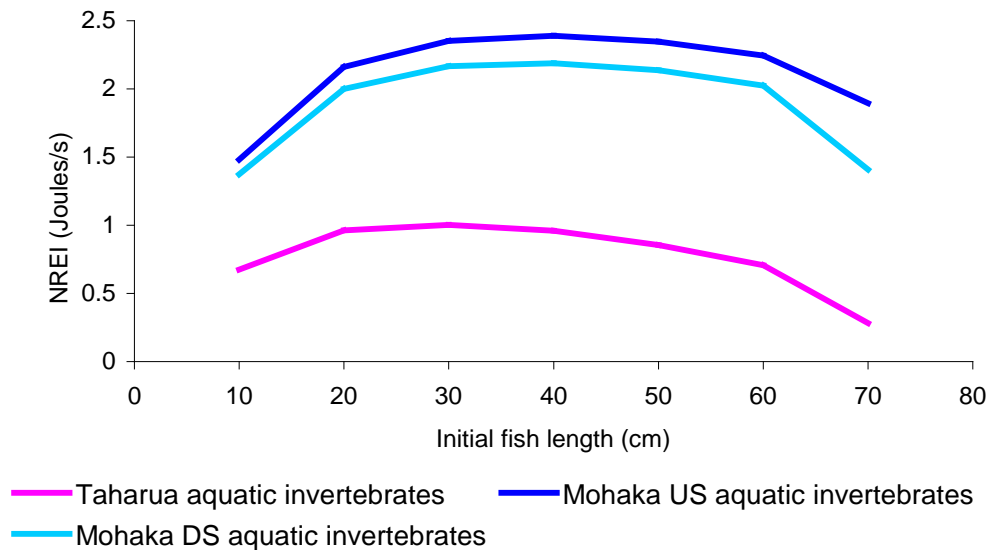


Figure 19. NREI predicted with the foraging and model for a range of size classes of brown trout for December 2009 for the Taharua and upstream and downstream Mohaka sites. Predictions assume same minimum prey length x fish length relationships as described in Figure 14.

3.5.5. Comparison of GREI and NREI modeled on aquatic drift vs. aquatic and terrestrial drift

Predictions of GREI and NREI based on aquatic and terrestrial invertebrate drift using standardised temperature are provided in Appendix 7. As expected, the addition of the terrestrial component of invertebrate drift resulted in increases in GREI/GRECmax and NREI across the fish sizes in all seasons. The inclusion of terrestrial drift also resulted in trout being less food limited, and the predicted trout growth potential remaining positive across all the trout size classes.

In summer and spring the order of the sites from highest to lowest for GREI/GRECmax and NREI remained the same when terrestrial invertebrate drift was included in the analysis. Furthermore, there was little difference in the magnitude of NREI between sites when comparing the aquatic, and aquatic plus terrestrial drift results. However, this was not the case in autumn.

In autumn, the order of sites from least food limited to most food limited for trout feeding on only aquatic invertebrates was: upstream Mohaka<Taharua< downstream Mohaka (Figure 16). However, the order of sites when terrestrial invertebrates were included was: upstream Mohaka<downstream Mohaka< Taharua (Figure A7.2.1).

The magnitude of difference in GREI/GRECmax and NREI between sites was small when the modelling was confined to aquatic invertebrates. However, when terrestrial drift was included, NREI in the Taharua was much greater than the Mohaka River sites (compare Figures 16 and A7.2.2).

These differences in model predictions with and without inclusion of terrestrial invertebrates in autumn were due to the sensitivity of the trout model to the presence of large, heavy invertebrates. In autumn, a single large (~25 mm) predatory terrestrial Carabid beetle was collected at the Taharua site. The trout growth modelling results shown in Appendix 7.2 included the carabid beetle. When the modelling was repeated without this beetle the order of sites from least food limited to most food limited *and* the magnitude of difference in GREI/GRECmax and NREI between sites was very similar to the modelling results based on only aquatic drift.

3.5.6. Effect of changes in turbidity on NREI

The influence of turbidity on NREI at each site was modelled for a 50 cm trout and the results for each season are shown in Figures 20 and 21.

The decreasing trend in trout growth potential (see Figures 20, 21 and 22), occurs because the prey reaction distance, and hence foraging radius and area, decreases with increasing turbidity, resulting in a reduction in energy intake (through reduced prey detection and capture).

NREI is most sensitive to changes in turbidity at very low turbidities (<2 NTU) (Figures 20, 21 and 22). Above 2 NTU there is a smaller rate of decline in NREI with increasing turbidity.

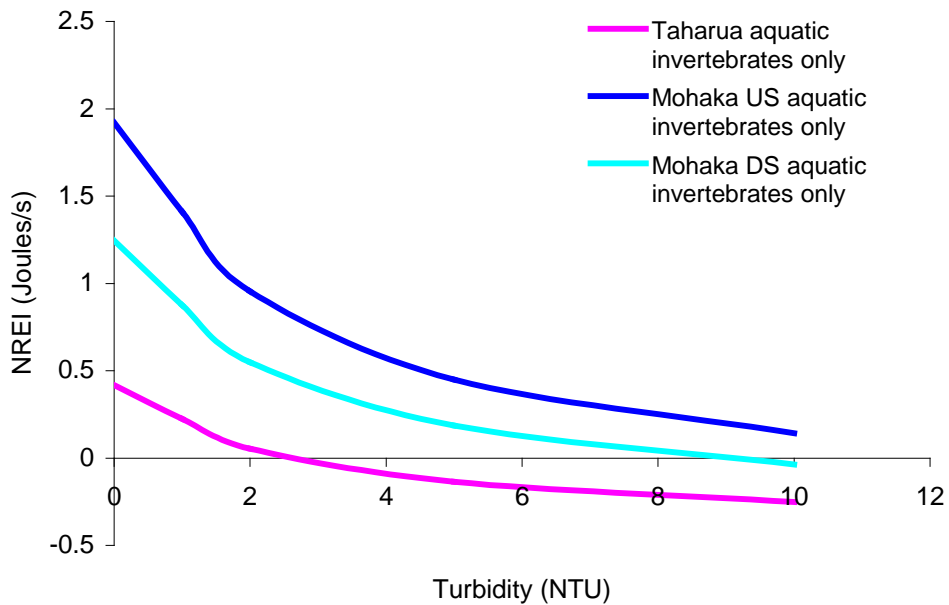


Figure 20. Predicted NREI versus turbidity for a 50 cm brown trout for February 2009 in the Taharua and upstream and downstream Mohaka sites. Predictions assume the same minimum prey length x fish length relationships as described in Figure 14.

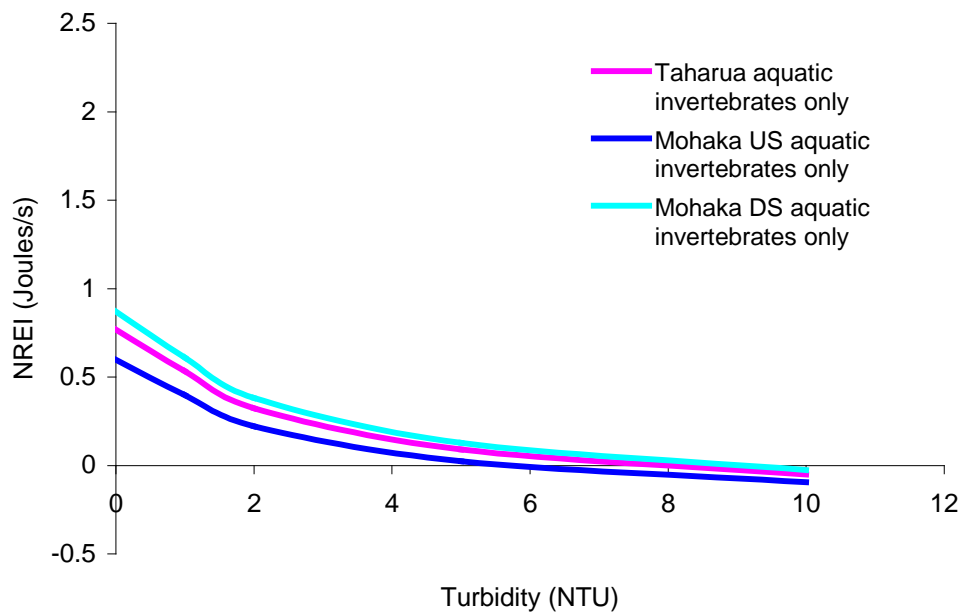


Figure 21. Predicted NREI versus turbidity for a 50 cm brown trout for April 2009 in the Taharua and upstream and downstream Mohaka sites. Predictions assume the same minimum prey length x fish length relationships as described in Figure 14.

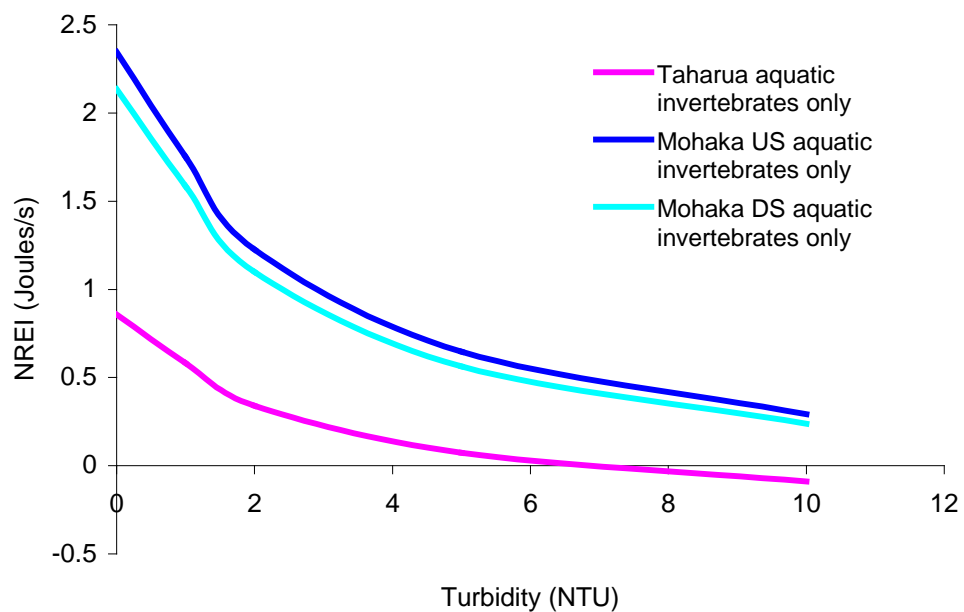


Figure 22. Predicted NREI versus turbidity for a 50 cm brown trout for December 2009 in the Taharua and upstream and downstream Mohaka sites. Predictions assume the same minimum prey length x fish length relationships as described in Figure 14.

4. DISCUSSION

4.1. Invertebrate drift

Summer was the only time a statistical difference in drift density or biomass was detected between sites. Biomass was highest at the upstream Mohaka site and lowest in the Taharua. Although there was less difference in drift biomass between sites at other seasons, drift size structure should also be considered because it has an important influence on trout growth potential. In particular, large invertebrates contribute disproportionately to GREI and NREI. Unfavourable size structure can be compensated by favourable biomass and *vice versa*, or favourable size structure can contribute positively to growth potential when there is little difference in overall biomass. For example, in summer although there were proportionately more small invertebrates (3-6 mm) (least preferred by adult trout) at the upstream Mohaka site this was compensated by high biomass which contributed to highest GREI and NREI at that site. In spring, although overall biomass was statistically similar between sites, the greater proportion of invertebrates > 9 mm at the upstream Mohaka site contributed to GREI and NREI being highest at this site.

There was an indication of a seasonal trend of highest drift density and biomass in summer in the Mohaka sites. Shearer *et al.* (2002) suggested that a seasonal trend in drift biomass (or density) that they recorded in the Maruia River was due to thermal influence on activity and emergence rates of invertebrates. There is less seasonal variation in water temperatures in spring-fed than run-off fed rivers and this may explain why the invertebrate drift biomass (and density) varied little between seasons in the Taharua. Death & Winterbourn (1994) also found that relative abundance of invertebrates was less seasonally variable at sites with more stable water temperature.

The two dairy influenced sites (Taharua and downstream Mohaka) had more small true flies and algal piercing caddis (*Oxyethira*) than the Mohaka reference site. These taxa thrive where algae proliferate in association with nutrient enrichment from agricultural enrichment. There were also similarities in invertebrate community structure between the upstream and downstream Mohaka River sites (*e.g.* there was a greater proportion of caddis flies in summer and spring, and stoneflies in autumn in the Mohaka sites than in the Taharua).

In general, Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddis flies), (known collectively as EPT taxa), are sensitive to nutrient enrichment and siltation (*i.e.* most prefer clean-water conditions). For this reason the proportion of EPT taxa in an aquatic invertebrate community is commonly used to assess stream health. Large EPT taxa are also preferred prey items for trout (see Section 4.2). The EPT taxa were an important part of invertebrate drift communities in the Taharua and Mohaka rivers. Although the contributions of each individual order varied between sites and across seasons, the proportion of EPT taxa was always higher at the upstream Mohaka site than the two affected sites indicating a healthier environment for stream communities (invertebrates and fish) upstream of the Taharua River. Also the highest proportion of mayflies occurred at the upstream Mohaka site at dusk in

all three seasons, although not always during the day. This is also consistent with enrichment at the Taharua and downstream Mohaka sites.

Our study focused on invertebrate drift because we have made models that allow drift to be interpreted in terms of its suitability and productivity for drift feeding trout. However, most aquatic invertebrate monitoring focuses on benthic invertebrates. Monitoring of benthic invertebrates in the Mohaka River has shown a decline in community health (*e.g.* MCI) downstream of the Taharua confluence compared to upstream for summer (HBRC 2008). Unfortunately, currently there is no index (other than percentage EPT) that allows interpretation of benthic invertebrate data in terms of its suitability and productivity as food for fish. In this regard, a comparative analysis of benthic and drifting invertebrate data among rivers would be informative, as features of drift such as density, taxonomic and size structure are dependent on benthic invertebrate communities (*e.g.* McLay 1968; Lehmkuhl & Anderson 1972; Hildebrand 1974; Statzner *et al.* 1987; Sagar & Glova 1992; Siler *et al.* 2001). Quinn and Hickey (1990) found that rivers with a greater proportion of their catchment in developed pasture had higher periphyton biomass and proportionately less free-drifting invertebrate taxa and more small, attached or burrowing taxa. Trout prefer large drifting invertebrates. Changes in benthic taxonomic composition and density can provide insights on the effects of dairying on the food supply for drift-feeding fish. However, interpretation of the value of benthic invertebrates as trout food depends on their availability *i.e.* whether they readily enter the drift or are able to be seen and browsed off the substrate by trout. A benthic invertebrate trout food index would need to take points such as this into consideration.

Relationships between the benthos and drift are not necessarily straightforward either. A study by Shearer *et al.* (2003) found that high periphyton biomass in the lower Pomahaka River (a river affected by agriculture) was associated with comparatively high benthic invertebrate biomass, not only of small algal associated taxa but also of *Deleatidium*. Although there were proportionately fewer *Deleatidium* in the benthos (an expected result of enrichment and algal proliferation), total *Deleatidium* density and biomass was nevertheless higher than at less enriched sites with lower algal biomass. On face value this suggested better feeding opportunities for trout. But Shearer *et al.* also found that the high algal biomass was associated with reduced propensity for *Deleatidium* to drift. In other words, although benthic sampling may indicate higher biomass of invertebrates, including favoured trout prey, their behaviour may make them less available to trout in the drift. Shearer *et al.*'s study has important implications for trout rivers, as it suggests that benthic community assessments alone may not provide a true indication of potential food-related effects of land intensification on predominantly drift-feeding fish. No algal samples were taken during our study of the Taharua and Mohaka rivers. However, there is anecdotal and biomonitoring evidence to suggest that summer algal biomass is greater in the Mohaka downstream of the Taharua confluence than upstream, and that algal proliferation below the Taharua began after the dairy conversions (see HBRC 2008). Frequent clogging of our drift nets by algae was common at the downstream Mohaka site and Taharua site in summer – which is consistent with algal proliferation. Pending future research funding, further progress on understanding the relationships between periphyton biomass and drifting behaviour of aquatic invertebrates

would be facilitated by synchronising drift, benthic invertebrate, and periphyton biomass (chlorophyll *a* and AFDW) assessments.

4.2. Predicted GREI and NREI

The feature of invertebrate drift that most influences GREI and NREI is size-structured biomass. GREI and NREI will increase with increasing drift biomass and increasing proportion of large invertebrates. An appreciation of these points helps interpretation of site and seasonal comparisons of drift and associated GREI and NREI.

The greatest variation in GREI and NREI between sites occurred in summer. In summer the site with the greatest energy available from aquatic drift for trout was the upstream Mohaka reference site followed by the downstream Mohaka site, with the least energy available at the “affected” Taharua site. The poorer summer drift at the Taharua site ought to result in trout greater than 40 cm being food limited ($\text{GREI}/\text{GREC}_{\text{max}} < 1$) and exhibiting the lowest growth of the three sites.

By contrast, in autumn the energy available to trout from the drift was relatively similar between sites. This resulted in food limitation predicted at similar size (*c.* 50 cm, Figure 14) among the sites, and little relative difference in predicted NREI between the sites. And the two affected sites (downstream Mohaka followed by Taharua) were predicted to have better feeding and growth potential than the upstream (reference) Mohaka site.

The energy available to trout from the drift in spring followed a similar pattern to summer, being highest at the upstream Mohaka site and lowest at the Taharua site. The lower drift at the Taharua site ought to result in trout greater than 45 cm being food limited ($\text{GREI}/\text{GREC}_{\text{max}} < 1$) and trout having the lowest growth potential (NREI) of the three sites.

In summer, aquatic invertebrate drift biomass in the Mohaka immediately below the Taharua confluence was impaired relative to the upstream reference site such that drift feeding trout growth potential would be adversely affected. Although there was no reference site in the Taharua, drift biomass and related trout growth potential was even lower in that river in summer, consistent with the gradient of potential dairy effects. However, there are natural physical differences between the rivers which could contribute to this pattern. The most obvious confounding factor is the mobile pumice sand bed in the Taharua, but which itself could be exacerbated by human-induced land disturbance in the catchment. The mobile bed ought to result in fewer species, fewer EPT taxa and lower densities over most of the bed. Deposition of pumice sand from the Taharua in the Mohaka immediately below the confluence could contribute to impaired invertebrate communities there. Some attention should be given to the significance of this potential confounding influence in HBRC’s benthic monitoring. Stable flow in the Taharua may promote periphyton proliferation on stable substrates *e.g.* submerged riparian vegetation. However, this would most likely occur in response to elevated nutrients as has occurred with dairy intensification in the catchment.

