

Interim Report: Invertebrate Drift And Trout Growth Potential In A Didymo (*Didymosphenia geminata*) Affected Reach Of The Mararoa River

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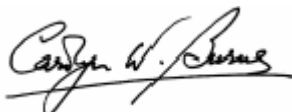
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EXECUTIVE SUMMARY

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. Didymo (*Didymosphenia geminata*) is an exotic benthic diatom which can cover kilometres of riverbed in dense mats up to 20 cm thick. These proliferations have the potential to alter the aquatic invertebrate food base for trout with negative consequences for growth and carrying capacity. These, and other, 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.

This report presents results of a study of invertebrate drift and growth potential of drift-feeding trout, determined using a drift foraging and bioenergetics growth model, in the Mararoa River (where didymo first became established). The investigation is a first step in assessing the effects of didymo on aquatic invertebrate drift and trout growth. The results are based on sampling one reach on only one occasion (April 2006) and so should be regarded as provisional pending further research.

Under moderate to heavy didymo biomass, invertebrate drift density and biomass were low and large aquatic invertebrates (> 10 mm) that are preferred by large trout were rare. Modelling predicted that food consumption and growth of drift-feeding trout larger than 20 cm would be limited and that trout larger than 38 cm would lose weight (i.e. they would have negative growth potential). Historically, trout between 40 and 60 cm have been common in the Mararoa River, its receiving river, the Waiau, and in other New Zealand rivers.

By themselves these results, being based on only one sampling occasion on one reach, are not sufficient to conclude that didymo reduces density of large drifting invertebrates and related growth of drift-feeding trout. Further research, taking account of the variability in drift density over time and space, is needed before definitive conclusions can be drawn. Such research should include: seasonal invertebrate drift sampling and modelling of trout growth and spatial comparisons with river reaches either unaffected by didymo or covering a range of didymo biomass. Modelling studies of the nature presented in this report should also be complemented by studies of actual trout growth and abundance.

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1. INTRODUCTION

1.1. Threats posed by didymo to trout fisheries

Didymo (*Didymosphenia geminata*) proliferations have the potential to alter the aquatic invertebrate food base for trout with negative consequences for growth and carrying capacity, and affect angling success and satisfaction by fouling anglers' lures and reducing aesthetic value. They also could affect water quality parameters such as pH and dissolved oxygen concentrations to a degree that could be harmful for trout. 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. Concerns over didymo impacts on trout fisheries have recently emerged from the USA. South Dakota Game, Fish and Parks biologists have reported that a brown trout population in Rapid Creek underwent severe decline following didymo invasion and proliferation, although whether didymo was the cause is unclear owing to other confounding environmental changes and lack of quantitative data.

With the likelihood of further spread of didymo within New Zealand, and in the absence of effective control measures presently, the publicity surrounding this invasion has the potential to do serious harm to our international trout fishing industry. It is also likely to increase fishing pressure on rivers which remain free of didymo, exacerbating problems that Fish and Game New Zealand has been having in managing increasing angling pressure on backcountry rivers.

In light of the above, it is imperative that the impact of didymo on New Zealand's trout fisheries be understood and communicated among the fishing fraternity and fishing industry. We need to know the nature and severity of the impacts and how widespread they are likely to be (e.g. which rivers are vulnerable and whether the impacts are lasting or variable). The outcomes will be: (1) informed fishing expectations and fisheries management decisions; (2) greater awareness by the public, especially anglers, of the risks of spreading didymo, and need for responsible behaviour in sanitising fishing gear; (3) informed international promotion of trout fishing in New Zealand (e.g. if perceived impacts have been over-stated, then dissemination of independent scientific evidence will help restore New Zealand's reputation as a premier trout angling destination).

1.2. Potential impact of didymo on aquatic invertebrate drift and trout growth

Trout are opportunistic predators that exhibit varied feeding behaviours and have varied diets, though 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.

Growth and size of drift-feeding trout should be limited by the finite energy availability 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 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.

Proliferations of periphyton (biofilm and algae on the river bed) commonly result in a change in aquatic invertebrate community composition, with large, drift-prone, EPT taxa (e.g. mayflies, caddisflies and stoneflies) being replaced by small (chironomids, algal piercing caddis) or non drifting taxa (oligochaetes, snails). Such altered benthic invertebrate communities have been found in association with didymo proliferations in the Mararoa River, (Kilroy et al. 2006). On the other hand, the same study found that total biomass of benthic invertebrates was higher in didymo affected sites than in unaffected sites. A similar result was reported by Shearer et al. 2003 but for native algal proliferations in the Pomahaka River, and in that case even the common mayfly *Deleatidium* spp. (a favoured trout prey) occurred at higher densities at sites with high algal biomass. However, in that study the higher densities of mayflies in the benthos were offset by reduced densities (no./m³) of mayflies in the drift (i.e. high algal biomass may have been inhibiting drift by mayflies).

Didymo proliferations, therefore, have the potential to impair drift-foraging energetics and reduce trout growth rate, thereby favouring small over large trout, through altering taxonomic and size structure of benthic and drifting aquatic invertebrate communities.

1.3. Study objectives

This report presents results of a study of invertebrate drift in the Mararoa River, Southland, where didymo first became established, and the growth potential of trout determined using a drift foraging and bioenergetics growth model (Hayes 2000; Hayes et al. 2000). The main objectives of the study were to:

1. determine aquatic invertebrate drift density, biomass, taxonomic and size composition at a didymo impacted site in the Mararoa River and compare these with historical values available from other rivers without didymo which support valued trout fisheries;

2. assess whether drift estimated in the study reach would potentially limit food consumption and growth by trout, based on predictions from the drift foraging and bioenergetics model.

The results are based on sampling one reach on only one occasion (April 2006) and so should be regarded as provisional pending further quarterly sampling over 2006 – 2007.

A secondary objective was to determine whether trout diet largely comprised drifting invertebrates, which was an assumption underpinning the growth predictions for drift-feeding trout. We did not sample trout from the Mararoa River for diet analysis because the river was too large to catch trout easily given the limited budget, time, and staff available. Instead we undertook this work in the upper Oreti River which was small enough for one diver to catch trout easily with a hand net. The reason for the ease of capture was that in such a small river, with overhanging bank and instream debris cover, large brown trout are relatively confined and attempt to hide in cover rather than swimming away from a diver. It is then a simple matter for the diver to place the net in front of the fish and scare it into the net. Brown trout in particular display this kind of hiding behaviour. While it is also possible to catch some trout in this manner in larger rivers, most trout, especially rainbows, evade capture by fleeing from divers.

The diet data from the upper Oreti River was collected for two reasons: (1) to bolster observations by fisheries scientists and anglers that trout feed predominantly on drift in back country rivers – and in this case on a Southland River in close proximity to the Mararoa; (2) to verify the minimum prey size thresholds (dependent on trout size) assumed in our trout growth model (see section 2.2.3).

An objective of future research should be to collect trout diet data from the Mararoa, or other didymo affected river, to determine the relative importance of drift feeding by trout in the presence of didymo. Drift netting (a gill net drifted with the current) or beach seining are the most promising methods for sampling trout for this objective.

2. METHODS

2.1. Data collection

2.1.1. *Water temperature*

A water temperature logger was installed under Station Bridge in the Mararoa River on 2 April 2006 and set to log at 30 minute intervals. These data were used to estimate mean daily water temperature for the month of April for trout growth modelling.

2.1.2. Periphyton

The biovolume of didymo was estimated in a run and a riffle according to the visual assessment methodology developed by Kilroy et al. (2006). This was done to provide an index of didymo biomass at the time of drift sampling for referencing with future drift sampling on the Mararoa and other rivers (e.g. Oreti River), and with benthic macroinvertebrate sampling undertaken by NIWA¹.

Visual estimates of didymo were made at 20 points across a run and a riffle within the sampling reach. At each point depth, water velocity at 0.4 x depth, and near bed water velocity (i.e. just above the stream substratum) was measured. A stone representing the sampling point was retrieved and a visual assessment made of the percentage cover of didymo on the stone surface. The average thickness of the mat was also estimated (calibrated against measurement with a ruler) and assigned a thickness score from 0 to 5 as follows: 0, none; 1, thin (< 1 mm thick); 2, medium (1-5 mm); 3, thick (6-15 mm); 4, very thick (16-30 mm); 5, extremely thick (> 30 mm). The percentage cover of other algae on the stone was assessed, placing these growths into categories based on colour and thickness. The categories were: green filamentous algae; thick brown/black mats; thin brown/black film; slimy diatom mats, mainly *Cymbella* sp. Percentage cover of didymo was multiplied by the thickness score to get a biovolume index between 0 and 500.

2.1.3. Invertebrate drift

Drift sampling was undertaken in the Mararoa River on 5 April 2006, within a reach of about 500 m up- and downstream of Station Bridge (2117612 E, 5510813 N NZMS 260). The river flow during sampling was 5.53 m³/s and the mean daily water temperature was 11.9 °C.

Invertebrate drift was sampled at eight sites along the 1 km reach during the day and dusk. At each site, two 0.18 m² (0.5 mm mesh) drift samplers were stacked vertically in the water column at approximately mid-depth and at the surface. Allowing for invertebrate width - length relationships, the 0.5 mm mesh retains invertebrates > 3 mm (Hayes et al. (2000), K Shearer, unpublished data). The level of sampling effort (i.e. eight sites on one day) was chosen to achieve 95 % confidence intervals within 25 % of the mean (Shearer et al. 2002).