While on the subject of confounding factors, the proximity of the sampling locations to the Taharua confluence also needs some consideration when interpreting the impaired drift and growth potential at the downstream Mohaka site in summer. Specifically, could this result simply be due to us sampling Taharua drift still in suspension at the downstream Mohaka site? In other words, since the Taharua drift density was lower than that recorded in the Mohaka upstream of the confluence, could the Taharua water have diluted our estimates of drift density at the downstream Mohaka site? We think this is unlikely. The mean location of the three drift samplers at the downstream Mohaka site was 430 m below the Taharua confluence, whereas research elsewhere indicates invertebrates drift in the order of 10s of metres (McLay 1970; Elliott 2002). Hence, the drift that we were sampling at the downstream Mohaka site will be influenced mainly by benthic invertebrates and associated benthic conditions (*e.g.* periphyton and substrate composition and hydraulics) in the vicinity of the samplers.

In autumn there was little variation in GREI and NREI. In spring the between site variation in GREI and NREI was driven by size structure of the drift rather than by overall biomass. The pattern (ranking) between sites was similar to that in summer, but the adverse influence of the Taharua on the downstream Mohaka site was more muted.

When assessing food limitation it is important to account for the dependence of maximum potential consumption on water temperature. Because of this dependence lower food availability in one river relative to another may be compensated by lower water temperature *i.e.* because of lower consumption demand. Unless the influence of temperature is factored out of the analysis, it is not possible to determine whether food or temperature is limiting growth. We achieved this by standardising temperature across the three sites. Nevertheless, there was very little difference between the food limitation and growth potential predictions based on site-specific temperatures (Appendix 6) and standardised temperatures (sections 3.5.2-3.5.4).

In summer, the water temperature in the Mohaka River was at least 2.4°C higher than in the Taharua. This ought to have some subtle, but interesting, consequences for trout growth. In terms of food limitation, the cooler water in the Taharua will partially make up for the poorer aquatic invertebrate drift supply, thereby reducing consumption demands and the metabolic costs of foraging. That is, owing to temperature dependent processing limitations, trout in the Taharua will not need as much food as trout in the warmer Mohaka in summer. But this also means that the scope for growth over summer in the Taharua may not be as great as in the Mohaka. The Taharua should be comparatively warmer than the Mohaka in winter (owing to groundwater influence), and this may partly compensate for reduced summer growth potential there; although low temperatures generally in winter means that this season usually makes a minor contribution to annual growth. Notwithstanding temperature-dependent processing constraints, large trout in the Taharua ought to be able to grow faster, and attain a greater maximum size if drift biomass was higher than we measured in summer. In autumn, there was only a 0.2°C temperature difference between sites, so relative differences in trout growth are more likely to be food than temperature related.

Our study focussed on drift feeding. Other potential prey and foraging strategies may be employed by trout to supplement an aquatic invertebrate drift diet. These include foraging on: drifting terrestrial invertebrates, benthic invertebrates (*i.e.* directly off the river bed), fish prey (piscivory), and mice. An insight into the diet of 66 brown trout in the Mohaka River system (including the Taharua River) is provided by McLennan and MacMillan (1984). They found caddis fly larvae and mayfly nymphs were the main prey items of brown trout. Stoneflies increased in importance in winter, and terrestrial insects from November to April. Caddis flies, mayflies and stoneflies also comprised the bulk of the invertebrate drift collected in our study (see discussion on EPT taxa in section 4.1). McLennan and MacMillan did not directly observe trout browsing on benthic invertebrates. However, they did record the common snail *Potamopyrgus* (a non-drifting invertebrate) in trout stomachs collected from the Taharua River which confirms that benthic browsing does occur. They concluded that piscivory was rare. The majority of their trout were >40 cm (big enough to prey on fish) yet only one small fish was eaten. Overall, McLennan and MacMillans (1984) results strongly support our supposition that drift feeding would be the main foraging strategy of trout in the Mohaka and Taharua rivers.

In McLennan & MacMillan's study terrestrial invertebrates were eaten by 9% of brown trout. However, they pointed out that the contribution of terrestrial drift by weight and therefore energy value was substantially greater because they were generally much larger than aquatic insects. Our modelling predictions included terrestrial invertebrate drift (see Appendices 3, 4 and 5) and demonstrated that, at least in February, April and December, it could have a substantial positive effect on trout growth potential, especially in the Taharua – highlighting the importance of stable, vegetated, riparian margins.

The contribution of terrestrial invertebrates to overall drift can be highly variable seasonally compared to aquatic drift, thus accurately assessing the influence of terrestrial drift on trout growth potential is problematical. Nevertheless, based on McLennan & MacMillans (1984) findings, it is clear that aquatic invertebrate drift is the primary food source for brown trout in the Mohaka and Taharua rivers - and it is this food source that is susceptible to land-use intensification down the length of the Taharua and into the Mohaka. Dairying may also have a localized adverse effect on terrestrial invertebrate supply to the drift to the extent that it reduces the scrub, bush and large grasses on the river's edge and surrounding land.

According to the modelling predictions with terrestrial invertebrate drift included in the diet, trout would not be food limited and would maintain positive NREI in the Taharua until they attained 60 cm or more in length. This appears to be inconsistent with the reports from anglers that trout size has declined in the Taharua since dairy conversion. Typical size of adult trout in backcountry rivers is 40 – 60 cm (Hayes 2002). Might this mean that *annual* food limitation in the Taharua is more severe than our drift samples suggest? Certainly closer consideration of this point is warranted but first we need to point out that NREI is not directly equivalent to growth rate. There are other demands on the trout's energy budget than just the energy cost in obtaining drifting prey which have a bearing on the maximum size a trout may attain. In the context of whole-life-time growth a very significant cost is the energy invested in reproduction

each year after maturity. This can be in the order of 46% for fast growing brown trout (Lien 1978). Allowing for this, and other costs, a 50 cm trout would need an NREI ≥ 1 in order to reproduce annually (Hayes *et al.* 2007). This threshold was exceeded for all three seasonal sampling occasions in the Taharua River for NREI predictions based on total drift.

The relaxing of the minimum prey size threshold (see methods section 2.3.2) in our modelling predictions will have contributed to overestimation of NREI. Trout ≥ 30 cm were assumed to eat prey 3 mm smaller than predicted by Wankowski's (1979) minimum prey size equation. This meant that whereas under the default minimum prey size threshold 40 - 60 cm trout could not eat the smallest drift size class modelled (3-6 mm (4.5 mm mid point)) under the relaxed minimum prey size class scenario they could. McLennan & MacMillan (1984) found that adult brown trout in the Mohaka and Taharua rivers consumed mainly prey items between 6-10 mm in length. We examined the effect of the relaxed minimum prey size class threshold by rerunning the model with the default minimum prey size equation and found that the minimum NREI threshold for annual reproduction was exceeded in autumn and spring but not in summer. So the evidence for the model overestimating observed size of trout in the Taharua is equivocal. More drift sampling (and diet analysis) would help resolve this matter.

Owing to the limitations of our sampling effort, the emphasis should be on our predictions of relative (*i.e.* comparison between sites) growth potential rather than magnitude.

4.3. Influence of turbidity on NREI

Agricultural activities have been strongly linked to increased turbidity in rivers (*e.g.* Quinn *et al.* 1997; Harding *et al.* 1999; Quinn & Stroud 2002). Turbidity relationships used in the brown trout foraging model have been used by the Ministry for the Environment to advise on the potential affects of turbidity associated with dairy farming (MfE 2009). Trout are mainly visual predators and increased turbidity (*i.e.* lower water clarity) is expected to have an adverse effect on them because it reduces their foraging area and foraging efficiency (see Figure 5 in Section 2.3.3). Hence trout spend more time (and energy) foraging in order to meet their food requirements (either by drift feeding or active searching).

We have provided empirical relationships and model predictions that can be used to predict how a change in turbidity will affect the aquatic energy available for trout growth in our study sites on a seasonal basis (Figures 5, 18, 19 and 20). An example of how an assessment of effects can be made for a 50 cm trout using Figures 18, 19 and 20) is given below.

Minimum, maximum and median turbidity measurements of 0.31, 8.53 and 1.26 NTU respectively have been recorded in the lower Taharua between 2000 and 2008 (MfE 2009). According to the turbidity/NREI relationships in Figures 20, 21 and 22 the minimum turbidity of 0.31 NTU would represent a 14% reduction in potential growth (NREI) of trout in the Taharua River in summer, a 10% reduction in autumn, and a 10% reduction in spring (assuming perfectly clear water as a baseline). For a worst-case scenario (*i.e.* a turbidity of

8.53 NTU), there would be a 152%, 101%, and 105% drop in NREI in summer, autumn, and spring, respectively.

Hayes & Hay (2006) indicated that the turbidity guidelines used in the past to interpret monitoring data for the Taharua River were (in their opinion) not stringent enough to assess effects on trout. The worked example above is not only a useful way of interpreting turbidity monitoring information to assess effects on trout, but would also aid in the development of turbidity guidelines more relevant to the protection of trout populations.

4.4. Future research

Drift densities and biomass vary significantly over time (seasonally and from day to day) and space (Shearer *et al.* 2002). Highest drift biomass occur in summer (Hayes *et al.* 2000) and this is also the time that is most critical for trout growth – owing to warmer water driving high consumption by trout. Thus, caution should be exercised in interpreting the three seasons of Taharua and Mohaka drift data and inferences from them concerning trout growth. Each “seasonal” data-set is based on only one day’s drift sampling. Moreover, we have not taken into consideration within-site spatial variation in the density, taxonomic and size structure composition of drift when comparing GREI and NREI predictions among sites. This would be required in order to make statistical comparisons of predicted growth among sites, but is a time-demanding task and would require further funding. On the other hand when there are statistically significant differences in drift biomass among sites, it is highly likely that differences in NREI will also be significant – since the errors in the empirical energetics equations in the foraging model are systematic (*i.e.* fixed), so apply equally to each site. Furthermore, the successful test of the drift foraging and bioenergetics growth model in the Maruia River, based on seasonal sampling (five occasions at three sites), demonstrates that robust growth predictions are possible with reasonable, targeted, sampling effort.

In this study, the effects on aquatic invertebrate drift of an agriculturally affected river (the Taharua) entering a river with no agricultural effects in the upper catchment (the Mohaka) have been assessed. However, the effect of dairying activities on aquatic drift and biomass along the Taharua River is unclear. This may warrant further investigation.

Assessment of the effects of dairying on trout populations in the Taharua and Mohaka would be usefully complemented by gathering information on trout populations themselves (*i.e.* in addition to modelling). Drift dive counts are one method of assessing trout populations, and some such data have already been collected. Comparisons of relative density and biomass of trout between the Taharua and Mohaka below and above the confluence would be useful. Actual size, condition and growth (size at age) data from these three sections would also be very useful and particularly as a complement to the NREI predictions. Trout otoliths and scales, paired with length and weight measurements, are required for estimating growth. Hawke’s Bay Fish & Game are in the process of collecting these data.

4.5. Conclusions

We found differences in invertebrate drift density and biomass between sites influenced by dairy farming and a reference site. Differences were also apparent across three seasons – summer, autumn and spring. In summer, when trout growth is greatest, drift density and biomass was significantly higher at the upstream Mohaka (reference) site. In autumn and spring there was no significant difference in density or biomass found between any of the sites.

Size structural differences between the sites and across the seasons were also apparent. Small invertebrates, least preferred by large trout, made up a larger proportion (by density and biomass) of the drift at the sites affected by dairying inputs (Taharua and downstream Mohaka sites). In all seasons, the upstream Mohaka reference site had the greatest density and biomass of large invertebrates (>6 mm), which are preferred by trout. An exception was in summer where the density, but not biomass, of large invertebrates was highest at the downstream Mohaka site.

We found taxonomic differences in the drift between sites affected and unaffected by dairying in the Taharua and Mohaka rivers in all three seasons. On all sampling occasions the upstream Mohaka site had the greatest proportion of EPT taxa. The highest proportion of mayflies occurred at the upstream Mohaka site at dusk in all three seasons (when trout feeding activity is often at its peak).

Our results, at least for summer and to some extent spring, were consistent with effects on invertebrates and trout expected from dairy farming in the Taharua and extending downstream to below its confluence with the Mohaka River, complementing conclusions from HBRC monitoring.

We found differences in GREI and NREI (indices of trout food availability and trout growth, respectively) between sites and season. In summer, predicted GREI and NREI were highest at the upstream Mohaka reference site, followed by the downstream site and Taharua, respectively – mirroring the pattern in aquatic invertebrate drift biomass (and density). In autumn, there was little difference in GREI between any of the sites. In spring the order of sites from highest to lowest GREI and NREI was the same as summer - mirroring the pattern in the proportional contribution of large invertebrates to the spring aquatic drift biomass.

We have also presented modelling evidence demonstrating that drift-feeding trout are very sensitive to reductions in water clarity and that minimum and maximum recorded turbidity levels in the Taharua River potentially limit trout growth.

Our results provide evidence for impaired aquatic invertebrate drift and trout growth potential at dairy-influenced sites in the Mohaka and Taharua Rivers in summer and to a lesser extent in spring. However, our results should be interpreted with caution as they are based on only three days sampling over three seasons. Moreover, although our results are consistent with effects expected from dairy farming (enrichment and/or siltation) definitively attributing cause to

dairy farming is limited by the absence of a reference site in the Taharua and pre-impact data. Furthermore, there are natural physical factors that may also be a confounding factor *e.g.* the mobile pumice bed in the Taharua and perhaps stable flow. Nevertheless, our results should be viewed in the context that biomonitoring has shown that water quality has been declining since dairy conversion in the Taharua catchment. Our study complements this effort and reveals the consequences of the current situation (drift and turbidity status) on the growth potential of drift feeding trout in dairy influenced sites.

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7. APPENDICES

Appendix 1. The drift foraging model concepts.

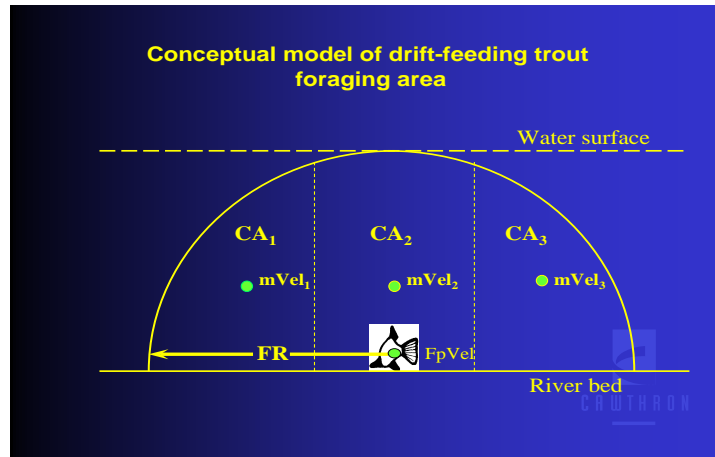


Figure A1.1. The drift foraging model is based on this conceptual model of a trout's drift foraging area (cross-sectional view looking upstream). The foraging model uses equations based on fish size and prey size to predict the foraging radius (FR) and hence the foraging area (foraging area is calculated for each size class in the drift). Optimal mean column water velocity ($mVel_2$) is estimated for a given sized fish with an empirical regression from the literature, and adjacent velocities ($mVel_1$, $mVel_2$) are estimated from information on velocity differentials across which trout feed while drift feeding (from Hayes & Jowett 1994). Predictions of the size dependant foraging area (sum of CA_1 , CA_2 , CA_3 sub areas), velocities within the foraging area, and drift density allow prediction of rate of drift delivery to the fish. Prey capture is restricted to a subset of prey falling within predicted maximum and minimum prey sizes which are limited by mouth gape, foraging cost benefit relationships, and gill raker spacing (Wankowski 1979; Bannon & Ringler 1986). The relationship for minimum prey length (in mm) is $0.115 \times$ fish length (in cm) (Hayes 2000; Hayes *et al.* 2000). Knowledge of the feeding efficiency of large drift-feeding brown trout allows prediction of gross rate of energy intake (Hughes *et al.* 2003 found that large brown trout capture 56% of suitable prey drifting through their foraging area). When foraging and metabolic costs are subtracted (using metabolic equations), net rate of energy intake (NREI) can be predicted which is converted into growth using an energy-weight relationship for trout. Modelling is carried out at a daily time step.

Appendix 2. Densities (no.m³) for day and dusk drifting aquatic invertebrate taxa in 3 mm size classes over all samples from the Mohaka and Taharua rivers in February, April and December 2009.

Table A2.1 Scientific names and common names of the main invertebrate groups collected in drift samples from the Mohaka and Taharua rivers in February and April 2009.

Scientific nomenclature	Common name
Annelida	Worms
Arachnida	Spiders
Blattodea	Cockroaches
Coleoptera	Beetles
Diplopoda	Millipedes, centipedes
Diptera	Flies
Ephemeroptera	Mayflies
Hemiptera	Bugs
Hymenoptera	Wasps, bees
Isoptera	Termites
Lepidoptera	Moths, butterflies
Megaloptera	Dobsonflies
Mollusca	Snails
Nematoda	Roundworms
Nematomorpha	Gordian "horse-hair" worms
Neuroptera	Lacewings
Odonata	Dragonflies, damselflies
Orthoptera	Crickets
Plecoptera	Stoneflies
Trichoptera	Caddis flies

Please note these notations in the following tables of day and dusk aquatic densities:

- ¹ beside an invertebrate group heading indicates that densities were aquatic in origin but identified no further than the Order level as they were in the terrestrial (adult) phase of their life cycle. These animals were included in the analyses of aquatic drift and for any trout modelling based on aquatic drift.
- ² beside an invertebrate group heading indicates that densities were terrestrial in origin.

Table A2.2 Densities (no.m³) for day drifting aquatic invertebrate taxa in 3 mm size classes over all samples from the Taharua River site, February 2009.

Day total drift taxa	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	66-69	114-117	117-124	124-126	129-132	132-135
Ephemeroptera ¹	0.007	0.022												
<i>Austroclima</i>	0.005	0.002												
<i>Deleatidium</i>	0.055	0.006												
<i>Nesameletus</i>	0.004	0.002												
<i>Zephlebia</i>	0.011													
Plecoptera ¹	0.007	0.007												
<i>Zelandobius</i>	0.010	0.004												
<i>Zelandoperla</i>	0.004	0.002												
Megaloptera														
<i>Archichauliodes</i>	0.002	0.002												
Coleoptera ²	0.258	0.027	0.002											
Dytiscidae	0.012	0.002												
Elmidae	0.385	0.006												
Diptera ²	0.039	0.002		0.005										
Anthomyiidae	0.002		0.004											
<i>Austrosimulium</i>	0.024													
Chironomidae	0.002													
<i>Chironomus</i>	0.015	0.007	0.005	0.002										
<i>Ephydrella</i>		0.005												
Empididae	0.002													
Eriopterini			0.002											
<i>Maoridamesa</i>	0.002													
Orthoclaadiinae	0.018	0.002												
<i>Paradixa</i>	0.006													
Tanypodinae	0.063	0.002												
<i>Tanytarsus</i>	0.016													
Trichoptera ¹	0.051	0.005												
<i>Aoteapsyche</i>	0.006													
<i>Beraeoptera</i>	0.051	0.002												
<i>Hudsonema</i>	0.007													
<i>Hydrobiosis</i>	0.005	0.004												
<i>Neurochorema</i>	0.007	0.004												
<i>Olinga</i>	0.025	0.006												
<i>Oxyethira</i>	0.018													
<i>Psilochorema</i>		0.002			0.002									
<i>Pycnocentria</i>	0.069													
<i>Pycnocentroides</i>	0.025	0.002												
<i>Zelolessica</i>	0.002													
Mollusca														
<i>Potamopyrgus</i>	0.002													
Annelida ²	0.004	0.004	0.004											
Arachnida ²	0.002													
Blattodea ²														
Diplopoda ²			0.002											
Hemiptera ²	0.066	0.002												
Hymenoptera ²	0.071	0.005	0.010	0.002										
Isoptera ²		0.002												
Lepidoptera ²	0.016	0.002												
TOTAL	1.378	0.144	0.030	0.010	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A2.3 Densities (no.m³) for dusk drifting aquatic invertebrate taxa in 3 mm size classes over all samples from the Taharua River site, February 2009.

Dusk total drift taxa	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	66-69	114-117	117-124	124-126	129-132	132-135
Ephemeroptera ¹	0.017	0.186												
<i>Austroclima</i>	0.017	0.048												
<i>Coloburiscus</i>	0.041													
<i>Deleatidium</i>	0.147	0.017												
<i>Nesameletus</i>		0.034	0.034											
Plecoptera														
<i>Zelandobius</i>	0.082													
<i>Zelandoperla</i>		0.017												
Coleoptera ²	0.574													
Elmidae	0.574	0.031												
Diptera ²	0.313	0.017	0.041											
<i>Austrosimulium</i>	0.392													
<i>Chironomus</i>			0.014											
Orthoclaadiinae	0.034													
Tanypodinae	0.034	0.017	0.027											
<i>Tanytarsus</i>	0.081													
Trichoptera ¹	0.382	0.048												
<i>Aoteapsyche</i>	0.031	0.017												
<i>Beraeoptera</i>	0.058													
<i>Hydrobiosis</i>	0.017	0.017												
<i>Olinga</i>	0.050													
<i>Oxyethira</i>	0.017													
<i>Psilochorema</i>	0.017													
<i>Pycnocentria</i>	0.058													
Annelida ²	0.030	0.017	0.045											
Arachnida ²			0.014											
Diplopoda ²		0.017												
Hemiptera ²	0.017													
Hymenoptera ²	0.096	0.034												
Lepidoptera ²	0.052													
Neuroptera ²	0.017													
TOTAL	3.150	0.517	0.175	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A2.4 Densities (no.m³) for day drifting aquatic invertebrate taxa in 3 mm size classes over all samples from the upstream Mohaka River site, February 2009.

Day total drift taxa	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	66-69	114-117	117-124	124-126	129-132	132-135
Ephemeroptera¹		0.005												
<i>Austroclima</i>	0.010													
<i>Coloburiscus</i>	0.003													
<i>Deleatidium</i>	0.040													
<i>Nesameletus</i>	0.003													
Plecoptera¹	0.003	0.016	0.008											
<i>Austroperla</i>	0.003		0.003											
<i>Zelandoperla</i>	0.038	0.003												
Megaloptera														
<i>Archichauliodes</i>	0.003													
Coleoptera²	1.371	0.029	0.003	0.005										
Elmidae	0.403	0.076												
Diptera²	0.033	0.005												
Anthomyiidae	0.005													
<i>Aphrophila</i>		0.003												
<i>Austrosimulium</i>	0.057													
<i>Maoridiamesa</i>	0.003													
Orthoclaadiinae	0.028													
Tanypodinae	0.005													
Trichoptera¹	0.019	0.003												
<i>Aoteapsyche</i>	0.008	0.003												
<i>Beraeoptera</i>	5.157													
<i>Costachorema</i>			0.003											
<i>Hudsonema</i>	0.003	0.005												
<i>Hydrobiosis</i>	0.018	0.016												
<i>Neurochorema</i>	0.008	0.003												
<i>Olinga</i>	0.317	0.046	0.003											
<i>Pycnocentria</i>	0.123													
<i>Pycnocentroides</i>	0.045													
Arachnida²	0.005													
Hemiptera²	0.155	0.003												
Hymenoptera²	0.045	0.005	0.029	0.005										
Lepidoptera²	0.013			0.003										
Neuroptera²	0.003													
Nematomorpha¹												0.003	0.002	
Orthoptera²	0.003													
TOTAL	7.927	0.221	0.048	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.002	0.000

Table A2.5 Densities (no.m³) for dusk drifting aquatic invertebrate taxa in 3 mm size classes over all samples from the upstream Mohaka River site, February 2009.

Dusk total drift taxa	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	66-69	114-117	117-124	124-126	129-132	132-135
Ephemeroptera ¹	0.956	0.107	0.016											
<i>Acanthophlebia</i>	0.016													
<i>Ameletopsis</i>					0.019									
<i>Austroclima</i>	0.049	0.017												
<i>Coloburiscus</i>	0.017													
<i>Deleatidium</i>	0.385	0.049	0.019											
<i>Nesameletus</i>	0.352	0.038												
<i>Zephlebia</i>	0.017													
Plecoptera														
<i>Zelandoperla</i>	0.284	0.017												
Coleoptera ²	0.347	0.173	0.035											
Elmidae	0.312	0.064												
Diptera ²	0.791	0.089			0.017	0.016								
<i>Austrosimulium</i>	0.124	0.047												
Eriopterini		0.017												
Orthoclaadiinae	0.017													
<i>Paradixa</i>	0.035													
Tanypodinae	0.129													
<i>Tanytarsus</i>	0.016													
Trichoptera ¹	0.870	0.512	0.019											
<i>Aoteapsyche</i>	0.019													
<i>Beraeoptera</i>	0.661	0.017												
<i>Hydrobiosis</i>	0.089	0.035												
<i>Olinga</i>	0.457	0.104												
<i>Pycnocentria</i>	0.016													
<i>Pycnocentrodes</i>	0.031	0.016												
Arachnida ²	0.017													
Hemiptera ²	0.251													
Hymenoptera ²	0.122													
Lepidoptera ²	0.276	0.017												
TOTAL	6.656	1.319	0.088	0.000	0.036	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A2.6 Densities (no.m³) for day drifting aquatic invertebrate taxa in 3 mm size classes over all samples from the downstream Mohaka River site, February 2009.

Day total drift taxa	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	66-69	114-117	117-124	124-126	129-132	132-135
Ephemeroptera¹	0.002	0.010	0.003											
<i>Atalophlebioides</i>	0.005	0.003												
<i>Austroclima</i>	0.032													
<i>Deleatidium</i>	0.080	0.025	0.002											
<i>Nesameletus</i>	0.002													
<i>Zephlebia</i>	0.003													
Plecoptera¹	0.006													
<i>Zelandobius</i>	0.009	0.016												
<i>Zelandoperla</i>	0.041	0.005												
Megaloptera														
<i>Archichauliodes</i>	0.002		0.003			0.002								
Odonata														
<i>Xanthocnemis</i>	0.002													
Coleoptera²	0.169	0.014		0.003										
Elmidae	0.558	0.071												
Hydrophilidae	0.006													
Diptera²	0.062	0.002		0.002										
Diptera¹	0.003													
Anthomyiidae	0.002	0.004	0.003											
<i>Aphrophila</i>		0.002												
<i>Austrosimulium</i>	0.074													
Chironomidae	0.006													
<i>Chironomus</i>	0.003	0.009	0.003											
<i>Culex</i>	0.011													
<i>Ephydrella</i>	0.016	0.007	0.002											
<i>Maoridamesa</i>	0.045	0.008												
Orthoclaadiinae	0.109													
<i>Paradixa</i>	0.006													
Tanyderidae		0.002												
Tanypodinae	0.033													
<i>Tanytarsus</i>	0.011													
Trichoptera¹	0.012	0.002												
<i>Aoteapsyche</i>	0.053	0.012												
Beraeoptera	1.810													
<i>Costachorema</i>		0.003												
<i>Hudsonema</i>	0.005													
<i>Hydrobiosis</i>	0.010	0.017	0.002	0.002										
<i>Neurochorema</i>	0.005	0.007												
<i>Olinga</i>	0.117	0.021	0.003											
<i>Oxyethira</i>	0.021													
<i>Psilochorema</i>		0.004	0.002											
<i>Pycnocentria</i>	0.094	0.004												
<i>Pycnocentroides</i>	0.011	0.002												
Blattodea²	0.002													
Hemiptera²	0.015													
Hymenoptera²	0.039		0.005	0.007										
Isoptera²		0.003												
Nematomorpha¹									0.002	0.002	0.002			0.004
TOTAL	3.488	0.251	0.027	0.013	0.000	0.002	0.000	0.000	0.002	0.002	0.002	0.000	0.000	0.004

Table A2.7 Densities (no.m³) for dusk drifting aquatic invertebrate taxa in 3 mm size classes over all samples from the downstream Mohaka River site, February 2009.

Dusk total drift taxa	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	66-69	114-117	117-124	124-126	129-132	132-135
Ephemeroptera ¹	0.133	0.161												
<i>Atalophlebioides</i>	0.007													
<i>Austroclima</i>	0.010	0.010												
<i>Coloburiscus</i>	0.010													
<i>Deleatidium</i>	0.255	0.033	0.019											
<i>Nesameletus</i>	0.058	0.029												
<i>Zephlebia</i>	0.010	0.007												
Plecoptera ¹														
<i>Zelandobius</i>	0.038	0.019												
<i>Zelandoperla</i>	0.155	0.038												
Megaloptera														
<i>Archichauliodes</i>			0.010											
Coleoptera ²	0.137	0.018												
Elmidae	0.415	0.040												
Diptera ²	0.607	0.044												
Anthomyiidae	0.016													
<i>Austrosimulium</i>	0.081													
Chironomidae	0.007													
<i>Ephydrella</i>	0.019													
<i>Maoriamesa</i>	0.063													
Orthoclaadiinae	0.158													
<i>Paradixa</i>	0.009													
Tanypodinae	0.071	0.009												
<i>Tanytarsus</i>	0.053	0.010												
Trichoptera ¹	0.328	0.053												
<i>Aoteapsyche</i>	0.081	0.010												
<i>Beraeoptera</i>	0.449													
<i>Hudsonema</i>	0.010													
<i>Hydrobiosis</i>	0.067	0.018												
<i>Neurochorema</i>	0.018		0.007											
<i>Olinga</i>	0.066	0.040												
<i>Oxyethira</i>	0.027													
<i>Psilochorema</i>	0.010													
<i>Pycnocentria</i>	0.057													
Arachnida ²	0.010													
Hemiptera ²	0.097			0.007										
Hymenoptera ²	0.051													
Lepidoptera ²	0.007													
Nematoda ²	0.019													
Nematomorpha ¹		0.010	0.018	0.010	0.010									
TOTAL	3.606	0.547	0.054	0.017	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A2.8 Densities (no.m³) for day drifting aquatic invertebrate taxa in 3 mm size classes over all samples from the Taharua River site, April 2009.

Day total drift taxa	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	66-69	114-117	117-124	124-126	129-132	132-135
Ephemeroptera ¹	0.003	0.025	0.005											
<i>Austroclima</i>	0.017	0.036												
<i>Coloburiscus</i>	0.008	0.005												
<i>Deleatidium</i>	0.069	0.066												
<i>Nesameletus</i>	0.005	0.005												
<i>Zephlebia</i>	0.005													
Plecoptera														
<i>Megaleptoperla</i>	0.005													
<i>Zelandobius</i>	0.027	0.003												
<i>Zelandoperla</i>	0.017													
Coleoptera ²	0.006		0.005					0.003						
Dytiscidae	0.003													
Elmidae	0.008	0.009												
Diptera ²	0.056	0.005												
<i>Austrosimulium</i>	0.124													
Chironomidae	0.061													
<i>Chironomus</i>	0.009													
Orthoclaadiinae	0.056	0.009												
<i>Paradixa</i>	0.003													
Tanypodinae	0.017	0.003												
Trichoptera ¹	0.003													
<i>Aoteapsyche</i>	0.005	0.005												
<i>Hudsonema</i>	0.017	0.034	0.006											
<i>Hydrobiosis</i>	0.017	0.028	0.008											
<i>Olinga</i>	0.003													
<i>Oxyethira</i>	0.037													
<i>Psilochorema</i>	0.005													
<i>Pycnocentria</i>	0.344	0.042												
<i>Triplectides</i>			0.003											
Mollusca														
<i>Physa</i>	0.003													
Hemiptera ²	0.006													
Hymenoptera ²	0.107	0.003												
Lepidoptera ²	0.041	0.005												
TOTAL	1.087	0.282	0.026	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000

Table A2.9 Densities (no.m³) for dusk drifting aquatic invertebrate taxa in 3 mm size classes over all samples from the Taharua River site, April 2009.

Dusk total drift taxa	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	66-69	114-117	117-124	124-126	129-132	132-135
Ephemeroptera ¹	0.029	0.041	0.016											
<i>Austroclima</i>		0.045												
<i>Coloburiscus</i>	0.014													
<i>Deleatidium</i>	0.104													
<i>Nesameletus</i>	0.016													
Plecoptera														
<i>Zelandobius</i>	0.030													
Coleoptera														
Dytiscidae	0.014													
Elmidae	0.059													
Diptera ²	0.250	0.055												
<i>Austrosimulium</i>	0.182													
Chironomidae	0.104	0.016												
<i>Chironomus</i>		0.016												
Orthoclaadiinae	0.047													
Tanypodinae	0.043													
Trichoptera ¹	0.043	0.031												
<i>Beraeoptera</i>	0.016													
<i>Hudsonema</i>			0.055											
<i>Hydrobiosis</i>	0.063													
<i>Oxyethira</i>	0.028													
<i>Polypsectropus</i>	0.016													
<i>Psilochorema</i>	0.031													
<i>Pycnocentria</i>	0.438													
<i>Pycnocentrodes</i>	0.047	0.016												
<i>Zelolessica</i>	0.014													
Mollusca														
<i>Physa</i>	0.016													
Arachnida ²	0.016													
Annelida ²						0.014								
Hemiptera ²	0.014													
Hymenoptera ²	0.055	0.030												
TOTAL	1.687	0.250	0.071	0.000	0.000	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A2.10 Densities (no.m³) for day drifting aquatic invertebrate taxa in 3 mm size classes over all samples from the upstream Mohaka River site, April 2009.

Day total drift taxa	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	66-69	114-117	117-124	124-126	129-132	132-135
Ephemeroptera¹		0.016												
<i>Deleatidium</i>	0.073	0.002												
<i>Zephlebia</i>	0.002													
<i>Nesameletus</i>	0.012	0.022												
Plecoptera¹	0.004													
<i>Austroperla</i>		0.002												
<i>Megaleptoperla</i>	0.002													
<i>Zelandoperla</i>	0.198	0.028												
Megaloptera														
<i>Archichauliodes</i>		0.004												
Coleoptera²	0.011		0.004											
Elmidae		0.002												
Diptera²	0.033	0.005												
<i>Austrosimulium</i>	0.064													
Chironomidae	0.006													
<i>Maoridamesa</i>	0.002													
Orthoclaadiinae	0.029													
<i>Tanytarsus</i>	0.007	0.002												
Trichoptera¹	0.039		0.002											
<i>Aoteapsyche</i>	0.002	0.002												
<i>Beraeoptera</i>	0.351													
<i>Costachorema</i>	0.003	0.002												
<i>Hudsonema</i>		0.003	0.004											
<i>Hydrobiosis</i>	0.008	0.013	0.006	0.006										
<i>Neurochorema</i>	0.007	0.006	0.002											
<i>Olinga</i>	0.022													
<i>Oxyethira</i>	0.015													
<i>Psilochorema</i>			0.002											
<i>Pycnocentria</i>	0.009	0.003												
<i>Pycnocentroides</i>	0.002													
Arachnida²	0.006													
Hemiptera²	0.015	0.003												
Hymenoptera²	0.123	0.011	0.003											
Lepidoptera²	0.004			0.004										
TOTAL	1.051	0.128	0.024	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A2.11 Densities (no.m³) for dusk drifting aquatic invertebrate taxa in 3 mm size classes over all samples from the upstream Mohaka River site, April 2009.

Dusk total drift taxa	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	66-69	114-117	117-124	124-126	129-132	132-135
Ephemeroptera ¹	0.011	0.097	0.040											
<i>Deleatidium</i>	0.116	0.010												
<i>Nesameletus</i>	0.020	0.037	0.018											
Plecoptera														
<i>Zelandoperla</i>	0.093	0.045												
Coleoptera														
Elmidae	0.009	0.010												
Diptera ²	0.716	0.059												
<i>Austrosimulium</i>	0.088	0.018												
Chironomidae		0.036												
<i>Maoridiamesa</i>	0.010													
Orthoclaadiinae	0.082	0.009												
Tanypodinae	0.010													
Tipulidae			0.054											
Trichoptera ¹		0.009	0.009											
<i>Aoteapsyche</i>	0.009													
<i>Beraeoptera</i>	0.078	0.054												
<i>Costachorema</i>		0.010												
<i>Hydrobiosis</i>	0.049	0.023	0.032											
<i>Pycnocentria</i>		0.011												
Hemiptera ²	0.020													
Hymenoptera ²	0.223	0.018	0.019											
Lepidoptera ²		0.009												
TOTAL	1.534	0.456	0.172	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A2.12 Densities (no.m³) for day drifting aquatic invertebrate taxa in 3 mm size classes over all samples from the downstream Mohaka River site, April 2009.

Day total drift taxa	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	66-69	114-117	117-124	124-126	129-132	132-135
Ephemeroptera¹	0.024	0.005												
<i>Austroclima</i>	0.012	0.009												
<i>Coloburiscus</i>	0.036													
<i>Deleatidium</i>	0.125	0.009												
<i>Nesameletus</i>	0.040		0.003											
<i>Zephlebia</i>	0.003													
Plecoptera														
<i>Taraperla</i>		0.005												
<i>Zelandobius</i>	0.009													
<i>Zelandoperla</i>	0.387	0.006												
Megaloptera														
<i>Archichauliodes</i>		0.006												
Neuroptera														
<i>Kempynus</i>		0.003												
Coleoptera²	0.003													
Elmidae	0.022													
Diptera²	0.112													
Anthomyiidae	0.009	0.021	0.009											
<i>Austrosimulium</i>	0.074													
Chironomidae	0.026													
<i>Maoridamesa</i>	0.036													
Orthoclaadiinae	0.440													
<i>Tanytarsus</i>	0.009													
Trichoptera¹	0.005													
<i>Aoteapsyche</i>	0.018	0.003	0.003											
<i>Beraeoptera</i>	0.162													
<i>Costachorema</i>	0.021	0.007	0.003											
<i>Hydrobiosis</i>	0.021	0.014	0.009		0.005									
<i>Neurochorema</i>	0.006													
<i>Olinga</i>	0.028													
<i>Oxyethira</i>	0.040													
<i>Pycnocentria</i>	0.062													
<i>Pycnocentrodes</i>	0.011													
<i>Triplectides</i>	0.006													
Annelida²	0.003	0.006												
Hemiptera²	0.030													
Hymenoptera²	0.122													
TOTAL	1.902	0.093	0.027	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A2.13 Densities (no.m³) for dusk drifting aquatic invertebrate taxa in 3 mm size classes over all samples from the downstream Mohaka River site, April 2009.