Samplers were positioned in 0.50 - 0.72 m deep water in the margins of runs where water velocities were sufficient to keep large drifting invertebrates in suspension and within or slightly greater than the suitable range for drift feeding by adult brown trout (Hayes & Jowett 1994). Trash racks (1 x 0.5 m frames with 1 cm spaced nylon fishing line strung lengthwise) were deployed in front of each sampler to catch drifting didymo clumps to minimise clogging of the nets and contamination of drift samples. Didymo which was caught on the trash racks

¹ NIWA is using Kilroy et al.'s (2006) visual assessment protocol to index didymo biomass in their benthic invertebrate sampling programme associated with their Didymo Ecology Phase 2 project for BNZ. The didymo biomass index provides a common thread for comparisons between Cawthron's invertebrate drift and NIWA's benthic invertebrate results.

was discarded without checking whether invertebrates were attached to it. Drifting didymo clumps may have contained an invertebrate fauna and some drifting invertebrates may have attached themselves to didymo clumps caught on the trash racks. We did not examine drifting didymo clumps to verify whether they contained invertebrates. We assumed that any invertebrates contained in drifting didymo clumps were not available to drift-feeding trout. The trash racks efficiently intercepted large didymo clumps (> 1 cm) but smaller clumps passed through and were caught in the drift nets. If our assumption that invertebrates associated with didymo clumps are not eaten by trout is correct then our drift samples will overestimate the density of invertebrate drift available to drift-feeding trout. On the other hand if drifting invertebrates were intercepted and retained by didymo clumps caught on the trash racks then we will have underestimated drift density (note that this assumes didymo clumps on the trash racks act as a filter). Anglers have reported that trout, particularly rainbows, have large amounts of didymo in their stomachs. Whether trout ingest didymo with the intention of eating invertebrates attached to it is unknown, but they would, nevertheless, derive some benefit from incidental ingestion of such invertebrates. Whether didymo clumps contain an invertebrate fauna and whether didymo clumps that attach to the trash racks filter drifting invertebrates ought to be the subjects of future research.

Sampling effort was broken into two periods: daylight and dusk. Daylight sampling commenced about 9.30 a.m. and dusk sampling about 5.40 p.m. and ended at about 7.25 p.m. when light level declined to $3 \times 10^{-5} \text{ kg/s}^3$ (0.02 lx).

Water velocity was measured within the mouths of the drift samplers with an electromagnetic current meter to allow estimation of volume of water sampled. During daylight sampling, which extended for 8.20 hours², 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 dislodge algae, and then redeployed in an attempt to prevent clogging. Nonetheless, occasional clogging of some samplers was detected. Volumes of water sampled over sampler deployment and redeployment periods (following washing) were estimated from the mean of water velocities measured at the beginning and end of sampler deployment periods. At dusk, water velocities in samplers were recorded only at the commencement of sampling (sampling duration was only 1.60 – 1.98 hours).

Drift samples were preserved with a mixture of 100 % ethanol and 2.5 % glyoxal (a formalin substitute).

2.1.4. Trout stomach samples

Stomach contents from a sample of 21 trout (585 – 700 mm fork length; 1.5 - 3.7 kg) were collected for diet analysis from the upper Oreti River downstream of Mt Nicholas Station

² Three samplers (top and mid sampler at one site and mid sampler at one site) were deployed for only 3.7 hours near the end of the day time sampling period after the original nets became separated from the sampling frames).

Bridge to determine the relative importance of drift versus benthic invertebrate foraging and piscivory (Appendix 2). The trout were obtained by Southland Fish and Game divers using hand nets. To minimise killing trout, 57 % of the samples were obtained by stomach flushing anaesthetised fish.

2.1.5. Sample processing

Invertebrate drift samples

A modified version of macroinvertebrate sample processing Protocol P3 (Stark et al. 2001) was developed for this project. Because the drift sampler trash racks were not entirely effective, considerable volumes of didymo were collected in the drift samples necessitating sub-sampling during processing.

The top and mid samples from each site were combined, then washed by elutriating through a 0.5 mm mesh sieve and teased apart in water to separate the invertebrates from the algae. The sample was then placed into a white sampling tray, which was separated into 16 equal segments by a 4 by 4 metal grid. Five segments were randomly chosen and pooled to provide the sub-sample for processing. A power analysis on all 16 segments from a sample indicated that processing more than five segments increased effect size (ability to estimate the true mean) by less than 2 % per additional segment. Effect size achieved with five segments ranged from 12.5 % and 17.7 % for 6 - 9 mm and 3 - 6 mm invertebrates, respectively (for Power = 0.8 and $\alpha = 0.05$).

For each sub-sample (i.e. five segments combined), invertebrates were sorted into 3 mm length classes, identified (to species level where practical, or coarser) and counted. Invertebrate abundances for the sub-sample were multiplied by 3.2 (i.e. 16/5 segments) to estimate abundance for the entire sample. Because large invertebrates (> 9 mm) have a disproportionate affect on drift biomass (and therefore predicted trout growth), but were comparatively rare, the unprocessed sample residue was scanned and large invertebrates removed, processed as for the sub-sample and included in the final results.

Trout stomach samples

Invertebrates from each trout stomach were sorted into 3 mm length classes, identified (to species level where practical, or coarser) and counted.

2.2. Data analysis and modelling

2.2.1. Invertebrate drift

Size-class specific drift densities (no. / m³) for each sample were calculated by dividing numbers of invertebrates per size class by water volume sampled (sampler cross sectional area x mean water velocity x sampling duration). Excel macros for taxon-specific length-biomass

relationships were used to estimate mean invertebrate dry weight and energy content for each 3 mm size class in each sample (using length-dry weight and taxa-energy content regressions from the literature).

Using length-biomass relationships from the literature is much more cost efficient 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 & Watzon 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 in assessing ecological impacts of didymo. For instance, if invertebrate condition in didymo affected rivers is less than that predicted by the literature length-biomass relationships used in our study then we will be overestimating invertebrate biomass and also predicted trout growth rate (i.e. we will have underestimated impacts of didymo). This also has implications for NIWA's ongoing investigation of the ecological effects of didymo on benthic invertebrates (in which length-biomass relationships are now being used to estimate mean invertebrate biomass from density data). This matter requires further research.

Size-class specific drift densities, dry weights and energy content estimated for each sample were averaged for all eight samples from the study reach to provide data input to the trout drift foraging and bioenergetics growth model.

Percent taxonomic and size-class composition was determined for drift density and biomass from the pooled samples. Drift density and biomass estimates and taxonomic composition from the Mararoa River were compared with three other South Island rivers supporting valued trout fisheries.

2.2.2. *Trout stomach contents*

The data from all 21 trout stomachs were combined to provide an overall representation of the prey items in the diet by percent taxonomic and size-class composition. An assessment was made on whether each prey taxon was drift prone to infer the proportion of prey likely to have been captured by drift foraging.

2.2.3. *Trout bioenergetics growth modelling*

Daily consumption and growth rate were predicted for drift-feeding brown trout for the 28 day period from 3 - 30 April 2006 using the coupled drift foraging and bioenergetics growth model "Trout_Energetics2" described in Hayes (2000) and successfully tested by Hayes et al. (2000). The bioenergetics growth model uses bioenergetics equations developed by Elliott (1976) and Elliott & Hurley (1999).

Bioenergetics models comprise suites of metabolic equations that quantify functional relationships between water temperature and other physical variables, consumption, digestion, metabolic, kinetic, and growth processes in fish using energy as a common unit. In essence, they quantitatively describe the working and efficiency of the fish's "engine". 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. Together, foraging and bioenergetics models can be used to determine how fish make a living within their environment.

Hayes et al.'s (2000) coupled foraging and bioenergetics growth model specifically addresses growth on a drifting invertebrate diet when data on drift are available. In addition to Hayes et al.'s successful test of the coupled model in New Zealand, the trout growth model, based on Elliott's (1976) and Elliott & Hurley's (1999) bioenergetics equations, have been rigorously tested in Europe (Elliott 1994; Elliott 2000). The coupled drift foraging and bioenergetics growth model used in this study is more fully described in Appendix 1.

Water temperature, required to drive the model, was obtained from the temperature logger installed under Station Bridge. The 30 minute temperature records were converted to daily means for input to the model.

Invertebrate drift data were summarised as described in section 2.2.1 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 volume of water sampled during each time period (for drift density), or the proportion of the sampling time in each period (for energy and dry weight).

To model drift foraging and trout growth, "Trout Energetics2" (Hayes 2000) requires the daytime drift foraging period to be estimated and an assumption to be made about night time foraging. The foraging radius of drift-feeding trout declines with reduction in light intensity. 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 a successful test of the model on the Maruia River. Using this same light threshold, we set the drift-foraging period to 13 h for the first half of April (3 - 15 April) and 12 h for the remainder of the month (16 - 30 April). This was based on the observed light level recordings taken during drift sampling on the Mararoa River adjusted for the change of photoperiod over April calculated using a day-length calculator on the internet (<http://www.qpais.co.uk/modb-iec/dayleng.htm>).

For night foraging, we assumed that trout were able to achieve maximum rations, without expending appreciable energy on foraging other than the small latent feeding and other activity costs in Elliott's (1976) and Elliott & Hurley's (1999) bioenergetics equations (see Hayes 2000). This was the same assumption made by Hayes et al. (2000) in their successful test of the model on the Maruia River.