Dusk total drift taxa	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	66-69	114-117	117-124	124-126	129-132	132-135
Ephemeroptera¹	0.038	0.122												
<i>Austroclima</i>	0.053	0.026												
<i>Coloburiscus</i>	0.117	0.013	0.013											
<i>Deleatidium</i>	0.213	0.025												
<i>Nesameletus</i>	0.084	0.013												
Plecoptera														
<i>Zelandoperla</i>	0.404	0.064												
Coleoptera²	0.013													
Elmidae	0.013	0.013												
Diptera²	0.839	0.397	0.369	0.025										
Anthomyiidae		0.026												
<i>Austrosimulium</i>	0.045													
Ceratopogonidae	0.013													
<i>Maoridiamesa</i>	0.070													
<i>Mishoderus</i>		0.013												
Orthoclaadiinae	0.716													
Tanypodinae	0.013													
<i>Tanytarsus</i>	0.013													
Trichoptera¹	0.013	0.026												
<i>Beraeoptera</i>	0.147													
<i>Costachorema</i>	0.038	0.025	0.013	0.013										
<i>Hudsonema</i>	0.044	0.013					0.013							
<i>Hydrobiosis</i>	0.076	0.039		0.013										
<i>Neurochorema</i>	0.027	0.025	0.013											
<i>Olinga</i>	0.013		0.013											
<i>Oxyethira</i>	0.013													
<i>Psilochorema</i>		0.013												
<i>Pycnocentria</i>	0.110													
Arachnida²	0.013													
Hymenoptera²	0.136													
Lepidoptera²	0.031													
TOTAL	3.306	0.853	0.421	0.052	0.000	0.000	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A2.14 Densities (no.m³) for day drifting aquatic invertebrate taxa in 3 mm size classes over all samples from the Taharua River site, December 2009.

Day total drift taxa	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	66-69	114-117	117-124	124-126	129-132	132-135
Ephemeroptera¹		0.012	0.002											
<i>Austroclima</i>	0.003													
<i>Coloburiscus</i>	0.004													
<i>Deleatidium</i>	0.009	0.008												
Plecoptera¹	0.012	0.033												
<i>Megaleptoperla</i>	0.002													
<i>Zelandobius</i>	0.066	0.024												
<i>Zelandoperla</i>	0.002													
Coleoptera²	0.015	0.028	0.007											
Elmidae	0.047													
Hydrophiliidae	0.001													
Scirtidae	0.004													
Diptera²	0.064	0.030	0.002	0.015	0.002									
Anthomyiidae		0.002												
<i>Austrosimulium</i>	0.001													
Eriopterini			0.001											
<i>Limonia</i>		0.002												
<i>Maoridamesa</i>	0.002													
Orthoclaadiinae	0.003													
Tanypodinae	0.006	0.004												
Trichoptera¹	0.006	0.002												
<i>Aoteapsyche</i>	0.004	0.001												
<i>Beraeoptera</i>	0.116													
<i>Costachorema</i>		0.002												
<i>Hudsonema</i>		0.004	0.002	0.003	0.002									
<i>Hydrobiosis</i>	0.001		0.002	0.001	0.001									
<i>Neurochorema</i>		0.004	0.002											
<i>Olinga</i>	0.001													
<i>Psilochorema</i>	0.002													
<i>Pycnocentria</i>	0.053	0.055	0.017	0.006										
<i>Pycnocentrodes</i>	0.042	0.001												
Hemiptera														
<i>Sigara</i>	0.006	0.001												
Annelida²		0.002												
Arachnida²	0.002													
Hemiptera²	0.018	0.002												
Hymenoptera²	0.007	0.002	0.001	0.024										
Lepidoptera²	0.017	0.004	0.002											
TOTAL	0.515	0.224	0.037	0.050	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A2.15 Densities (no.m³) for dusk drifting aquatic invertebrate taxa in 3 mm size classes over all samples from the Taharua River site, December 2009.

Dusk total drift taxa	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	66-69	114-117	117-124	124-126	129-132	132-135
Ephemeroptera ¹	0.044	0.147	0.017											
<i>Austroclima</i>	0.017													
<i>Deleatidium</i>	0.034	0.015												
<i>Nesameletus</i>	0.018													
Plecoptera ¹	0.008													
<i>Zelandobius</i>	0.376	0.070												
Coleoptera ²	0.017	0.009												
Elmidae	1.234													
Scirtidae	0.008													
Diptera ²	0.491	0.025	0.009											
<i>Aphrophila</i>	0.008													
<i>Austrosimulium</i>	0.018													
<i>Chironomus</i>		0.015	0.009											
<i>Paradixa</i>	0.008													
Tanypodinae	0.112	0.015												
Trichoptera ¹	0.024	0.009												
<i>Aoteapsyche</i>	0.024													
<i>Beraeoptera</i>	0.429													
<i>Costachorema</i>	0.008	0.008												
<i>Hudsonema</i>			0.008											
<i>Hydrobiosis</i>	0.008													
<i>Pycnocentria</i>	0.220	0.195	0.048	0.008										
<i>Pycnocentrodes</i>	0.183	0.008												
<i>Triplectides</i>				0.009										
Annelida ²	0.008	0.008												
Hemiptera ²	0.008													
Hymenoptera ²			0.008											
TOTAL	3.304	0.525	0.099	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A2.16 Densities (no.m³) for day drifting aquatic invertebrate taxa in 3 mm size classes over all samples from the upstream Mohaka River site, December 2009.

Day total drift taxa	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	66-69	114-117	117-124	124-126	129-132	132-135
Ephemeroptera ¹	0.032	0.044	0.018	0.002										
<i>Ameletopsis</i>	0.004													
<i>Austroclima</i>	0.002	0.002												
<i>Coloburiscus</i>	0.009	0.002												
<i>Deleatidium</i>	0.118	0.104	0.006											
<i>Zephlebia</i>	0.002	0.002												
Plecoptera ¹	0.005	0.038	0.019	0.010										
<i>Acroperla</i>	0.021	0.002												
<i>Austroperla</i>		0.019												
<i>Zelandoperla</i>			0.002											
Megaloptera														
<i>Archichauliodes</i>		0.002	0.002											
Coleoptera ²	0.199	0.008	0.029											
Elmidae	0.050	0.021												
Hydrophilidae		0.002												
<i>Liodesus</i>	0.002													
Scirtidae		0.002												
Diptera ²	1.408	0.045	0.008											
<i>Aphrophila</i>		0.002												
<i>Austrosimulium</i>	0.002													
Trichoptera ¹	0.007	0.008	0.002											
<i>Aoteapsyche</i>	0.000	0.005	0.000	0.002										
<i>Beraeoptera</i>	0.460													
<i>Costachorema</i>		0.003												
<i>Hudsonema</i>	0.006	0.018	0.007	0.003										
<i>Hydrobiosis</i>	0.004	0.010	0.002											
<i>Neurochorema</i>		0.004												
<i>Olinga</i>	0.074	0.039	0.018											
<i>Polyplectropus</i>		0.005		0.002										
<i>Psilochorema</i>			0.002											
<i>Pycnocentria</i>	0.009													
<i>Pycnocentroides</i>	0.052													
Arachnida ²	0.013													
Hemiptera ²	0.180	0.054												
Hymenoptera ²	0.008		0.006	0.010										
Lepidoptera ²	0.025	0.003	0.006											
Orthoptera ²			0.002											
TOTAL	2.690	0.437	0.126	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A2.17 Densities (no.m³) for dusk drifting aquatic invertebrate taxa in 3 mm size classes over all samples from the upstream Mohaka River site, December 2009.

Dusk total drift taxa	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	66-69	114-117	117-124	124-126	129-132	132-135
Ephemeroptera ¹	0.182	0.247	0.050											
<i>Austroclima</i>		0.033												
<i>Coloburiscus</i>	0.017													
<i>Deleatidium</i>	0.110	0.040												
Plecoptera ¹		0.010												
<i>Acroperla</i>	0.017	0.017												
<i>Austroperla</i>	0.010	0.017												
Coleoptera ²	0.443													
Elmidae	0.010													
Diptera ²	2.074	0.017												
<i>Austrosimulium</i>	0.012													
Orthoclaadiinae	0.010													
Trichoptera ¹	0.017	0.022												
<i>Aoteapsyche</i>	0.012		0.017											
<i>Beraeoptera</i>	0.373													
<i>Hudsonema</i>	0.010													
<i>Hydrobiosis</i>	0.039	0.022												
<i>Neurochorema</i>			0.012											
<i>Olinga</i>	0.146	0.022	0.027											
<i>Polypsectropus</i>		0.012												
<i>Psilochorema</i>		0.010												
<i>Pycnocentria</i>	0.012													
<i>Pycnocentroides</i>	0.032													
Hemiptera ²	0.020													
Lepidoptera ²	0.106													
TOTAL	3.651	0.468	0.105	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A2.18 Densities (no.m³) for day drifting aquatic invertebrate taxa in 3 mm size classes over all samples from the downstream Mohaka River site, December 2009.

Day total drift taxa	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	66-69	114-117	117-124	124-126	129-132	132-135
Ephemeroptera¹	0.010	0.006	0.010		0.002									
<i>Austroclima</i>	0.002	0.003												
<i>Coloburiscus</i>	0.015	0.002	0.002											
<i>Deleatidium</i>	0.025	0.016	0.004											
<i>Neozephebia</i>			0.002											
<i>Nesameletus</i>			0.001											
Plecoptera¹	0.012	0.014	0.014	0.002										
<i>Acroperla</i>	0.047	0.016												
<i>Taraperla</i>	0.001													
<i>Zelandobius</i>	0.019	0.035												
<i>Zelandoperla</i>	0.009													
Megaloptera														
<i>Archichauliodes</i>	0.001													
Coleoptera²	0.049	0.026	0.009											
Elmidae	0.206	0.026												
Scirtidae		0.006												
Diptera²	0.620	0.021		0.002										
Anthomyiidae		0.003	0.002	0.002										
<i>Aphrophila</i>		0.008												
<i>Austrosimulium</i>	0.002													
Simuliidae	0.002													
<i>Limonia</i>		0.002												
<i>Maoridamesa</i>	0.018	0.008												
<i>Paradixa</i>	0.001													
Tanypodinae	0.009	0.004												
Trichoptera¹	0.037	0.010												
<i>Beraeoptera</i>	0.785	0.006												
<i>Costachorema</i>	0.003	0.002	0.003	0.002										
<i>Hudsonema</i>	0.010	0.004	0.004	0.004	0.001	0.002	0.002							
<i>Hydrobiosis</i>	0.002		0.001	0.004	0.002									
<i>Neurochorema</i>		0.006	0.001											
<i>Olinga</i>	0.020	0.004	0.002											
<i>Polyplectropus</i>				0.001										
<i>Pycnocentria</i>	0.009	0.009	0.009											
<i>Pycnocentrodes</i>	0.038													
Hemiptera														
<i>Sigara</i>	0.003													
Arachnida²	0.014													
Hemiptera²	0.014	0.003												
Hymenoptera²	0.014	0.003	0.006	0.023	0.003									
Lepidoptera²	0.007	0.002	0.002											
Orthoptera²		0.002												
TOTAL	2.004	0.247	0.071	0.041	0.007	0.002	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A2.19 Densities (no.m³) for dusk drifting aquatic invertebrate taxa in 3 mm size classes over all samples from the downstream Mohaka River site, December 2009.

Dusk total drift taxa	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	66-69	114-117	117-124	124-126	129-132	132-135
Ephemeroptera ¹	0.072	0.421	0.014											
<i>Austroclima</i>	0.071	0.014												
<i>Coloburiscus</i>	0.094		0.006											
<i>Deleatidium</i>	0.063	0.014												
<i>Zephlebia</i>	0.007													
Plecoptera ¹		0.012	0.007		0.006									
<i>Acroperla</i>	0.127													
<i>Zelandobius</i>	0.074	0.045												
Coleoptera ²	0.049		0.006											
Elmidae	0.886	0.021												
Hydrophilidae	0.007													
Sciirtidae	0.022	0.007												
Diptera ²	0.977	0.007												
Anthomyiidae		0.014												
<i>Aphrophila</i>	0.014	0.006												
<i>Austrosimulium</i>	0.044													
<i>Chironomus</i>		0.006												
<i>Maoridiamesa</i>	0.049	0.014												
Orthoclaadiinae	0.014													
Tanypodinae	0.012													
<i>Tanytarsus</i>	0.022													
Trichoptera ¹	0.087	0.026												
<i>Beraeoptera</i>	1.137													
<i>Costachorema</i>	0.022		0.006											
<i>Hudsonema</i>	0.006	0.007	0.022											
<i>Hydrobiosis</i>			0.014											
<i>Olinga</i>	0.043													
<i>Psilochorema</i>				0.006										
<i>Pycnocentria</i>	0.027		0.007											
<i>Pycnocentrodes</i>	0.102													
Hemiptera														
<i>Sigara</i>	0.007													
Arachnida ²	0.015													
Annelida ²	0.007													
Hemiptera ²	0.007													
Hymenoptera ²	0.027	0.007	0.021	0.007										
Lepidoptera ²	0.042													
TOTAL	4.136	0.623	0.104	0.014	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 3. Predicted GREI and NREI based on aquatic invertebrate drift and total drift (aquatic + terrestrial) and site-specific temperatures – Summer.

A3.1 Taharua River February 2009

The drift foraging model predicted that trout greater than 40 cm would be food limited in the Taharua River on a diet of only aquatic invertebrates (Figure A3.1.1). However, with the inclusion of terrestrial invertebrates, trout are predicted to reach a size of at least 60 cm before they would be food limited.

Predicted NREI based on aquatic invertebrates fell below 0 when trout exceeded 65 cm (Figure A3.1.2). NREI remained relatively positive for trout at all sizes modelled when terrestrial drift was included in the modelling. However, the net energy available to trout when terrestrial invertebrates were included in the drift was sufficient for positive growth potential across all the fish size classes (Figure A3.1.2).

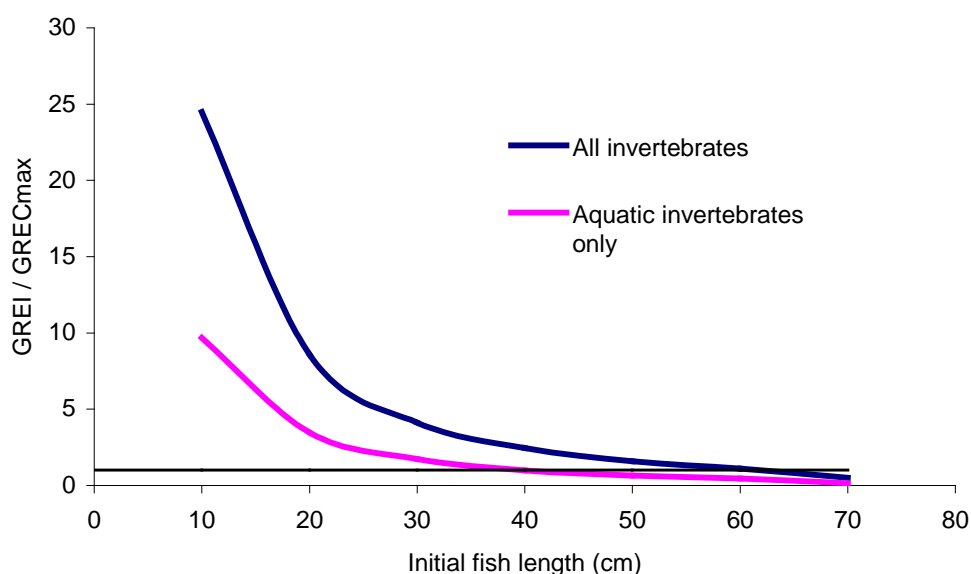


Figure A3.1.1 GREI/GRECmax predicted with the drift-foraging model for a range of size classes of brown trout for February 2009 for the Taharua. Solid black line indicates GREI/GRECmax = 1, below which trout ought to be food limited. Predictions assume the following minimum prey length x fish length relationships: for trout ≤ 30 cm – prey length (in mm) = 0.115 x fish length (in cm); for trout > 30 cm, prey length (in mm) = 0.115 x fish length (in cm) – 3 mm.

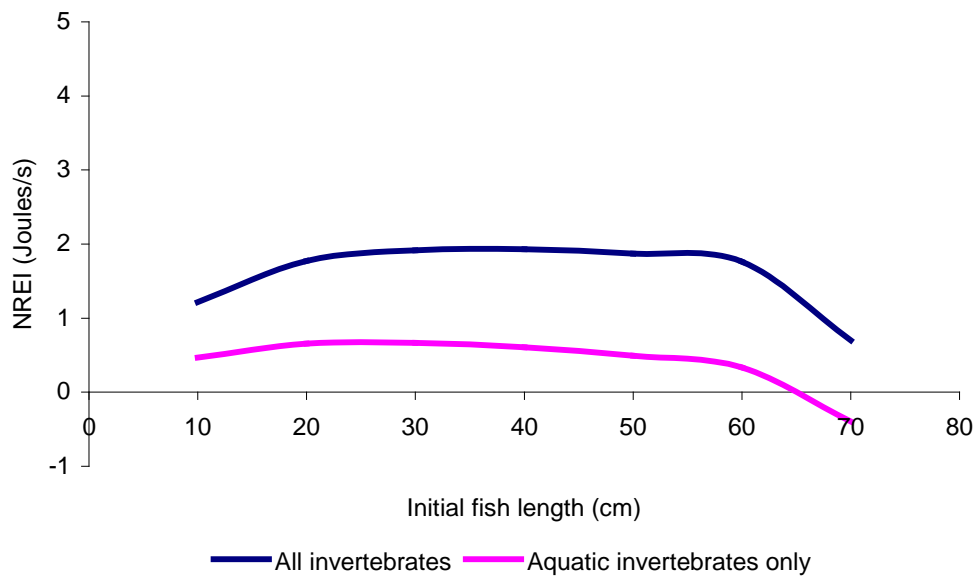


Figure A3.1.2 NREI predicted with the foraging model for a range of size classes of brown trout for February 2009 for the Taharua. Predictions assume the minimum prey length x fish length relationships given in Figure A3.1.1.

A3.2 Mohaka River February 2009

Trout feeding on aquatic drift were predicted to be food limited ($GREI/GREC_{max} < 1$) at the Mohaka River sites once they reached 50 cm (Figure A3.2.1). With the inclusion of terrestrial invertebrates, trout ≤ 70 cm were not food limited at the upstream Mohaka site (Figure A3.2.1). Trout were predicted to be food limited when they were greater than 65 cm at the downstream Mohaka site – similar to the Taharua site (Figures A3.1.1 and A3.2.3).