Daily energy consumption and growth rate were modelled for seven size classes of trout for the period 3 - 30 April, progressing in 10 cm length increments from 10 cm to 70 cm. The initial weight of fish in each size class (Table 1) was estimated from a length/weight relationship calculated for brown trout in the Maruia River (Hayes et al. 2000).

Table 1. Initial weights for trout growth modelling estimated from initial length of 10 cm size classes using a brown trout length/weight regression from the Maruia River (from Hayes et al. 2000).

Initial fish length (cm)	Initial fish weight (g)
10	13
20	96
30	305
40	691
50	1302
60	2187
70	3389

The model was run assuming that the trout were feeding exclusively on invertebrate drift during the daytime foraging period (with consumption estimated by the drift-foraging model) and maximum invertebrate rations at night. The energetic costs of drift foraging were included. The foraging model assumes that the 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 during the day, and all night.

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 is not limiting for drift-feeding trout – given the restricted size range of most drifting invertebrates. The minimum prey length relationship is: prey length (in mm) = $0.115 \times \text{fish length (in cm)}$, 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 trout < 20 cm because it is the 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 of size classes available in the drift.

Diet analysis from trout in the upper Oreti River undertaken for this study indicated that trout fed on smaller prey than the above minimum prey size predictions. In order to examine the influence of this on predicted growth we also ran the model with minimum prey size reduced by 3 mm.

Trout consumption and growth rate predictions for the Mararoa River were made for the following two invertebrate drift diet scenarios:

1. all drifting invertebrates including aquatic and terrestrial sources;
2. only aquatic drifting invertebrates.

For comparison, consumption and growth rate predictions were also made for the Maruia River (where Hayes et al. 2000 conducted their successful test of the model) using aquatic invertebrate drift data collected from that river in April 1995 and the water temperature and foraging period data from the Mararoa River.

Maximum potential daily energy consumption by trout was also estimated. This allowed energy consumption based on drift to be expressed as a proportion of maximum consumption, which is a measure of the degree of predicted food limitation experienced by drift-feeding trout.

No allowance was made for a reproduction energy deficit at the beginning of the modelled period (as would normally be applied in spring – see Hayes 2000), under the assumption that mature trout that had spawned the previous winter would have regained their energy reserves and be gaining weight by April (i.e. they should be in a growth (in weight) phase).

3. RESULTS

3.1. Periphyton

The average visual biovolume index of didymo in the riffle and run surveyed in the Mararoa study reach was 292 and 194, respectively. As the biovolume scale ranges from 0 - 500, this would suggest that at the time of sampling, didymo coverage of the substrate was moderate. In the riffle, coverage of didymo was most evident along the margin – with little found in mid-channel (thalweg) where mean column water velocity was high (0.84-1.15 m/s). In the run, mean water velocities were moderated (0.06 – 0.73 m/s) and didymo coverage was more uniform across the channel. However, Larned et al. (2006) described this reach as heavily infested with didymo when they assessed it about two weeks after us during which time a

major flood occurred. Therefore, for consistency it might be better to consider the Mararoa reach as supporting a moderate to heavy level of didymo biomass during our drift sampling.

3.2. Invertebrate drift

Thirty-three aquatic invertebrate taxa were identified from the Mararoa River day drift samples and 24 from the dusk samples (Appendix 3, 4). Twenty taxa were found in common between the day and dusk samples. Mayflies, beetles and caddisflies were the most common drifting invertebrate groups, contributing 89.1 % to day drift and 87.5 % to dusk drift (Figure 1). Mayflies and aquatic Diptera contributed a higher proportion of the dusk drift than day drift, whereas the proportions of caddisflies and beetles were lower during dusk than day. The mayfly *Deleatidium* spp. (larvae and adults) was the most abundant drifting invertebrate, contributing 49.6 % and 55.2 % to day and dusk drift respectively.

Taxa that are generally associated with high algal biomass such as algal piercing caddis (*Oxyethira* spp.) and chironomids were not common in the drift (Appendix 3, 4), although this may have been 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, but the 6 - 9 mm size class contributed the greatest biomass (Table 2). Extrapolation of the patterns evident in Table 2 suggests that invertebrates < 3 mm are likely to be the most abundant in the drift, but make a comparatively minor contribution to total biomass. Moreover, as discussed in section 2.2.3, invertebrates < 3mm are expected to be ignored as prey by trout > 20 cm.

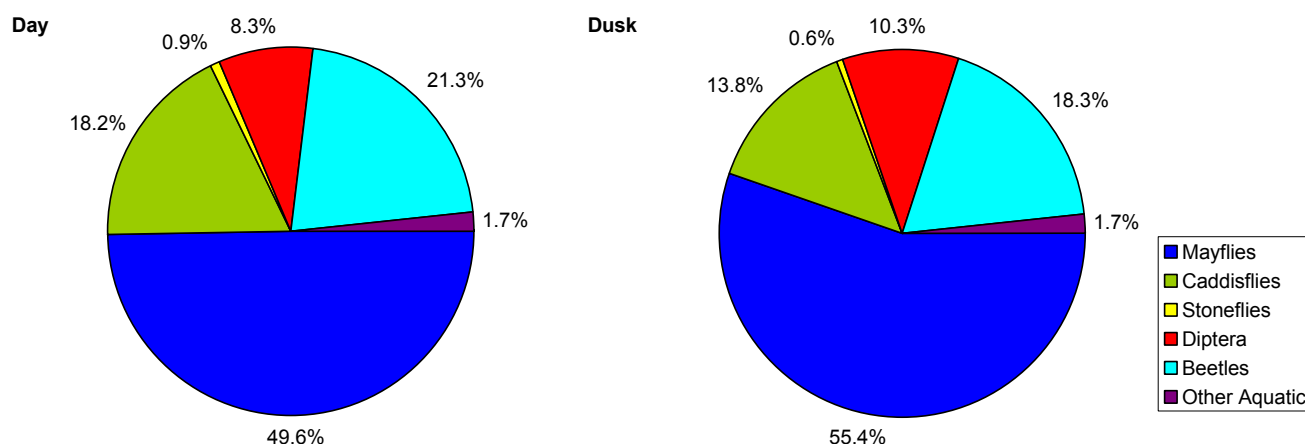


Figure 1. Percentage composition by number of main aquatic invertebrate groups in April 2006 day and dusk drift samples from the Mararoa River.

Drift densities and biomass recorded from the Mararoa River can be placed in perspective by comparison with other rivers. Table 3 lists mean drift density and biomass estimates for the Maruia, Waikaia, lower Pomahaka, and Mararoa rivers and Table 4 lists background

information on flow, temperature, and periphyton biomass indices from the same rivers. The data from the other rivers was collected by Cawthron in February and April during past research programmes on trout bioenergetics growth modelling funded by the Foundation for Research, Science and Technology and Fish and Game New Zealand.

Aquatic invertebrate drift density and biomass was similar among the three Southland and Otago rivers (Table 3) and significantly higher in the Maruia River. The Mararoa and Waikaia had the lowest density and biomass estimates. Although drift density in the Mararoa River was slightly higher than in the Waikaia, biomass was relatively lower (but not significantly lower), indicating invertebrates were, on average, smaller in the Mararoa. Figure 2 demonstrates this point further, with the Waikaia drift having higher proportions of large invertebrates than the Mararoa.

Table 2. Mean drift density and biomass (\pm SE) for each 3 mm size class of aquatic invertebrates in the Mararoa River (April 2006). “-” indicates no animals were found in this size class.

Size class midpoint (mm)	Density (no./m ³)	Biomass (mg/m ³)
4.5	0.130 (0.020)	0.058 (0.009)
7.5	0.084 (0.014)	0.148 (0.032)
10.5	0.003 (0.001)	0.007 (0.003)
13.5	0.002 (0.001)	0.007 (0.004)
16.5	<0.001 (<0.001)	0.001 (0.001)
19.5	<0.001 (<0.001)	<0.001 (<0.001)
22.5	-	-
25.5	<0.001 (<0.001)	<0.001 (<0.001)
28.5	<0.001 (<0.001)	<0.001 (<0.001)
223.5 ¹	<0.001 (<0.001)	0.003 (0.003)

¹ Gordian worm (Nematomorpha)

Table 3. Mean aquatic invertebrate daylight drift density and biomass (\pm standard error) in the Maruia, Waikaia, Pomahaka, and Mararoa rivers. The Maruia is a tributary of the Buller River, the Waikaia is a tributary of the Maitai River (Southland), and the Pomahaka is a tributary of the lower Clutha River (Otago).

	Density (no.m ³)	Biomass (mg.m ³)
Maruia ^a	0.85 (0.18)	1.37 (0.36)
Waikaia ^b	0.21 (0.10)	0.28 (0.09)
Pomahaka ^b	0.29 (0.18)	0.32 (0.14)
Mararoa ^c	0.22 (0.03)	0.23 (0.04)

^aSampled in April 1995.

^bSampled in February 1997.

^cSampled in April 2006.

In the Mararoa and Pomahaka Rivers, the 3 - 6 and 6 - 9 mm size classes contributed over 90 % of the density and over 95 % of the biomass of drifting aquatic invertebrates (Figure 2). In comparison, the large size classes (> 9 mm) were more prominent in drift from the Maruia

and Waikaia Rivers. Of the three reference rivers, the Pomahaka had by far the highest periphyton biomass (as indicated by chlorophyll *a* and AFDW) (Table 4).

Table 4. Flow, water temperature and chlorophyll *a* and AFDW of periphyton for the drift sampling sites in the Maruia, Waikaia, Pomahaka, and Mararoa Rivers.

	Mean water temperature (°C)	Chlorophyll <i>a</i> (mg/m ²)	AFDW (g/m ²)
Maruia ^a	13.9	0.39	0.33
Waikaia ^b	13.0	5.39	9.67
Pomahaka ^b	13.2	74.14	14.470
Mararoa ^c	11.1	n/a	20 – 250 ^d

^aSampled in April 1995. Water temperature is for the month preceding drift sampling.

^bSampled in February 1997. Water temperature is for the month preceding drift sampling.

^cSampled in April 2006. Water temperature is for April 2006 as preceding month data were not available.

^dRange of potential didymo biomass based on relationships between the biovolume index and AFDW presented in Kilroy et al. (2006) Figure A4 from investigations in the Mararoa and Waiau rivers. The AFDW range given in Table 3 covers the lowest and highest AFDW recorded by Kilroy et al. for the biovolume index range that we recorded from the Mararoa River on 5 April 2006 (194 – 292). This provides a conservative estimate of AFDW and this approach was taken because the relationships between AFDW and the biovolume index presented by Kilroy et al. are highly variable.

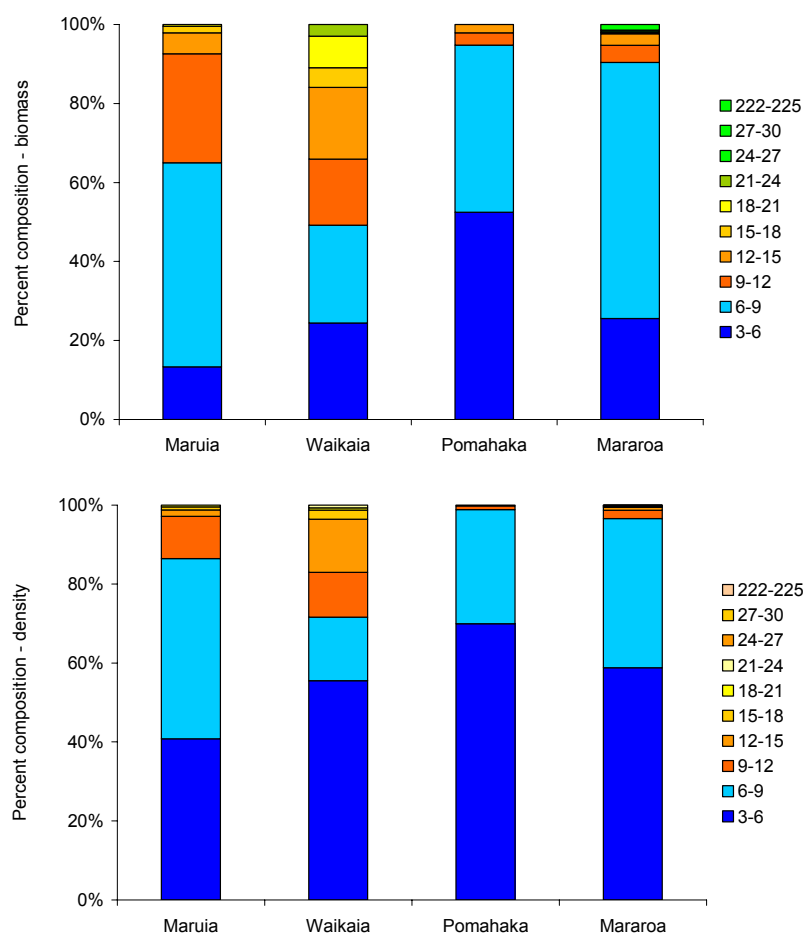


Figure 2. Percent composition by density (bottom) and biomass (top) of each 3 mm size class in the drift (daylight and dusk combined) from the Maruia, Waikaia, Pomahaka, and Mararoa rivers. The 222 – 225 mm invertebrate size category contained one Gordian worm.

3.3. Trout Diet

Twenty four invertebrate taxa were found in the stomachs of the 21 trout collected from the upper Oreti River where didymo was rare. The number of prey items per stomach ranged from 0 to 17 invertebrates. Mayflies and caddisflies were the most common prey item and contributed 80 % to the collective diet (Figure 3). The mayfly *Deleatidium* was the most abundant prey item, representing 38 % of all the items in stomachs and this is an actively drifting insect. Terrestrial invertebrates were among the least common prey items. Didymo was not present in any of the trout guts and neither were fish prey.

Of the aquatic insects in the diet, 98 % could be considered drift-prone. The remaining 2 % included annelids, water bugs and the fly larvae *Neocurupira*. The small number of aquatic invertebrates present in the trout stomachs not normally associated with drifting behaviour suggests that brown trout in the upper Oreti River are predominantly drift feeding rather than benthic feeding.

Most of the prey items were in the size ranges 3 - 6 and 6 - 9 mm (Figure 4). Less than 0.2 % were in the 0 - 3 mm size range, supporting the exclusion of this size class in drift sampling (a consequence of using 0.5 mm mesh in the drift samplers – see section 2.1.3) – at least for large fish. The minimum prey length relationship used in the foraging model predicts that the minimum prey length for the 585 - 700 mm trout collected from the upper Oreti River for diet analysis should be 6.7 mm and 8.1 mm, respectively. This appears to be slightly overestimating minimum prey sizes eaten by the Oreti trout (Figure 4). This means that the growth model under its standard minimum prey size assumptions may underestimate the growth of trout.

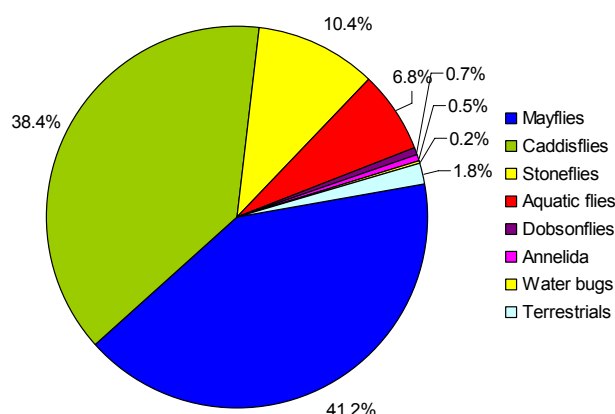


Figure 3. Percent composition by number of main invertebrate groups in trout stomachs in the upper Oreti River (April and May 2006).

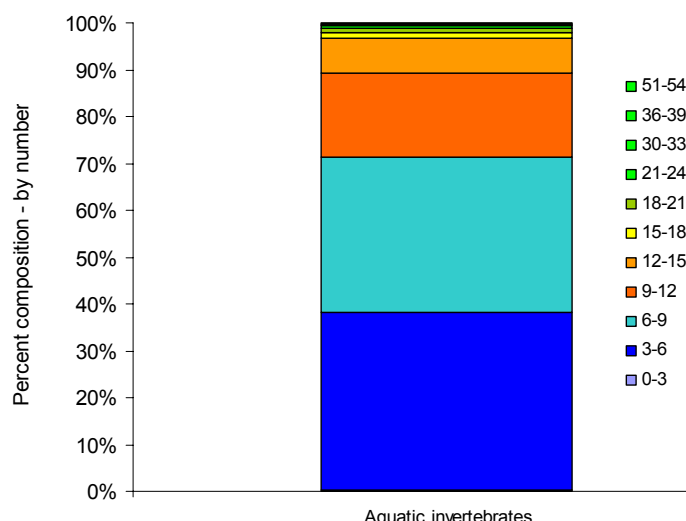


Figure 4. Percent composition by number of 3 mm aquatic invertebrate size classes in trout stomachs from the upper Oreti River (April and May 2006).

3.4. Trout growth modelling

The drift foraging and bioenergetics growth model predicted that drift-feeding would limit the growth of trout greater than 20 cm in the Mararoa River (Figures 5 and 6). Daily consumption as a proportion of maximum consumption was predicted to decline steeply as fish exceed 20 cm, and by 38 cm consumption would be insufficient to meet body maintenance requirements (i.e. growth rate would be zero). From that size on, trout are predicted to experience negative growth rate (i.e. they would lose weight). The contribution by terrestrial invertebrate drift makes little difference to these predictions (Figures 5 and 6). Note that these predictions are conservative for an invertebrate diet because they assume that trout could attain maximum rations at night. Consumption and growth potential for daytime drift feeding are lower than these estimates.

The consumption and growth rates predicted for the Mararoa River are much lower than those for the Maruia River (Figures 5 and 6) where predicted growth has been shown to match observed trout growth and maximum size and trout up to 45 cm could achieve maximum daily rations and growth rate (Hayes et al. 2000). The Maruia River drift density and size structure was predicted to be able to support growth in trout up to about 60 cm based on aquatic invertebrates alone (and based on the water temperatures and estimated foraging periods for the Mararoa in April 2006).