In summer, the inclusion of terrestrial prey made a positive contribution to the potential NREI for trout across all the size classes at all the sites (Figures A3.1.2, A3.2.2 and A3.2.4). This contribution was most noticeable at the upstream Mohaka and Taharua sites.

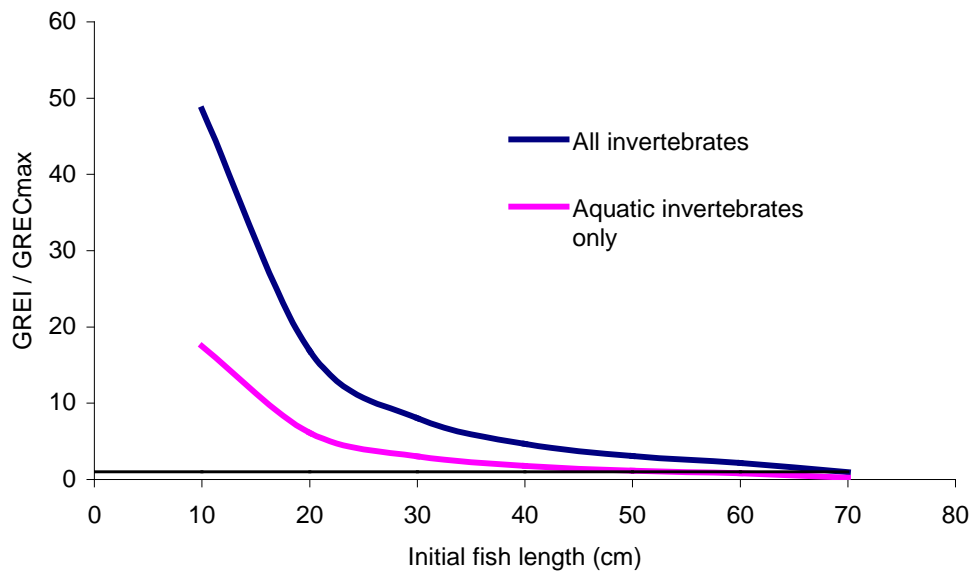


Figure A3.2.1 GREI/ GRECmax predicted with the drift-foraging model for a range of size classes of brown trout for February 2009 for the upstream Mohaka site. Solid black line indicates GREI/GRECmax = 1, below which trout ought to be food limited. Predictions assume the minimum prey length x fish length relationships given in Figure A3.1.1.

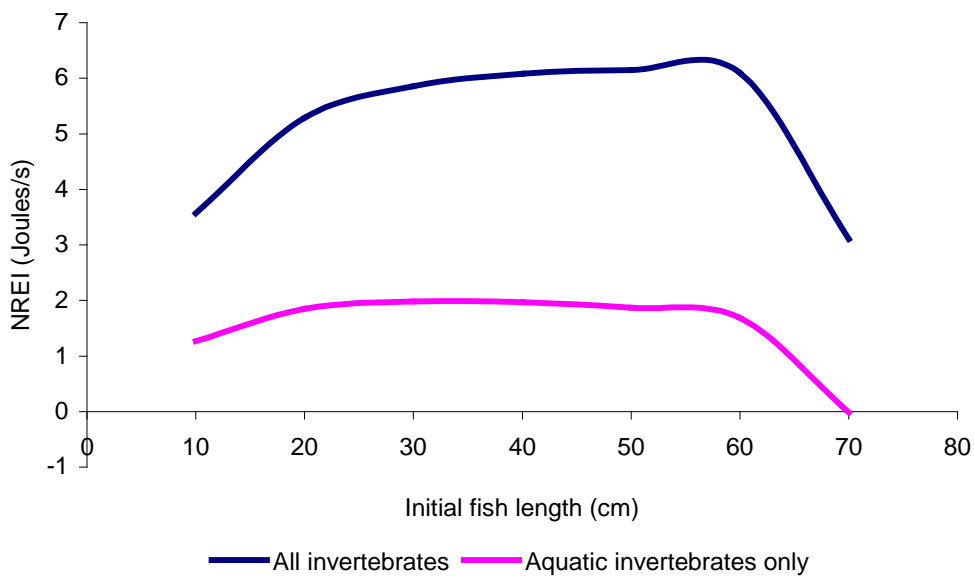


Figure A3.2.2 NREI predicted with the foraging model for a range of size classes of brown trout for February 2009 for the upstream Mohaka site. Predictions assume the minimum prey length x fish length relationships given in Figure A3.1.1.

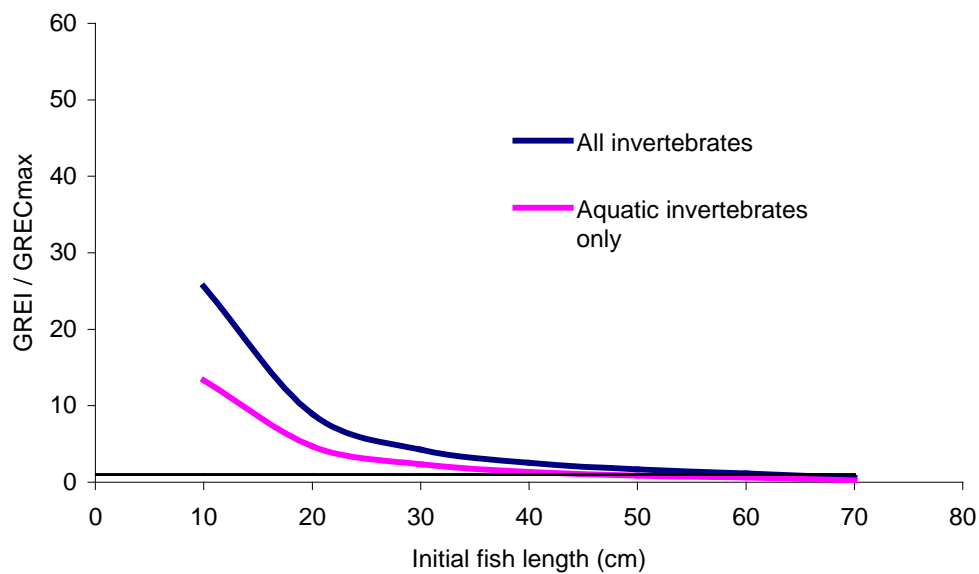


Figure A3.2.3 GREI/ GRECmax predicted with the drift-foraging model for a range of size classes of brown trout for February 2009 for the downstream Mohaka site. Solid black line indicates GREI/GRECmax = 1, below which trout ought to be food limited. Predictions assume the minimum prey length x fish length relationships given in Figure A3.1.1.

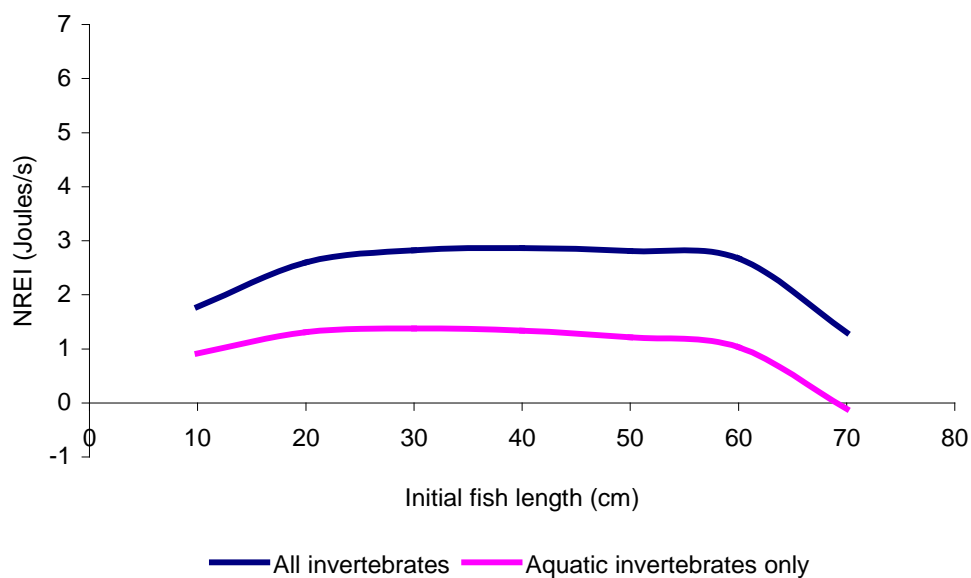


Figure A3.2.4 NREI predicted with the foraging model for a range of size classes of brown trout for February 2009 for the downstream Mohaka site. Predictions assume the minimum prey length x fish length relationships given in Figure A3.1.1.

Appendix 4. Predicted GREI and NREI based on aquatic invertebrate drift and total drift (aquatic + terrestrial) and site-specific temperatures – Autumn.

A4.1 Taharua River April 2009

The drift foraging model predicted that trout greater than 50 cm would be food limited (GREI/GRECmax <1) in the Taharua River on a diet of only aquatic invertebrates (Figure A4.1.1). However, the model predicted that no trout ≤ 70 cm would be food limited with the inclusion of terrestrial invertebrates (Figure A4.1.1).

On an aquatic invertebrate diet, predicted NREI in the Taharua declined gradually after fish reached about 35 cm, and then declined more steeply after 60 cm (Figure A4.1.2). However, when terrestrial drift was included in the modelling NREI did not start to decline until trout were greater than 60 cm. Overall, the net energy available to trout based on aquatic invertebrates in autumn was sufficient for positive growth potential across all the fish size classes modelled, which was not the case in summer (Figure 3.1.2 c.f. Figure A4.1.2). For both summer and autumn the net energy available to trout when terrestrial invertebrates were included in the drift was sufficient for positive, and much higher, growth potential across all the fish size classes.

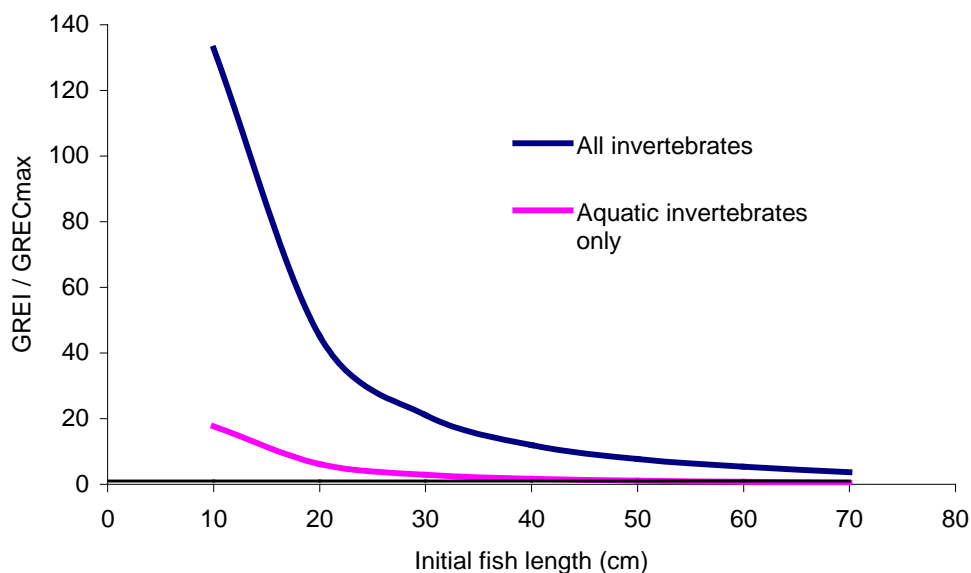


Figure A4.1.1. GREI/ GRECmax predicted with the drift-foraging model for a range of size classes of brown trout for April 2009 for the Taharua. Solid black line indicates GREI/GRECmax = 1, below which trout ought to be food limited. Predictions assume the following minimum prey length x fish length relationships: for trout ≤ 30 cm – prey length (in mm) = 0.115 x fish length (in cm); for trout >30 cm – prey length (in mm) = 0.115 x fish length (in cm) – 3 mm.

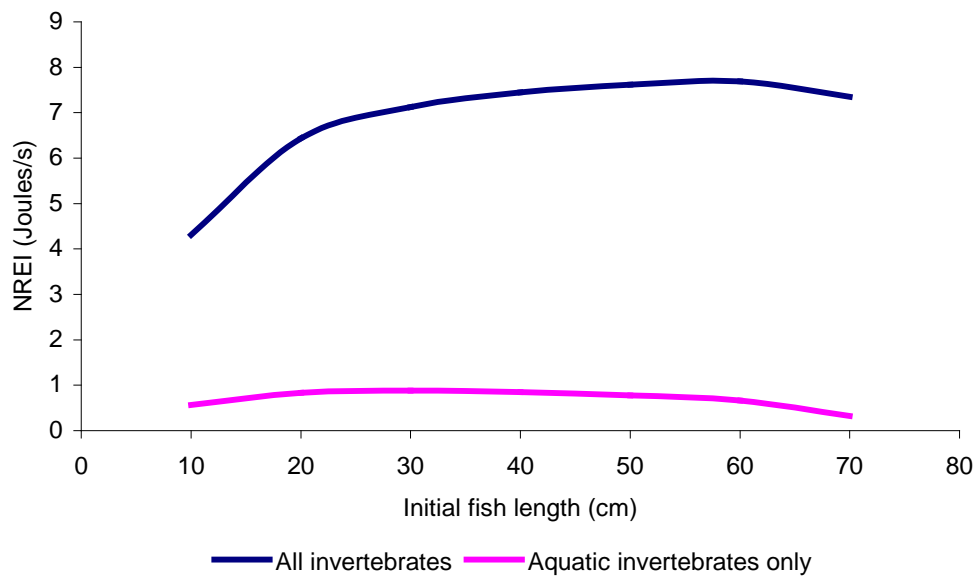


Figure A4.1.2. NREI predicted with the foraging model for a range of size classes of brown trout for April 2009 for the Taharua. Predictions assume the minimum prey length x fish length relationships given in Figure A4.1.1.

A4.2 Mohaka River April 2009

Trout above 50 cm were predicted to be food limited ($GREI/GREC_{max} < 1$) feeding on aquatic drift at the upstream Mohaka River site (Figure A4.2.1) (similar to the Taharua River site in autumn). At the downstream Mohaka site trout greater than 55 cm were predicted to be food limited on aquatic drift (Figure A4.2.3). With the inclusion of terrestrial invertebrates, the model predicted that trout would not be food limited until they exceeded 65 cm at each site (Figures A4.2.1 and A4.2.3).

As for summer, the inclusion of terrestrial prey in autumn made a positive contribution to the potential NREI for trout across all the size classes at all the sites (Figures A.4.1.2, A4.2.2 and A4.2.4). However, in autumn the contribution of terrestrial drift was not as noticeable at the upstream Mohaka site as it had been in summer (compare Figure A3.2.2 with Figure A4.2.2).

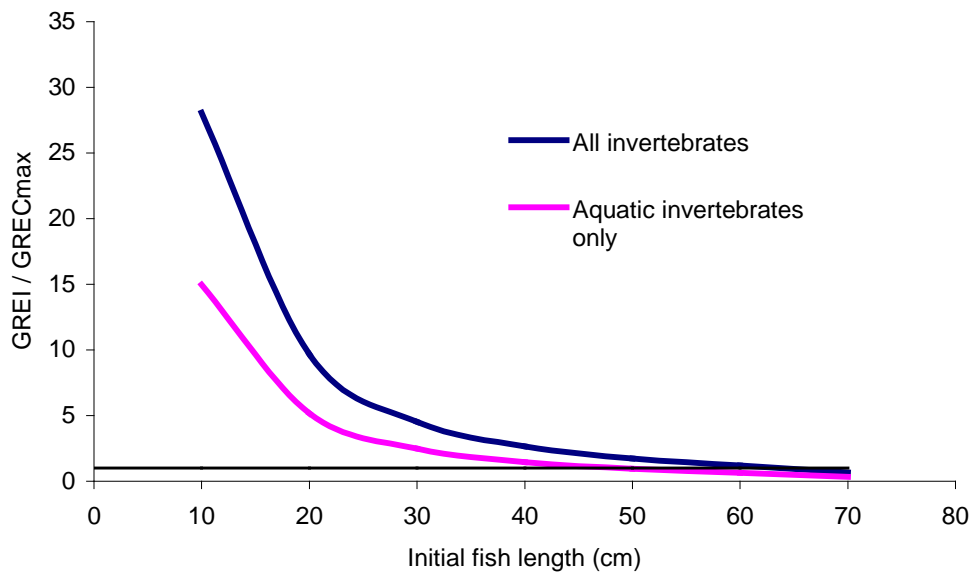


Figure A4.2.1. GREI / GRECmax predicted with the drift-foraging model for a range of size classes of brown trout for April 2009 for the upstream Mohaka site. Solid black line indicates GREI/GRECmax = 1, below which trout ought to be food limited. Predictions assume the minimum prey length x fish length relationships given in Figure A4.1.1.

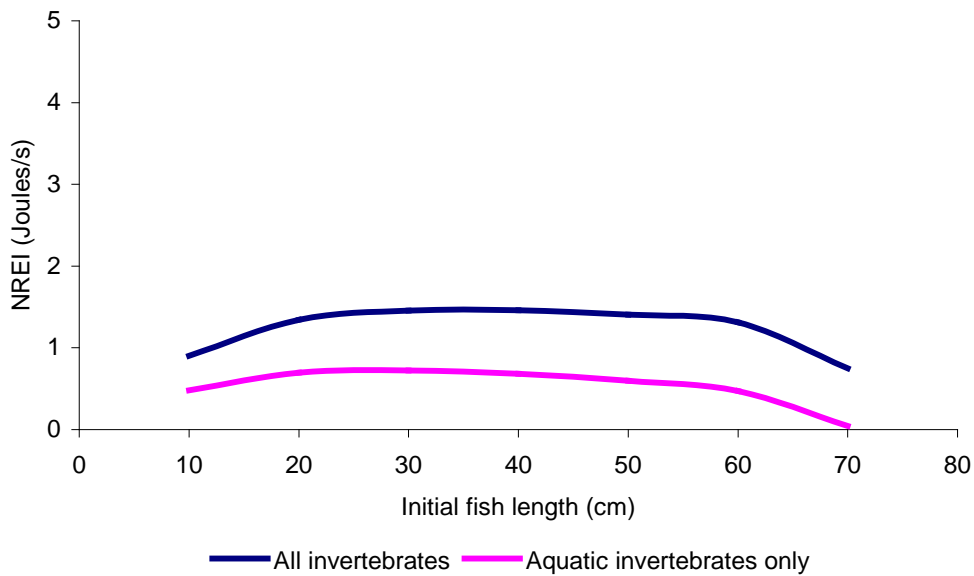


Figure A4.2.2 NREI predicted with the foraging model for a range of size classes of brown trout for April 2009 for the upstream Mohaka site. Predictions assume the minimum prey length x fish length relationships given in Figure A4.1.1.