The results from the diet analysis on the upper Oreti River indicated that the trout length versus minimum prey length relationship used in the growth model overestimated minimum prey sizes eaten by trout in the 585 – 700 mm range. This raises the question whether the model has underestimated predicted growth of the larger fish in our analysis. To investigate this issue we reprogrammed the model, reducing the allowable minimum prey size for fish

greater than 27 cm by 3 mm. The 27 cm cut-off was applied because the minimum prey size for fish less than this falls within the 0 – 3 mm prey size class which was not retained by our drift samplers. We expect exclusion of the 0 – 3 mm prey size class to have only a minor effect on predicted growth rate of trout less than 27 cm because, as mentioned in section 2.2.3, small fish are able to capture the greatest size range of available drifting prey and they require less food than large fish.

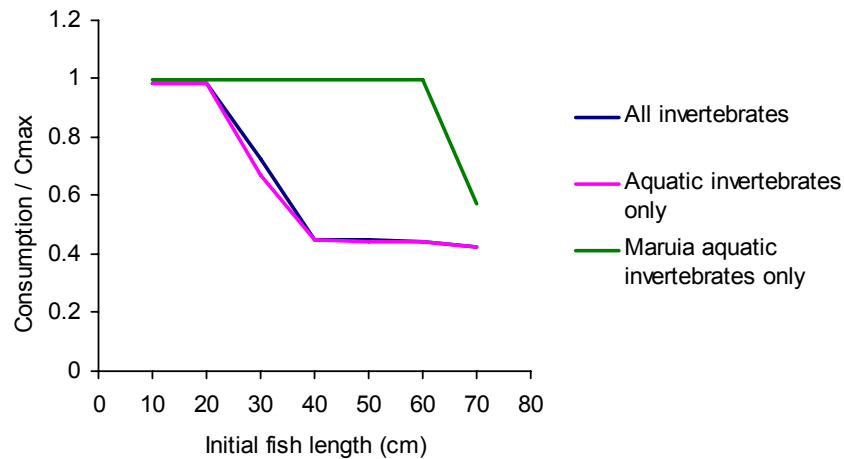


Figure 5. Mean daily energy consumption (based on drift feeding) as a proportion of potential maximum consumption predicted with the coupled drift-foraging and bioenergetics growth model for a range of size classes of brown trout for April 2006 for the Mararoa and Maruia rivers. Predictions assume the following minimum prey length x fish length relationship: $prey\ length\ (in\ mm) = 0.115 \times fish\ length\ (in\ cm)$.

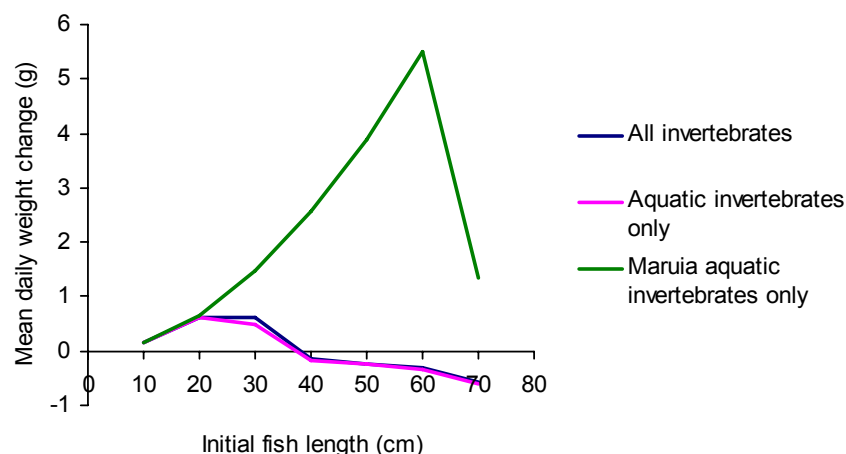


Figure 6. Mean daily weight change (growth rate) predicted with the coupled foraging and bioenergetics growth model for a range of size classes of brown trout for April 2006 for the Mararoa and Maruia rivers. Predictions assume the following minimum prey length x fish length relationship: $prey\ length\ (in\ mm) = 0.115 \times fish\ length\ (in\ cm)$.

Trout energy consumption and growth predictions for the Mararoa River with the revised minimum prey size assumption differed only slightly from the original predictions; energy consumption and growth potential being slightly greater (Figures 7 and 8).

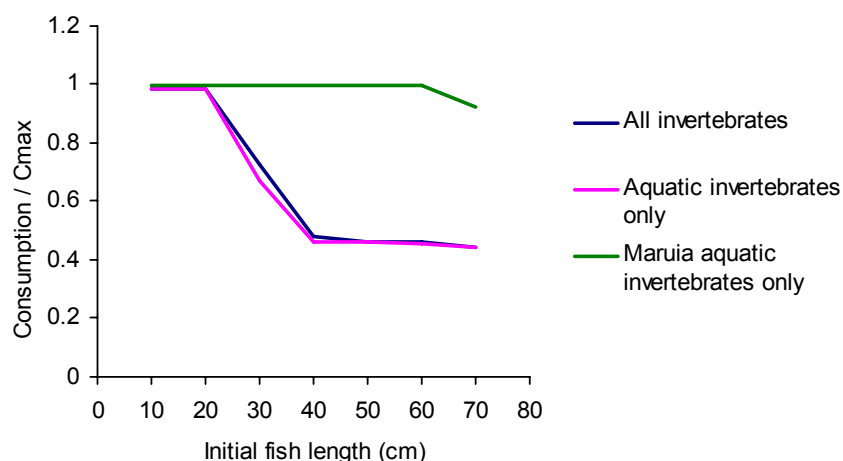


Figure 7. Mean daily energy consumption (based on drift feeding) as a proportion of potential maximum consumption predicted with the coupled drift-foraging and bioenergetics growth model for a range of size classes of brown trout for April 2006 for the Mararoa and Maruia rivers. Predictions assume the following minimum prey length x fish length relationships: for trout ≤ 270 mm – *prey length (in mm) = 0.115 x fish length (in cm)*; for trout > 270 mm – *prey length (in mm) = 0.115 x fish length (in cm) - 3mm*.

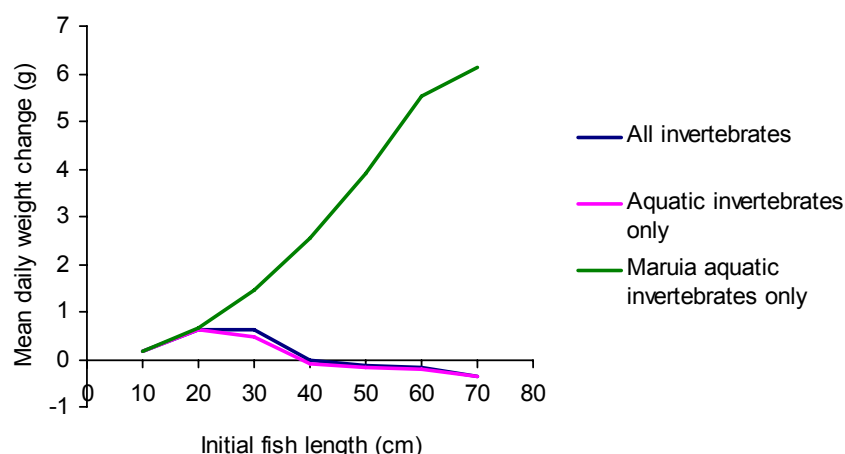


Figure 8. Mean daily weight change (growth rate) predicted with the coupled foraging and bioenergetics growth model for a range of size classes of brown trout for April 2006 for the Mararoa and Maruia rivers. Predictions assume the following minimum prey length x fish length relationships: for trout ≤ 270 mm – *prey length (in mm) = 0.115 x fish length (in cm)*; for trout > 270 mm – *prey length (in mm) = 0.115 x fish length (in cm) - 3mm*.

4. DISCUSSION

4.1. Invertebrate drift

In a preliminary ecological study of didymo in New Zealand, Kilroy et al. (2006) found that high didymo biomass was associated with increased density but altered community composition of benthic invertebrates; communities in didymo affected sites had proportionately more chironomids and algal piercing caddisflies which generally are small. Kilroy et al. (2006) did not estimate size composition of their benthic invertebrate samples, but the mean size of invertebrates (determined by dividing dry weight of the samples by number of invertebrates) was smaller at didymo affected sites than at control sites. An unaddressed issue raised by Kilroy et al. (2006) was whether the presence of didymo would be beneficial or detrimental to trout fisheries. They noted that investigations on drift were required to make progress on this matter.

Our investigation in the Mararoa River at a time when didymo biomass was moderate to heavy confirmed that small invertebrates dominated the drift and that large invertebrates (> 10 mm) were rare. However, this was not attributable to domination by taxa commonly associated with algal proliferation such as chironomids and algal piercing caddis. Mayflies (mostly *Deleatidium* spp.) dominated the drift (> 50 %) and these are regarded as drift prone and preferred trout prey.

The Mararoa River experienced a large flood in January 2006 (about 2.5 months before our drift sampling), resulting in significant bed movement which reset didymo biomass to low levels. It is likely that the same flood reset the benthic invertebrate community and that it was in a recovery phase when we sampled the drift in April. This is a confounding factor which may have contributed to low drift biomass, especially of large invertebrates, in our study.

Ideally, benthic invertebrate communities ought to have been sampled for comparison at the same time as drift sampling. NIWA had planned to do this, but benthic sampling was delayed until two weeks after we sampled drift and, unfortunately, another large flood (although smaller than the January one) occurred during this period. The results of NIWA's benthic invertebrate and didymo biomass sampling were not available at the time of writing the present report. However, the intention is that the benthic and drifting invertebrate investigations will be synchronised in the future and the results from the respective studies integrated.

The density and biomass of invertebrate drift that we estimated from the Mararoa were much lower than estimates from the Maruia River in April 1995, but similar to estimates from the Waikaia and lower Pomahaka Rivers made in February 1997. The Maruia drift estimates (the April estimate and four other seasonal estimates) have been shown, with drift foraging and growth modelling, to explain observed growth rate and maximum size of trout in that river (Hayes et al. 2000) (Appendix Figure A1.3). The Pomahaka drift was dominated by small invertebrates – as was the case for the Mararoa drift (Figure 1), but the Waikaia drift had proportionally more large invertebrates which support higher growth potential in trout.

Drifting invertebrate size structure in the Mararoa was most similar to that recorded from the lower reaches of the Pomahaka River (which was sampled at a time when native periphyton biomass was high (Table 4)). A study by Shearer et al. (2003) suggested that high periphyton biomass in the Pomahaka River was associated with comparatively high benthic invertebrate biomass, not only of small algal associated taxa but also of *Deleatidium* mayflies – as was also found by Kilroy et al. (2006) in didymo affected sites in the Mararoa and Waiau rivers. However, Shearer et al.'s study also suggested that 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, they may be less available to trout in the drift. Shearer et al.'s study has important implications for trout rivers impacted by didymo, as it suggests that benthic community assessments alone may not provide a true indication of potential food related impacts on predominately drift-feeding fish. Further investigation into the relationships between periphyton biomass and drifting behaviour of aquatic invertebrates may be possible if future benthic invertebrate and didymo biomass (chlorophyll *a* and AFDW) assessments are synchronised with drift surveys.

The Pomahaka trout fishery was in decline when we sampled for drift in February 1997 (as indicated by angler usage determined by roving creel survey - Young & Hayes 1998) but the Waikaia trout fishery was in good shape. Drift densities and biomass vary significantly over time (seasonally and from day to day) and space (Shearer et al. 2002). Given this, and the comparative data from the Waikaia and Pomahaka rivers, caution should be exercised in interpreting the Mararoa drift data and inferences from it concerning trout growth. We should be careful not to infer too much from such limited data (i.e. drift sampling in one reach on one occasion). Nevertheless, 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. So, it is important that the April 2006 drift sampling in the Mararoa River be followed up with additional seasonal sampling over 2006 – 2007 to strengthen the data and reduce uncertainty in the conclusions drawn from them.

4.2. Predicted trout growth

Notwithstanding the above caution, our modelling predictions indicate that growth of trout greater than 20 cm would be limited by the available drift estimated in the Mararoa River in April 2006 and that trout greater than 38 cm would lose weight (i.e. experience negative growth). The mechanism for this is predicted to be a failure by 20 – 38 cm trout to achieve maximum daily rations and for larger trout to attain maintenance rations. The increasing energetic costs of feeding on small drifting prey as trout grow (Hayes et al. 2000) will be an additional, but in this case comparatively minor, reason for reduced growth potential with increasing fish size – the main reason being that trout simply cannot get enough food. Moreover, our predictions are conservative for an invertebrate diet because they assume that trout could attain maximum rations at night. Consumption as a proportion of maximum consumption, and growth potential, for diurnal (daytime) drift feeding will be lower than our daily (24 hour) predictions.

Reducing the minimum prey size threshold in the foraging model, to account for smaller than expected prey eaten by Oreti River trout, made little difference to predicted energy consumption and growth in the Mararoa River. This adjustment to the model made the smallest drift size class retained by our drift samplers (3 – 6 mm) available to the entire size range of trout modelled. The reason for the adjustment having little effect was that the energy reward for foraging effort by trout was much less (6.5 times less) for 3 – 6 mm invertebrates than for larger invertebrates.

Traditionally a substantial proportion of trout caught by anglers and observed by drift divers in the Mararoa, and its receiving river – the Waiau, and in other New Zealand rivers have been in the size range 40 - 60 cm (Figure 6). 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, foraging on benthic invertebrates directly (i.e. off the river bed), piscivory (foraging on prey fish), and eating mice. Our modelling predictions included terrestrial invertebrate drift and demonstrated that, at least in April, it had only a minor positive effect on trout growth potential. Whether trout can profitably forage directly on benthic invertebrates in didymo affected reaches is unknown, but unlikely given the blanketing nature of didymo confining most large invertebrates to the underside of stones. Kilroy *et al* (2006) also considered that dense mats of didymo could restrict benthic feeding by fish due to the coverage of the algal mats and the smallness of the invertebrates likely to be living in these mats. Moreover, our trout diet analysis from the upper Oreti River, where didymo was rare, indicates that most prey was likely sourced from the drift. Drift feeding appears to be the predominant foraging behaviour exhibited by trout in the upper reaches of rivers where gradient interacting with floods create sufficient stream power and substrate instability to favour mobile, drifting invertebrates over invertebrates with limited mobility. Research on drift-feeding char (a related salmonid) overseas has found that they switched to benthic browsing only when the drift rate, and drift prey capture rate, declined to low levels (drift rate threshold for switching to benthic foraging was about 15 prey per 5 minutes) (Fausch *et al.* 1997) – which confirms that drift feeding is a preferred foraging strategy. The extent to which trout feed on fish in the Mararoa River is unknown. However, when prey fish are abundant and available, piscivory can be energetically more profitable than invertebrate feeding. Elliott & Hurley (2000) showed that trout can grow three times faster on a fish than an invertebrate diet. An extensive diet study is needed to determine whether trout obtain a significant growth subsidy from piscivory in the Mararoa and other rivers. Given that small prey fishes are generally not very abundant in rivers like the Mararoa far from the sea, it is unlikely that the majority of the trout population would benefit significantly from piscivory. Trout are known to gorge on mice during occasional mice plagues which coincide with irregular beech forest and tussock masting (flowering and seeding periods). Anglers ascribe some of their catches of very large, trophy, trout in backcountry rivers to these mice plagues. However, because they are irregular, mice plagues are unlikely to contribute significantly to the growth rate of most trout, and cannot be considered a reliable alternative food source to compensate for reductions in drift feeding opportunities that may prove attributable to didymo.

4.3. Trout abundance monitoring

An inference from our provisional results from trout growth modelling is that trout larger than 40 cm could be expected to decline in the Mararoa River and other didymo affected rivers. Trout abundance data from drift dive surveys by Southland Fish and Game on the Mararoa and Waiau rivers are equivocal in this regard and there is yet insufficient data post-didymo to make statistical comparisons (Figures 9 – 12). Drift dive data are available from the Waiau River from 1996 to 2006 although there is a three year gap in the record between 2003 – 2005. Unfortunately this gap means there are no immediate pre-didymo data. Trout abundance increased in the Waiau River after 1997 following an increase (in December 1996) in the residual flow regime arising from new resource consent conditions imposed on Meridian Energy Ltd. The single post-didymo drift dive indicates a reduction in the abundance of trout > 25 cm since the previous dive undertaken in 2001 (Figures 9, 10). An unbroken drift dive data set is available from the middle reaches of the Mararoa River for the period 1999 – 2005 (Figure 11). Abundance of trout > 25 cm was trending down over the pre-didymo period 1999 – 2004 and then increased post-didymo in 2005. Drift dive data are available for three years (2004 – 2006) from the lower Mararoa River; one year pre-didymo and two years post-didymo. These data indicate that abundance of brown trout > 25 cm decreased following didymo invasion whereas rainbow trout increased (Figure 12).

4.4. Future research

Our study of drift and predicted trout growth in the Mararoa River lacked spatial and temporal controls against which to assess the effects of didymo. That is because no drift sampling had been conducted prior to didymo becoming established and the algae is now throughout the river. However, being mindful of this shortcoming, we concurrently sampled drift, and logged water temperature, at two sites in the Oreti River initially intended to provide an upstream control versus downstream impact comparison in that river and for comparison with the Mararoa River. Unfortunately, just prior to sampling, didymo was found to occur throughout the Oreti, although it was rare enough at the upstream site during our April sampling to be discounted. Drift samples from the two Oreti sites were collected, but have not yet been processed, so were not able to be included in this report. We intend to undertake similar drift sampling at the Oreti and Mararoa sites over 2006 – 2007 on at least a quarterly time frame to cover temporal variability in drift over a gradient in didymo biomass from low (Oreti upstream site) to medium (Oreti downstream site) to high (Mararoa site). These data will provide a firmer foundation from which to predict trout growth potential over various spatial and temporal scales.

In order to adequately determine the effects of didymo on trout populations, it is important to gather information on trout populations in southern South Island in addition to modelling growth potential. Southland Fish and Game's drift dive monitoring database is a useful start and it is vitally important that this monitoring is continued at least annually on a selection of didymo affected and unaffected rivers. It is also important to obtain information on actual

trout growth rates and body condition. Southland Fish and Game has some archival data on trout growth rates in Southland rivers, but these are based on small sample sizes. Sampling sufficient numbers of trout for robust growth and condition analysis is logistically challenging and possibly beyond Fish and Game's financial and staffing resources, but is a critical requirement for future research aimed at assessing the effects of didymo on trout populations.