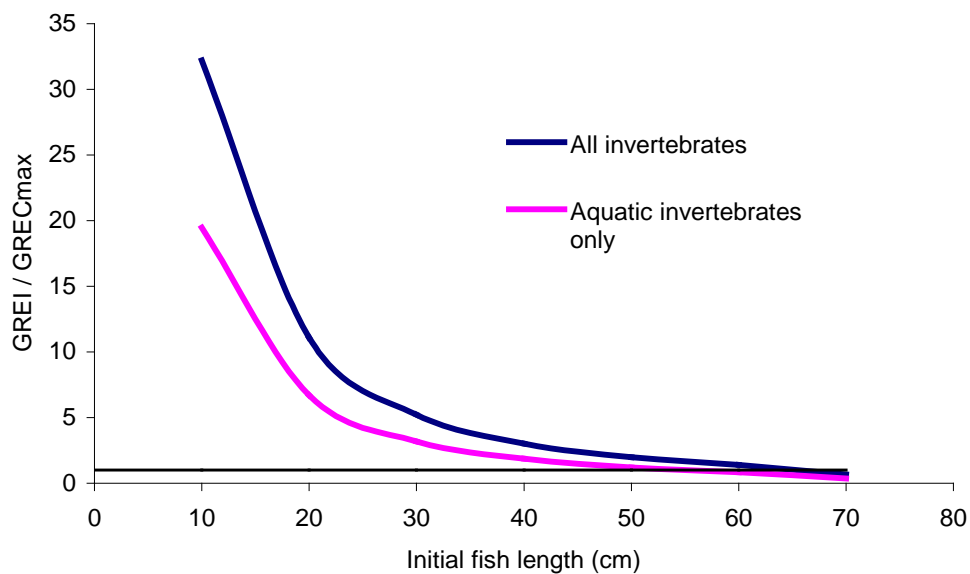


Figure A4.2.3 GREI/ GRECmax predicted with the drift-foraging model for a range of size classes of brown trout for April 2009 for the downstream Mohaka site. Solid black line indicates GREI/GRECmax = 1, below which trout ought to be food limited. Predictions assume the minimum prey length x fish length relationships given in Figure A4.1.1.

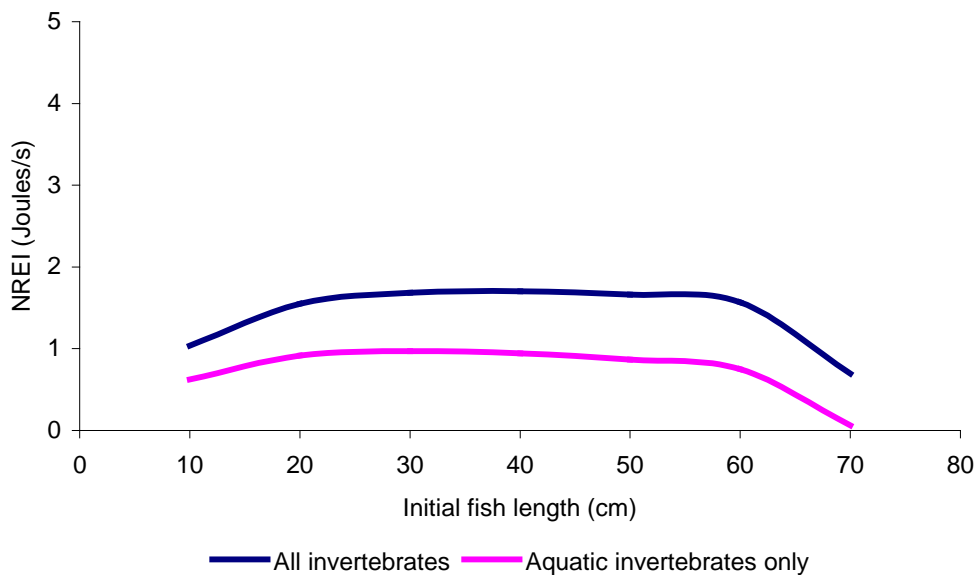


Figure A4.2.4 NREI predicted with the foraging model for a range of size classes of brown trout for April 2009 for the downstream Mohaka site. Predictions assume the minimum prey length x fish length relationships given in Figure A4.1.1.

Appendix 5. Predicted GREI and NREI based on aquatic invertebrate drift and total drift (aquatic + terrestrial) and site-specific temperatures – Spring.

A5.1 Taharua River December 2009

The drift foraging model predicted that trout greater than 50 cm would be food limited in the Taharua River on a diet of only aquatic invertebrates (Figure A5.1.1). With the inclusion of terrestrial invertebrates, the model predicted that trout would not become food limited until they were >70 cm (Figure A5.1.1).

On an aquatic invertebrate diet, predicted NREI in the Taharua declined after fish reached about 30 cm (Figure A5.1.2). NREI did not start to decline until trout reached 40 cm when terrestrial drift was included in the modelling. The net energy available to trout based on aquatic invertebrates and aquatic + terrestrial in spring was sufficient for positive growth potential across all the fish size classes, as was also the case in autumn. In summer, positive growth potential through all the size classes occurred only with the inclusion of terrestrial invertebrates (see Figure 3.1.2).

As for the summer and autumn results, trout of all sizes modelled had a far greater growth potential and less chance of food limitation in spring when terrestrial drift was included in their diet.

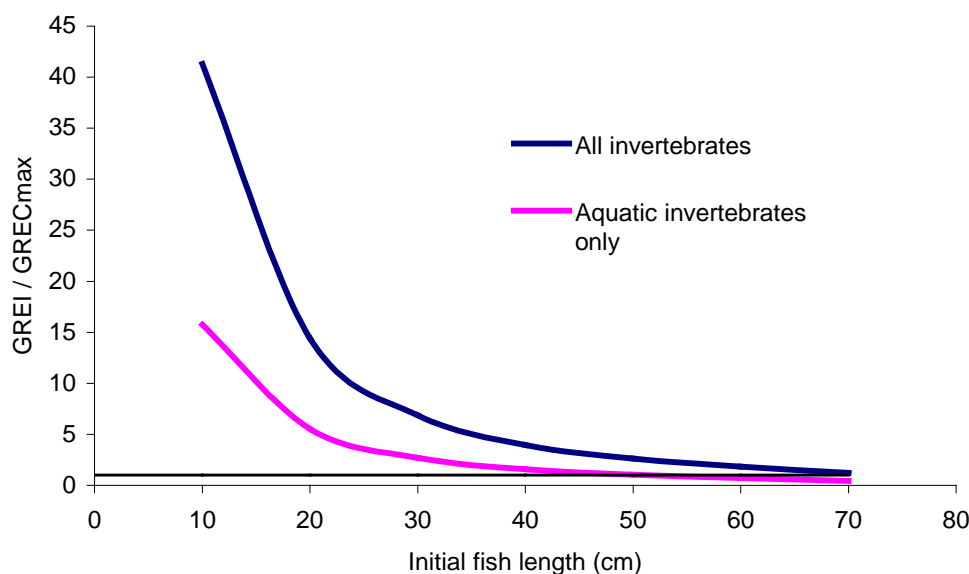


Figure A5.1.1. GREI/ GRECmax predicted with the drift-foraging model for a range of size classes of brown trout for December 2009 for the Taharua. Solid black line indicates GREI/GRECmax = 1, below which trout ought to be food limited. Predictions assume the following minimum prey length x fish length relationships: for trout ≤ 30 cm – prey length (in mm) = $0.115 \times$ fish length (in cm); for trout >30 cm – prey length (in mm) = $0.115 \times$ fish length (in cm) – 3 mm.

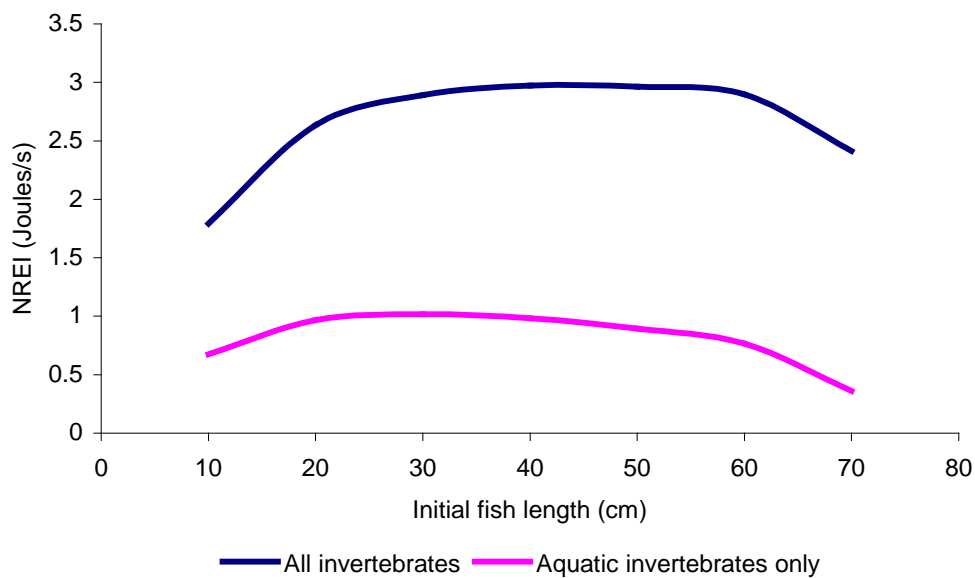


Figure A5.1.2. NREI predicted with the foraging model for a range of size classes of brown trout for December 2009 for the Taharua. Predictions assume the minimum prey length x fish length relationships given in Figure A5.1.1.

A5.2 Mohaka River December 2009

Trout above 60 cm were predicted to be food limited ($GREI/GREC_{max} < 1$) feeding on aquatic drift at both Mohaka River sites (Figures A5.2.1 and A5.2.3) (slightly better than the Taharua River site in spring). With the inclusion of terrestrial invertebrates, the model predicted that trout ≤ 70 cm would not be food limited at either site (Figures A4.2.1 and A4.2.3).

As for summer and autumn, the inclusion of terrestrial prey in autumn made a positive contribution to the potential NREI for trout across all the size classes at all the sites (Figures A.5.1.2, A5.2.2 and A5.2.4). In spring the contribution of terrestrial drift was comparable to summer at the upstream Mohaka site and lower in autumn (compare Figure A5.2.2 with Figures A3.2.2 and A4.2.2).

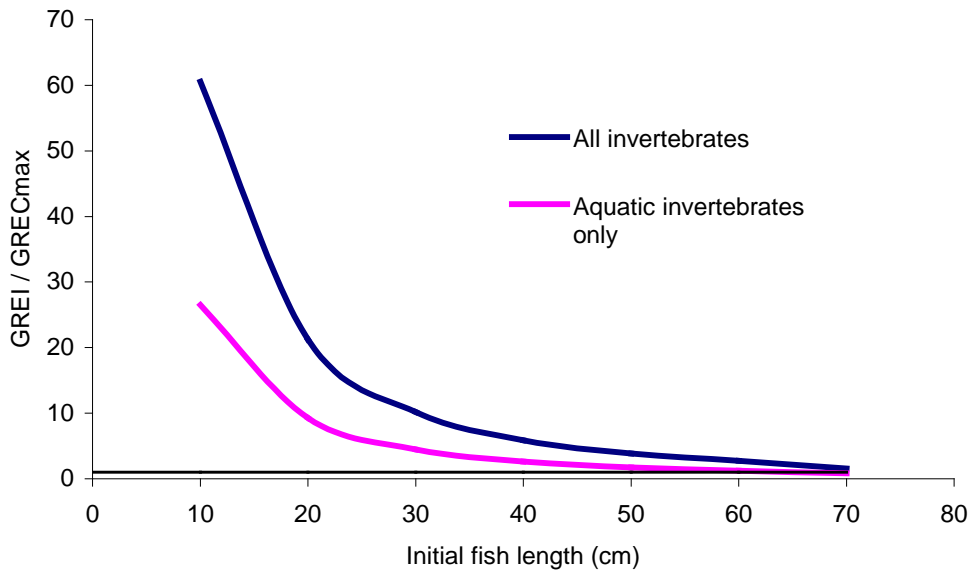


Figure A5.2.1. GREI/ GRECmax predicted with the drift-foraging model for a range of size classes of brown trout for December 2009 for the upstream Mohaka site. Solid black line indicates GREI/GRECmax = 1, below which trout ought to be food limited. Predictions assume the minimum prey length x fish length relationships given in Figure A5.1.1.

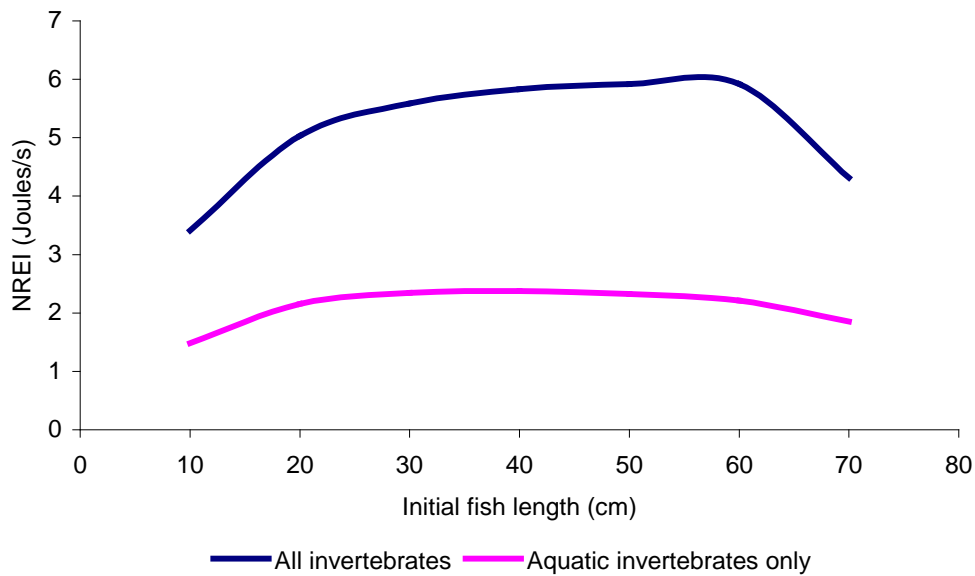


Figure A5.2.2 NREI predicted with the foraging model for a range of size classes of brown trout for December 2009 for the upstream Mohaka site. Predictions assume the minimum prey length x fish length relationships given in Figure A5.1.1.

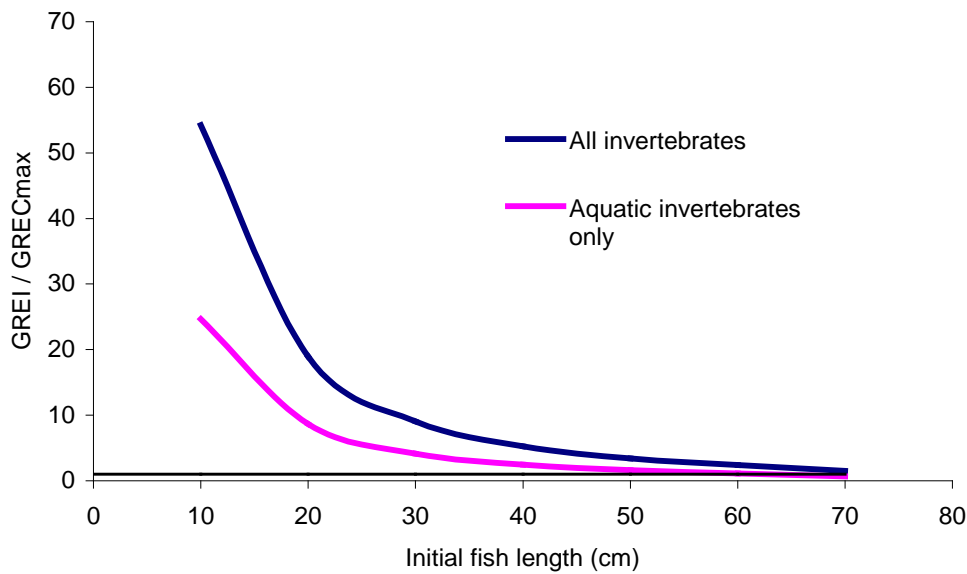


Figure A5.2.3 GREI/ GRECmax predicted with the drift-foraging model for a range of size classes of brown trout for December 2009 for the downstream Mohaka site. Solid black line indicates GREI/GRECmax = 1, below which trout ought to be food limited. Predictions assume the minimum prey length x fish length relationships given in Figure A5.1.1.

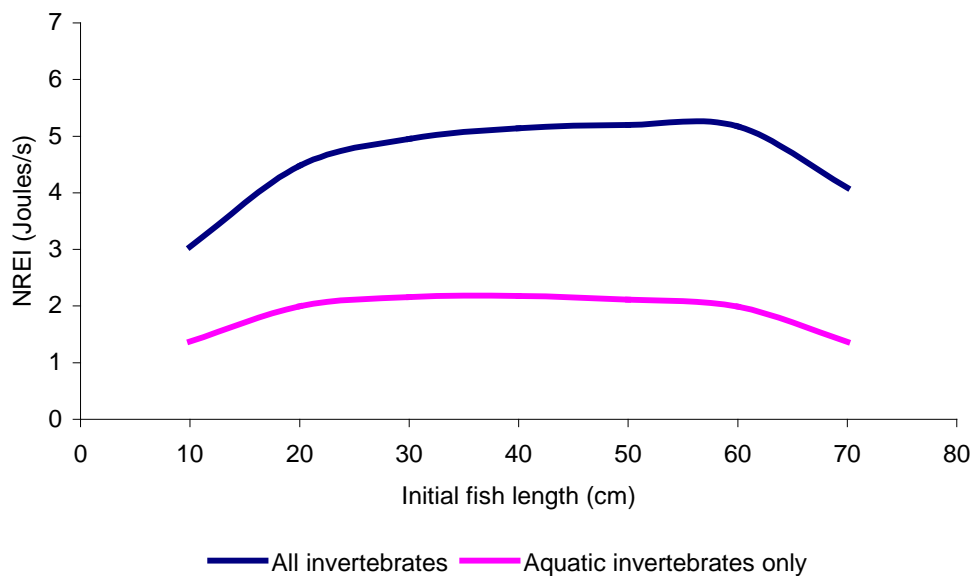


Figure A5.2.4 NREI predicted with the foraging model for a range of size classes of brown trout for December 2009 for the downstream Mohaka site. Predictions assume the minimum prey length x fish length relationships given in Figure A5.1.1.

Appendix 6. Predicted GREI and NREI based on aquatic invertebrate drift and site-specific temperatures.

The following graphs in Appendix 6 have been included for comparison with GREI and NREI graphs calculated using aquatic invertebrate drift and standardised temperature (Sections 3.5.2, 3.5.3 and 3.5.4 of the main report)⁵.

Overall the GREI/GRECmax and NREI predictions based on site-specific temperatures were very similar to those based on standardised temperatures. There were slight shifts in the length at which trout became food-limited (*i.e.* GREI/GRECmax \leq 1) and/or experienced a decline in NREI when predictions were based on site-specific temperatures.

A6.1 Between sites comparison of GREI/GRECmax and NREI for February (summer).