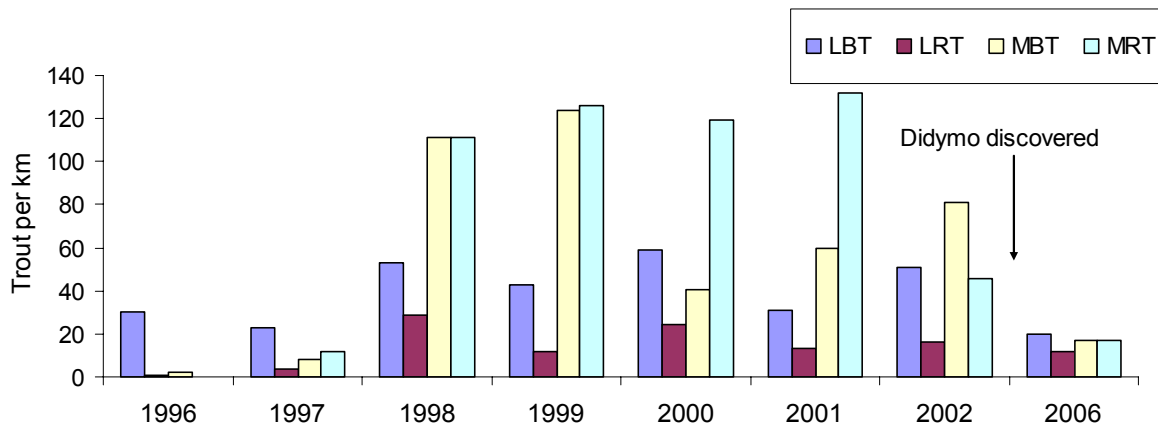


Figure 9. Average abundance of medium (25 – 40 cm) and large (> 40 cm) brown and rainbow trout in the Waiau River (at Excelsior and Redcliff sites) between 1998 and 2006 estimated from Southland Fish and Game drift dive surveys. LBT, MBT, LRT, MRT = large and medium brown and rainbow trout, respectively.

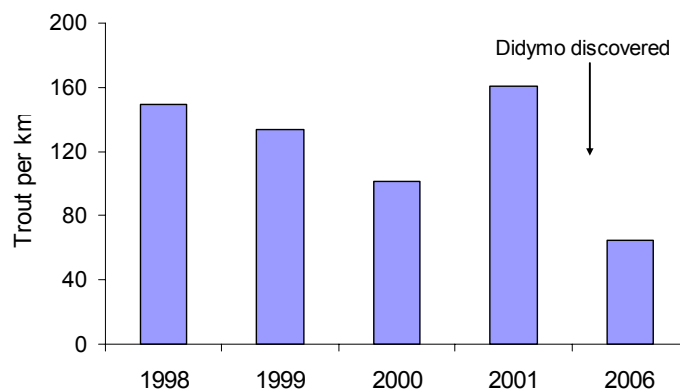


Figure 10. Average abundance of medium (25 – 40 cm) and large (> 40 cm) brown and rainbow trout combined from four to eight sites in the Waiau River between 1998 and 2006 estimated from Southland Fish and Game drift dive surveys. Four sites were surveyed between 1998 and 2001 and eight sites were surveyed in 2006.

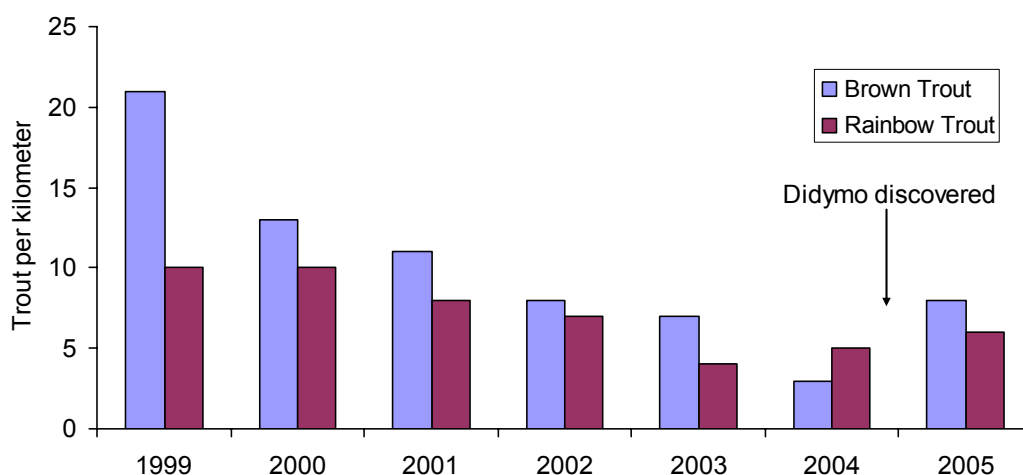


Figure 11. Abundance of medium (25 – 40 cm) and large (> 40 cm) brown and rainbow trout in the middle reaches of the Mararoa River between 1999 and 2005 estimated from Southland Fish and Game drift dive surveys.

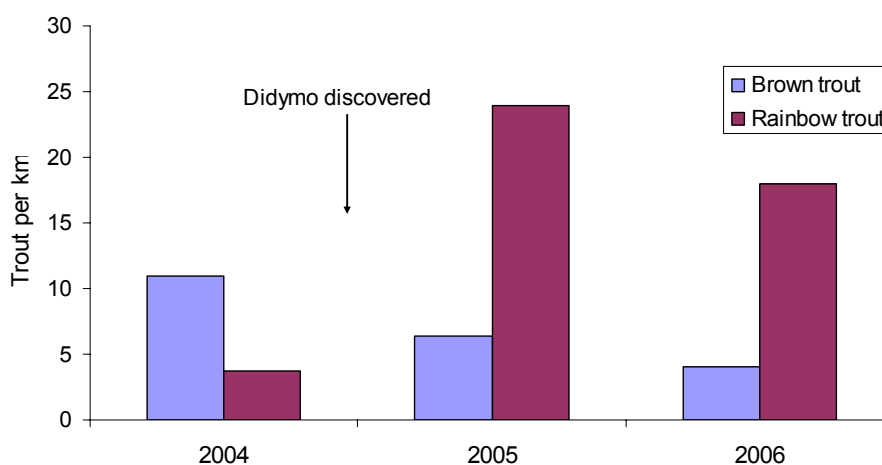


Figure 12. Abundance of medium (25 – 40 cm) and large (> 40 cm) brown and rainbow trout in the lower reaches of the Mararoa River between 2004 and 2006 estimated from Southland Fish and Game drift dive surveys.

4.5. Conclusions

This investigation is a first step in assessing the effects of didymo on aquatic invertebrate drift and trout growth potential. The results are based on sampling one reach in the Mararoa River on only one occasion (April 2006) and so should be regarded as provisional pending further quarterly sampling over 2006 – 2007. Under moderate to heavy didymo biomass, invertebrate

drift density and biomass were low, and large invertebrates, preferred by trout, rare. Modelling predicted that this would limit food consumption of drift-feeding trout larger than 20 cm, resulting in reduced growth, and that trout larger than 38 cm would lose weight (i.e. they would have negative growth potential).

By themselves these results are not sufficient to conclude that didymo reduces density of large drifting invertebrates and related growth of drift-feeding trout. Further research, taking account of the variability in drift density over time and space, is needed before definitive conclusions can be drawn. Such research should include: seasonal invertebrate drift sampling and modelling of trout growth and spatial comparisons with river reaches either unaffected by didymo or covering a range of didymo biomass. Pending ongoing funding, we intend to undertake such research. We aim to sample drift and predict trout growth potential in the Mararoa reach and two reaches in the Oreti River on at least two further occasions to assemble a comparative quarterly data set (sampling has already been undertaken on these reaches on two occasions). Modelling studies of the nature presented in this report should also be complemented by studies of actual trout growth and abundance.

5. ACKNOWLEDGEMENTS

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7. APPENDICES

Appendix 1. The coupled drift foraging and bioenergetics growth model: concepts, components, and output.

Structure of the coupled drift foraging and bioenergetics growth model (Trout_Energetics2 – Hayes 2000)

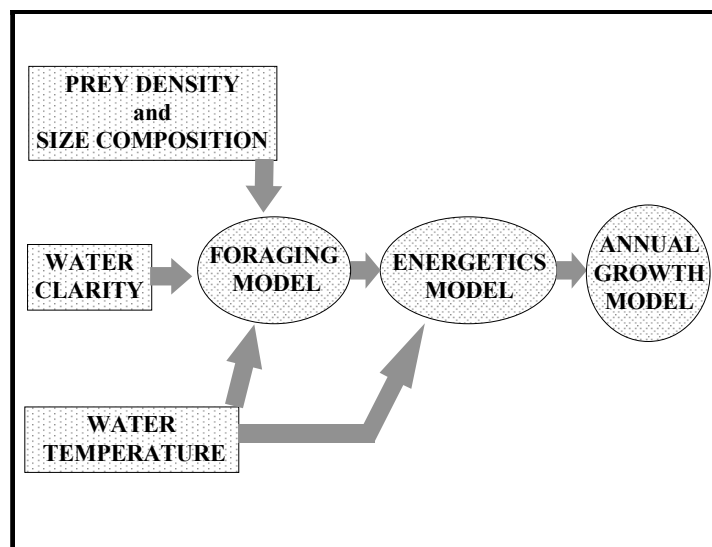


Figure A1.1. Components of the coupled drift foraging and bioenergetics growth model and data inputs.