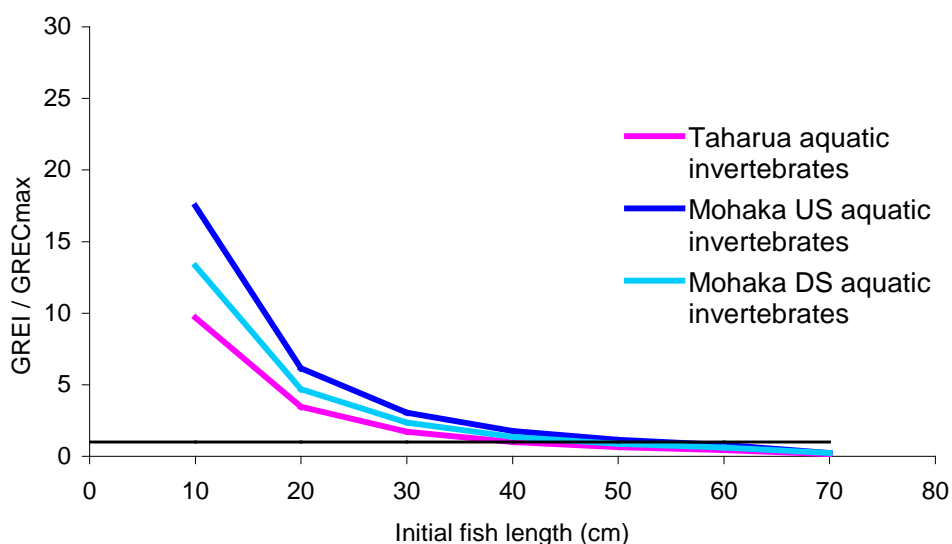


Figure A6.1.1 GREI/ GRECmax predicted with the drift-foraging model for a range of size classes of brown trout in February 2009 for the Taharua and upstream and downstream Mohaka sites. Solid black line indicates GREI/GRECmax = 1, below which trout ought to be food limited. Predictions assume the following minimum prey length x fish length relationships: for 10 and 20 cm trout prey length (in mm) = 0.115 x fish length (in cm); for trout \geq 30 cm – prey length (in mm) = 0.115 x fish length (in cm) – 3 mm.

⁵ See Section 3.5 for site-specific mean temperatures

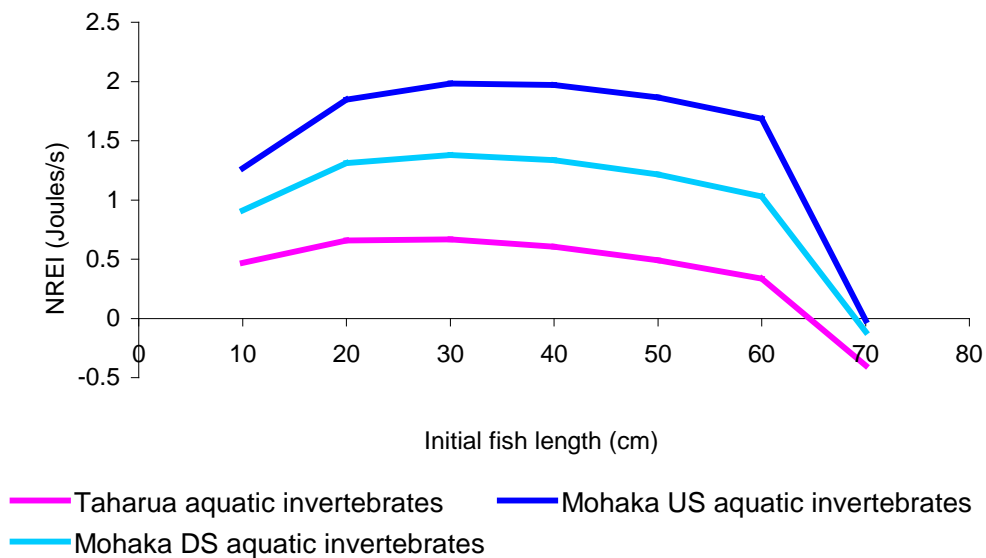


Figure A6.1.2 NREI predicted with the foraging model for a range of size classes of brown trout for February 2009 for the Taharua and upstream and downstream Mohaka sites. Predictions assume the same minimum prey length x fish length relationships as described in Figure A6.1.1.

A6.2 Between sites comparison of GREI/GRECmax and NREI for April (autumn).

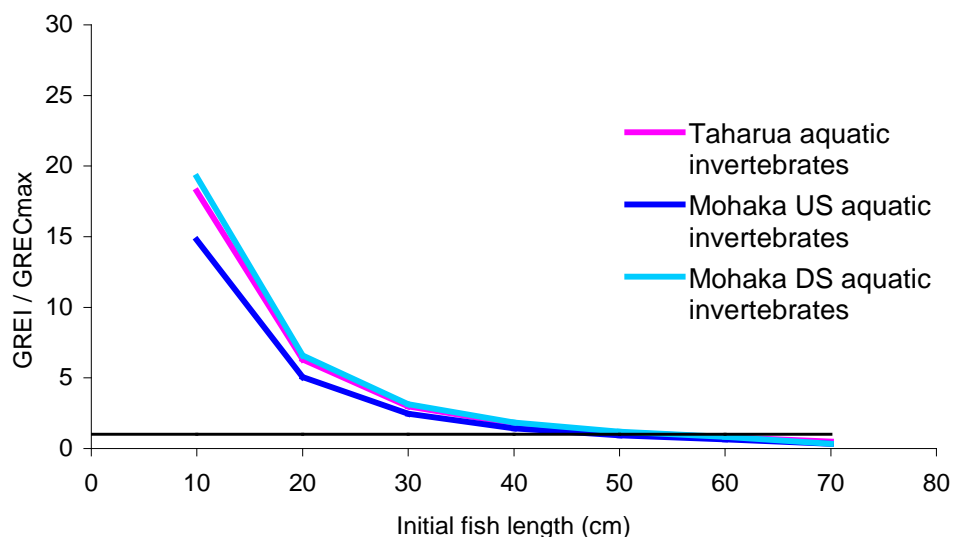


Figure A6.2.1 GREI/ GRECmax predicted with the drift-foraging model for a range of size classes of brown trout for April 2009 for the Taharua and upstream and downstream Mohaka sites. Solid black line indicates GREI/GRECmax = 1, below which trout ought to be food limited. Predictions assume the same minimum prey length x fish length relationships as described in Figure A6.1.1.

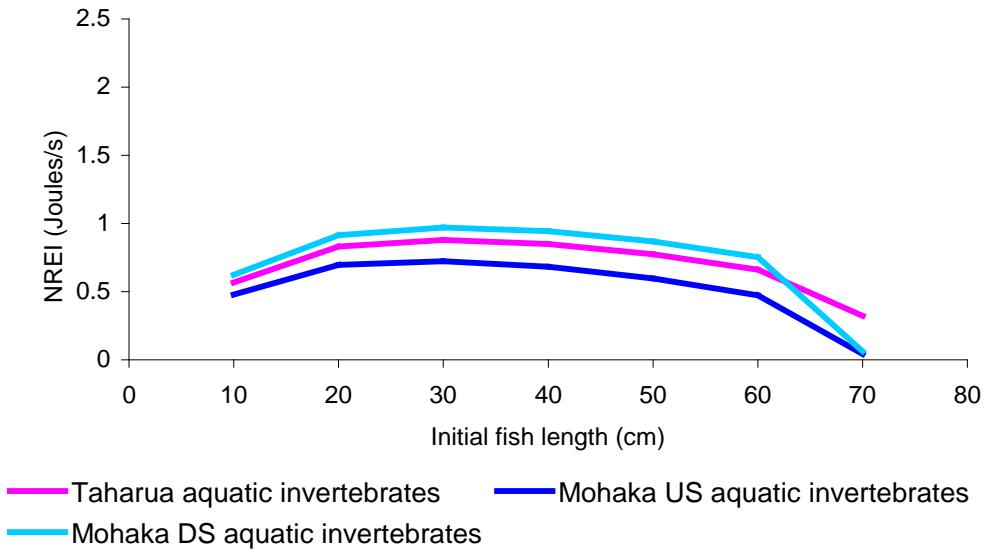


Figure A6.2.2 NREI predicted with the foraging model for a range of size classes of brown trout for April 2009 for the Taharua and upstream and downstream Mohaka sites. Predictions assume the same minimum prey length x fish length relationships as described in Figure A6.1.1.

A6.3 Between sites comparison of GREI/GRECmax and NREI comparison for December (spring).

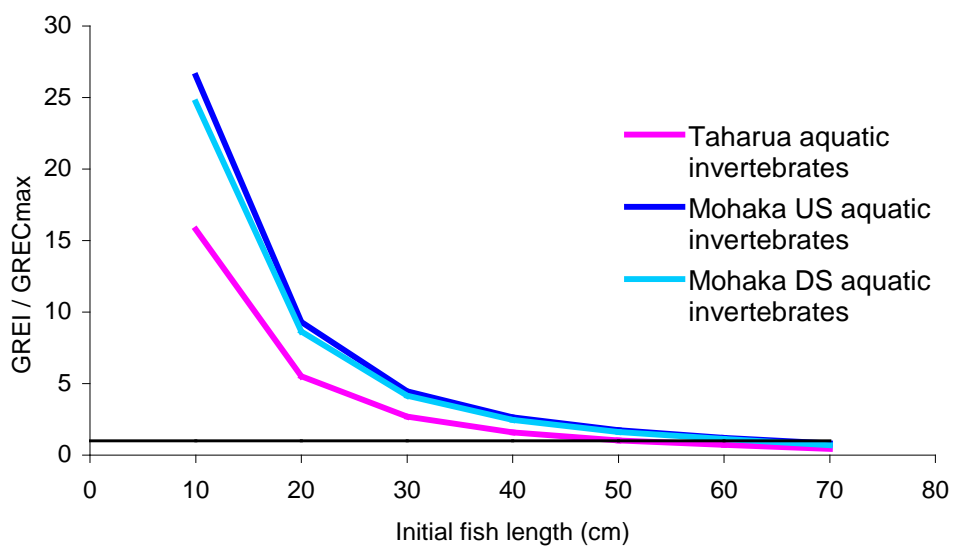


Figure A6.3.1 GREI/ GRECmax predicted with the drift-foraging model for a range of size classes of brown trout for December 2009 for the Taharua and upstream and downstream Mohaka sites. Solid black line indicates GREI/GRECmax = 1, below which trout ought to be food limited. Predictions assume the same minimum prey length x fish length relationships as described in Figure A6.1.1.

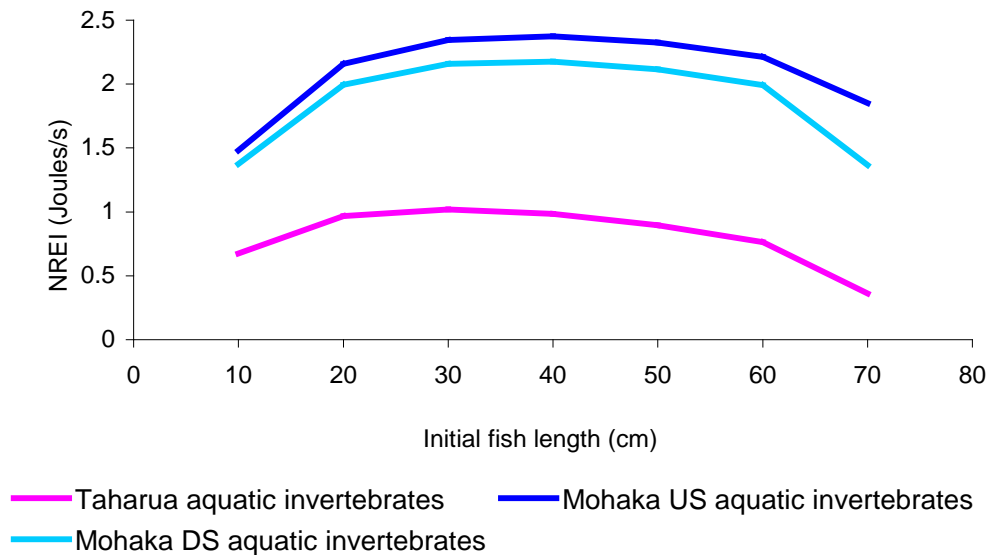


Figure A6.3.2 NREI predicted with the foraging model for a range of size classes of brown trout for December 2009 for the Taharua and upstream and downstream Mohaka sites. Predictions assume the same minimum prey length x fish length relationships as described in Figure A6.1.1.

Appendix 7. Predicted GREI and NREI based on total invertebrate drift (aquatic +terrestrial) and standardised temperatures.

The following graphs in Appendix 7 have been included to show the influence of the addition of the terrestrial component of the drift on the GREI and NREI for fish up to 70 cm in length. These graphs can be compared to the graphs calculated using aquatic invertebrate drift and standardised temperature (Sections 3.5.2, 3.5.3 and 3.5.4 of the main report).

A7.1 Between sites comparison of GREI/GRECmax and NREI for February (summer).

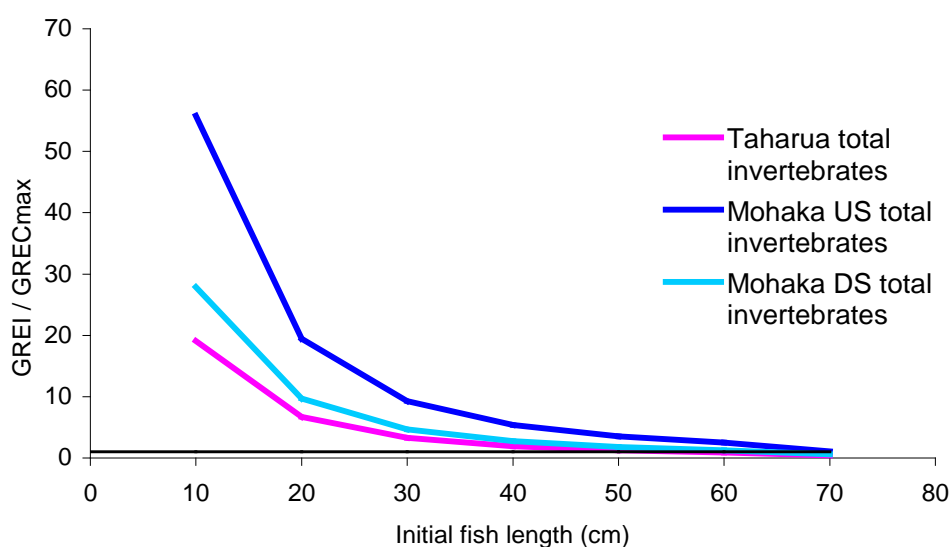


Figure A7.1.1 GREI/ GRECmax predicted with the drift-foraging model for a range of size classes of brown trout in February 2009 for the Taharua and upstream and downstream Mohaka sites. Solid black line indicates GREI/GRECmax = 1, below which trout ought to be food limited. Predictions assume the following minimum prey length x fish length relationships: for 10 and 20 cm trout prey length (in mm) = 0.115 x fish length (in cm); for trout ≥ 30 cm – prey length (in mm) = 0.115 x fish length (in cm) – 3 mm.

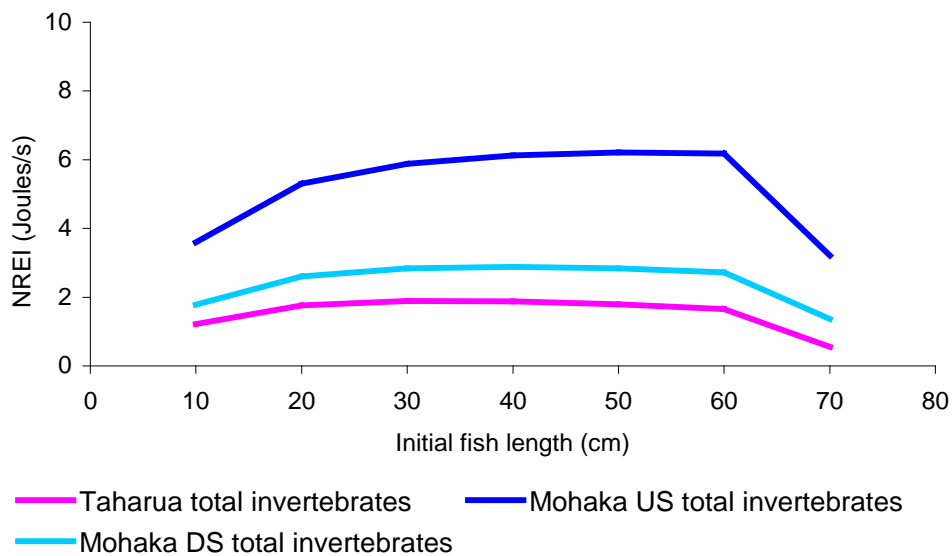


Figure A7.1.2 NREI predicted with the foraging model for a range of size classes of brown trout for February 2009 for the Taharua and upstream and downstream Mohaka sites. Predictions assume the same minimum prey length x fish length relationships as described in Figure A7.1.1.

A7.2 Between sites comparison of GREI/GRECmax and NREI for April (autumn).

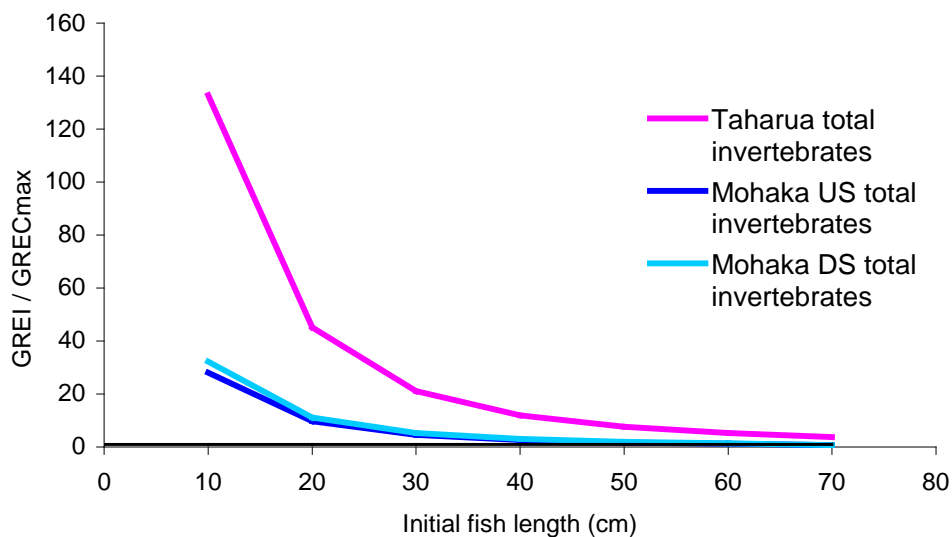


Figure A7.2.1 GREI/ GRECmax predicted with the drift-foraging model for a range of size classes of brown trout for April 2009 for the Taharua and upstream and downstream Mohaka sites. Solid black line indicates GREI/GRECmax = 1, below which trout ought to be food limited. Predictions assume the same minimum prey length x fish length relationships as described in Figure A7.1.1.

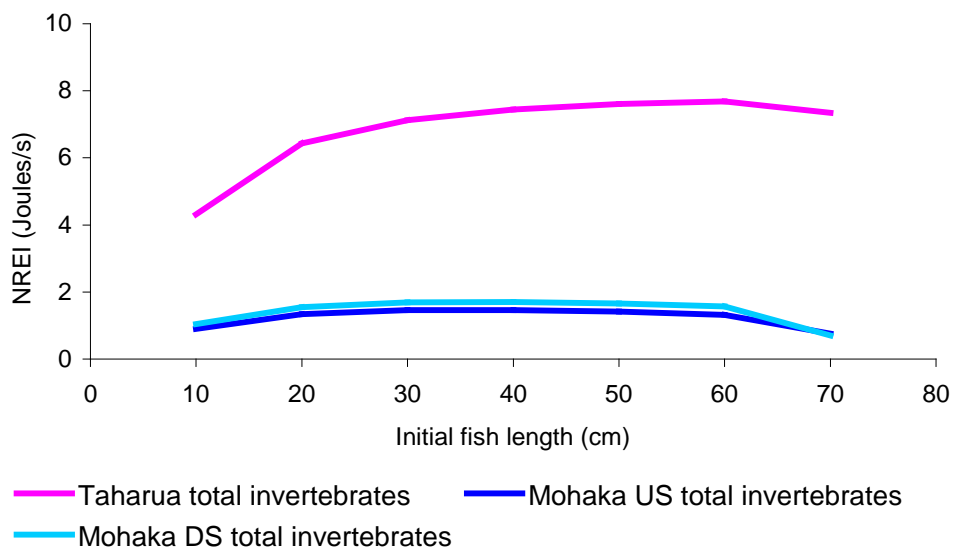


Figure A7.2.2 NREI predicted with the foraging model for a range of size classes of brown trout for April 2009 for the Taharua and upstream and downstream Mohaka sites. Predictions assume the same minimum prey length x fish length relationships as described in Figure A7.1.1.

A7.3 Between sites comparison of GREI/GRECmax and NREI for December (spring).

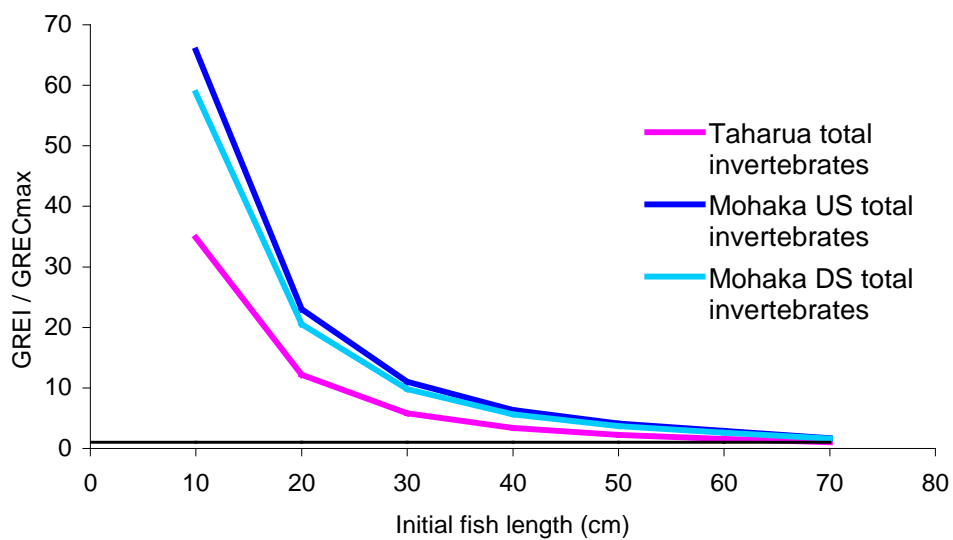


Figure A7.3.1 GREI/ GRECmax predicted with the drift-foraging model for a range of size classes of brown trout for December 2009 for the Taharua and upstream and downstream Mohaka sites. Solid black line indicates GREI/GRECmax = 1, below which trout ought to be food limited. Predictions assume the same minimum prey length x fish length relationships as described in Figure A7.1.1.

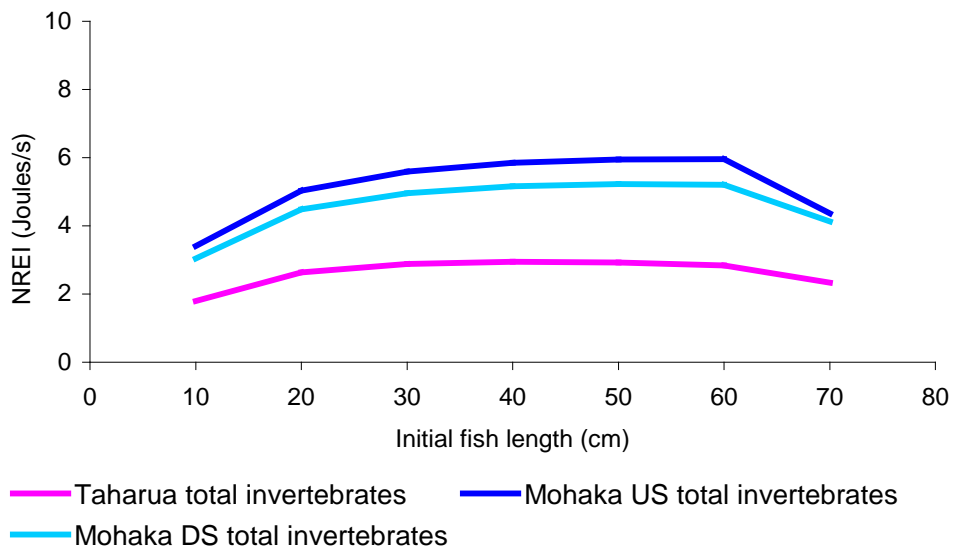


Figure A7.3.2 NREI predicted with the foraging model for a range of size classes of brown trout for December 2009 for the Taharua and upstream and downstream Mohaka sites. Predictions assume the same minimum prey length x fish length relationships as described in Figure A7.1.1.

Appendix 8. Predicted GREI and NREI based on total invertebrate drift (aquatic +terrestrial) and site-specific temperatures.

The following graphs in Appendix 8 have been included for comparison with GREI and NREI graphs calculated using aquatic and terrestrial invertebrate drift and standardised temperature (see Appendix 7).⁶

Overall the GREI/GRECmax and NREI values predicted using site-specific temperatures were again very similar to those using standardised temperatures (Appendix 7).

A8.1 Between sites comparison of GREI/GRECmax and NREI for February (summer).

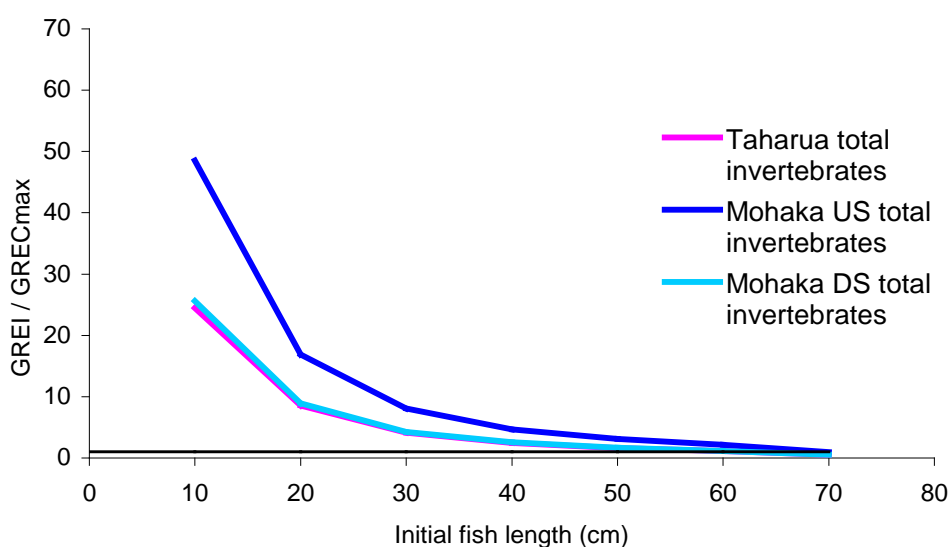


Figure A8.1.1 GREI/ GRECmax predicted with the drift-foraging model for a range of size classes of brown trout in February 2009 for the Taharua and upstream and downstream Mohaka sites. Solid black line indicates GREI/GRECmax = 1, below which trout ought to be food limited. Predictions assume the following minimum prey length x fish length relationships: for 10 and 20 cm trout prey length (in mm) = 0.115 x fish length (in cm); for trout ≥ 30 cm – prey length (in mm) = 0.115 x fish length (in cm) – 3 mm.

⁶ See Section 3.5 for site-specific mean temperatures.

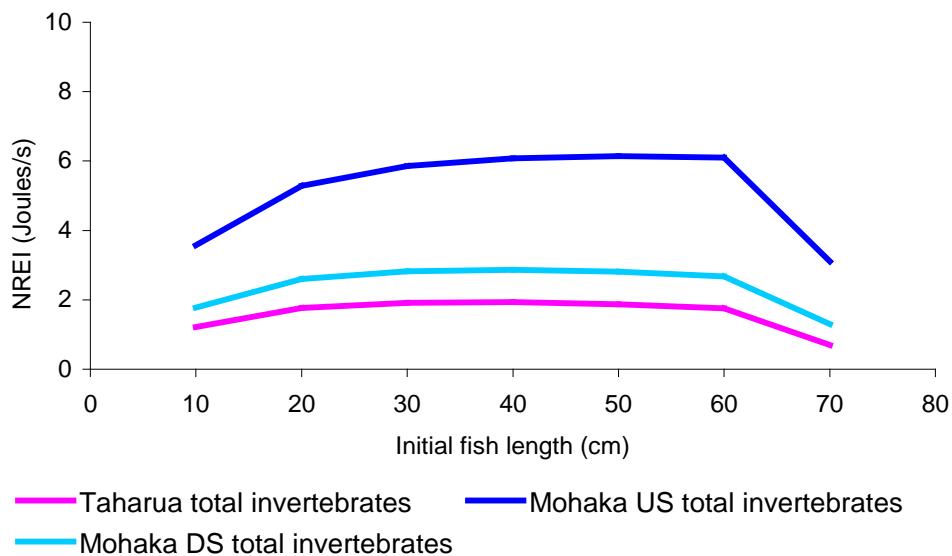


Figure A8.1.2 NREI predicted with the foraging model for a range of size classes of brown trout for February 2009 for the Taharua and upstream and downstream Mohaka sites. Predictions assume the same minimum prey length x fish length relationships as described in Figure A8.1.1.

A8.2 Between sites comparison of GREI/GRECmax and NREI for April (autumn).

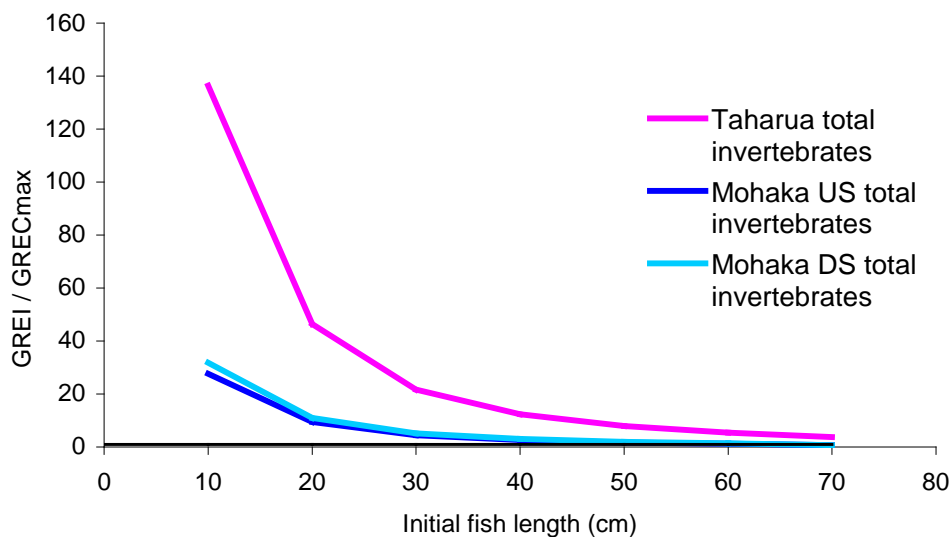


Figure A8.2.1 GREI/ GRECmax predicted with the drift-foraging model for a range of size classes of brown trout for April 2009 for the Taharua and upstream and downstream Mohaka sites. Solid black line indicates GREI/GRECmax = 1, below which trout ought to be food limited. Predictions assume the same minimum prey length x fish length relationships as described in Figure A8.1.1.

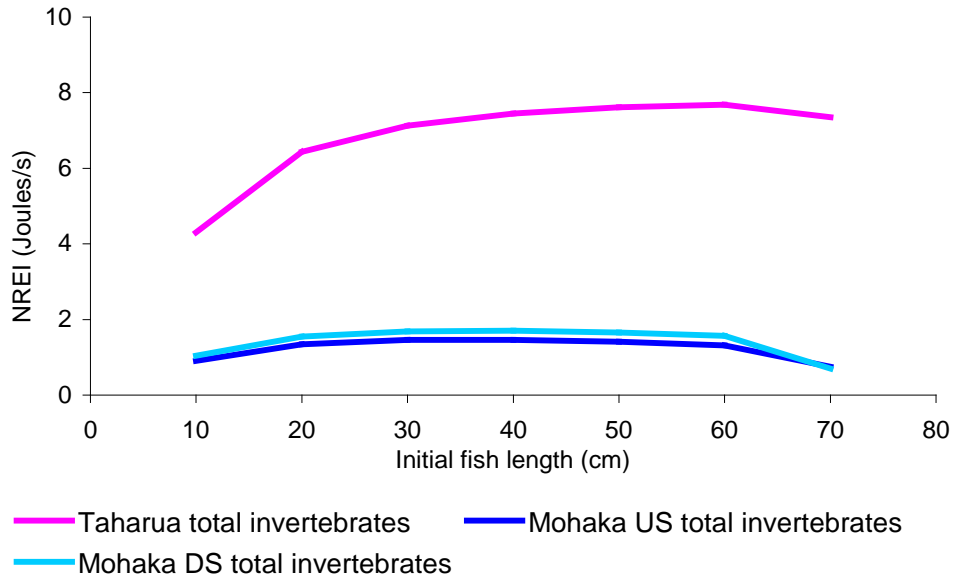


Figure A8.2.2 NREI predicted with the foraging model for a range of size classes of brown trout for April 2009 for the Taharua and upstream and downstream Mohaka sites. Predictions assume the same minimum prey length x fish length relationships as described in Figure A8.1.1.

A8.3 Between sites comparison of GREI/GRECmax and NREI for December (spring).

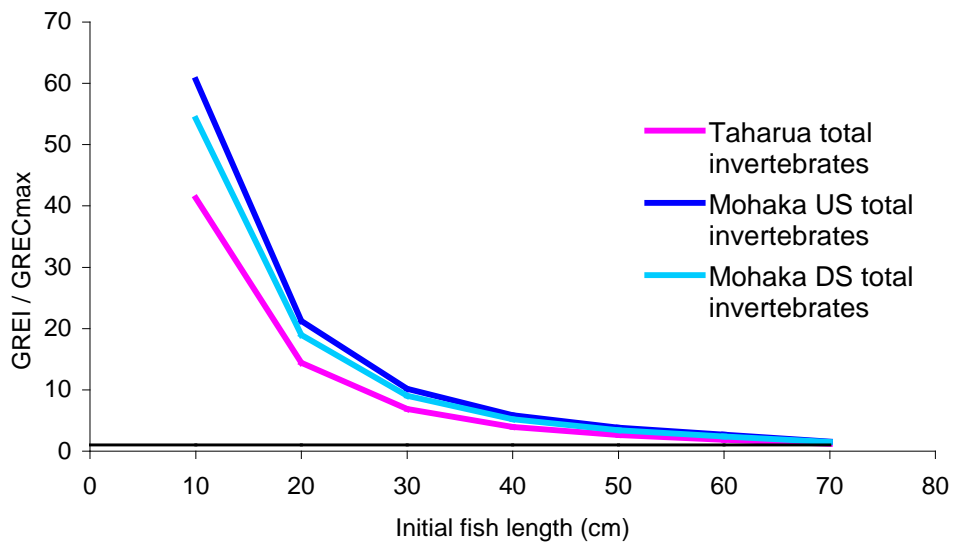


Figure A8.3.1 GREI/ GRECmax predicted with the drift-foraging model for a range of size classes of brown trout for December 2009 for the Taharua and upstream and downstream Mohaka sites. Solid black line indicates GREI/GRECmax = 1, below which trout ought to be food limited. Predictions assume the same minimum prey length x fish length relationships as described in Figure A8.1.1.

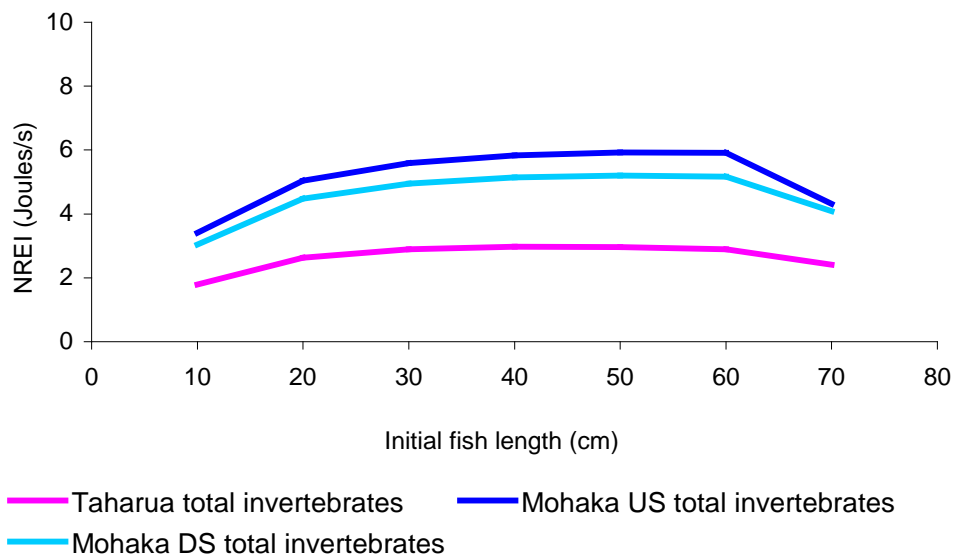


Figure A8.3.2 NREI predicted with the foraging model for a range of size classes of brown trout for December 2009 for the Taharua and upstream and downstream Mohaka sites. Predictions assume the same minimum prey length x fish length relationships as described in Figure A8.1.1.