The drift foraging model

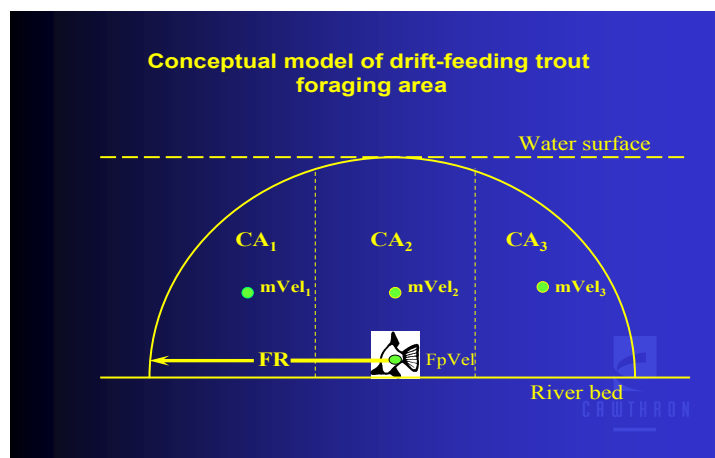


Figure A1.2. The drift foraging model is based on this conceptual model of a trout's drift foraging area (cross-sectional view looking upstream). The foraging model uses equations based on fish size and prey size to predict the foraging radius (FR) and hence the foraging area (foraging area is calculated 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 ($mVel_1$, $mVel_3$) are estimated from information on velocity differentials across which trout feed while drift feeding (from Hayes & Jowett 1994). Predictions of the size dependent 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 $0.115 \times \text{fish length (in cm)}$ (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. Growth modelling is carried out at a daily time step with final daily weight used as input for initial weight the following day (when modelling over time periods greater than one day). When modelling annual or whole-lifetime growth, reproduction costs can be subtracted once the fish reaches maturity (using literature values on reproductive energy investment).

The bioenergetics growth model

Bioenergetics models comprise suites of metabolic equations that quantify functional relationships between water temperature and other physical variables, consumption, digestion, metabolic, kinetic, and growth processes in fish using energy as a common unit. In essence they quantitatively describe the working and efficiency of the fish's engine at the scale of the average individual. Bioenergetics models do not deal with how fish gain their food (energy) – that is the role of foraging models (described above).

Bioenergetics models are based on the energy balance equation:

$$\Delta B = C_e - F - U - (R_a + R_s + R_d)$$

Where ΔB is the energy accumulated for growth and reproduction, C_e is consumption (energy intake), F and U are the energy losses in faeces and urine, R_a and R_s are the energy costs of active and standard metabolism, and R_d is the energy cost of digestion (including specific dynamic action) [$(R_a + R_s + R_d) = R$] (Elliott 1976).

Bioenergetics models offer a more satisfying and informative approach to analysing and interpreting growth than simply comparing growth between populations or constructing regression models based on various environmental variables. They are attractive because they provide a way to link fish growth and other physiological processes with underpinning physical variables and prey levels via the universal currency of energy. They force the investigator to take a sound conceptual and systematic approach to fish growth and feeding investigations.

It is important to appreciate that because fish are cold-blooded their metabolic rate, food consumption and processing rate, and therefore their growth rate is temperature dependent (Elliott 1994; Elliott & Hurley 1998, 1999). The relationships between these processes and temperature and weight are non-linear (usually exponential or power functions) and have been described, in the form of bioenergetics equations, for several fish species through detailed laboratory studies (e.g. Elliott 1976, 1994; Brett & Groves 1979). The interplay between the non-linear responses of consumption and metabolic rate to temperature results in species specific temperature preferenda for growth (i.e. optimal temperature ranges for growth). For a more thorough review of the underlying features of fish bioenergetics and growth, specifically for brown trout, see Elliott (1976, 1994; Elliott & Hurley 1998, 1999).

While the energy balance equation is internally consistent, nevertheless, this does not ensure that the particular bioenergetics model employed will accurately predict growth. There are potential sources of error in the equations that estimate the parameters of the energy balance equation. These equations usually take the form of multiplicative power functions of weight x exponential functions of temperature (i.e. of the form $a \cdot W^b \exp(cT)$). Sensitivity analyses have shown that biases in the power functions describing the changes in maximum consumption (C_{max}) and standard metabolism (R_s [and probably also R_{max}]) with weight produce the

greatest error in model output (Rice et al. 1983; Bartell et al. 1986 cited in Ney 1993). Such errors may cause bioenergetics models to incorrectly estimate the magnitude and pattern of growth for the species or population under investigation. Model failure can be indicated by observed growth exceeding maximum growth predictions.

The parameters other than growth, in the energy balance equation are usually derived from laboratory studies of fish in controlled conditions. It is often the case that bioenergetic models are constructed from bioenergetics equations begged and borrowed from several species of fish because a full suite of equations rarely exists for the species of interest. It is also common in bioenergetics modelling to make predictions beyond the size range of fish used for developing the bioenergetics equations. As with species borrowing, this practice is undertaken not by choice but for pragmatic reasons because most studies that have developed the basic bioenergetics equations have been laboratory based using juvenile fish. The practices of species borrowing and exceeding the size range of fish upon which bioenergetics equations have been developed are recognised potential sources of error in bioenergetics modelling (Ney 1993) but often are unavoidable in practical applications of these models given the current information base.

Fortunately, brown trout have been the subject of intensive bioenergetics and growth investigations (see Elliott 1994 for review; and more recently Elliott et al. 1995; Elliott & Hurley 1998, 1999; Elliott 2000). These studies have provided one of the most complete, and reliable, suites of bioenergetics equations available for any fish species. Elliott's (1976) and Elliott & Hurley's (1999) bioenergetics equations have been rigorously tested in Europe (Elliott 1994; Elliott 2000) and Hayes et al.'s (2000) coupled drift foraging and bioenergetics growth model (which uses these bioenergetics equations) successfully predicted growth of brown trout in the Maruia River, New Zealand (Figure A1.3.)

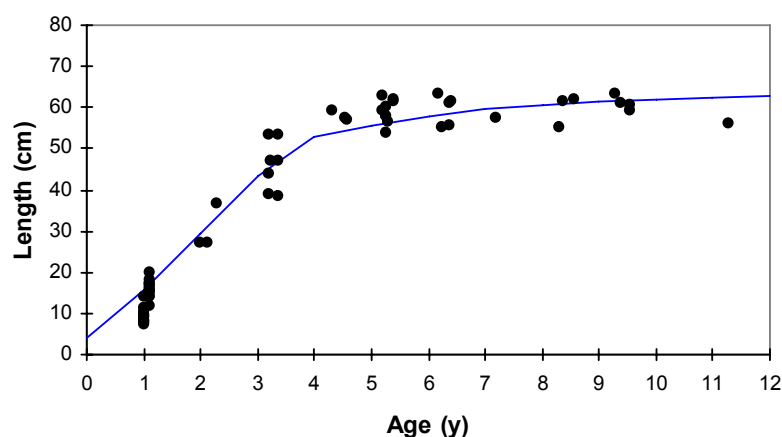


Figure A1.3. Predicted growth (solid line) versus observed growth (size at age) (dots) for brown trout in the Maruia River. Predictions were made with Hayes et al.'s (2000) coupled foraging and bioenergetics growth model. Size at age reaches an asymptote because of the combined costs of reproduction and drift foraging costs after the fish matures at age four.

Appendix 2. Details of trout caught from the upper Oreti River for diet analysis. Fultons condition factor was calculated according to the formula: $K = 10^5 \cdot W/L^3$

Date	Sex	Fork length (mm)	Weight (kg)	Condition
3-Apr-06	M	665	3.40	1.16
3-Apr-06	M	655	2.90	1.03
3-Apr-06	M	650	2.90	1.06
3-Apr-06	M	700	3.70	1.08
4-May-06	M	660	3.01	1.05
4-May-06	M	650	2.98	1.08
4-May-06	M	680	3.01	0.96
4-May-06	M	610	2.92	1.29
4-May-06	F	585	2.52	1.26
4-May-06	M	630	3.57	1.43
4-May-06	M	650	2.58	0.94
4-May-06	M	650	3.01	1.09
4-May-06	F	640	1.47	0.56
4-May-06	M	650	1.98	0.72
4-May-06	M	585	2.44	1.22
4-May-06	F	570	2.44	1.32
4-May-06	M	600	2.32	1.08
4-May-06	M	645	2.66	0.99
4-May-06	M	670	2.66	0.89
4-May-06	M	680	2.98	0.95
4-May-06	M	625	2.38	0.98

Appendix 3. Counts (over all samples) of day drifting aquatic invertebrate taxa in 3 mm size classes for all sites combined (Mararoa River, April 2006).

Day aquatic drift taxa	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	27-30	222-225
Ephemeroptera										
<i>Deleatidium</i>	221.6	195.2								
Leptophlebiidae ¹			1							
<i>Oniscigaster</i>		1	1							
Plecoptera										
<i>Stenoperla</i>	1									
<i>Zelandoperla</i>	6.4									
Coleoptera										
Elmidae	114.6	66								
Diptera										
<i>Aphrophila</i>	1		3.2							
Anthomyiidae			1							
<i>Austrosimulium</i>	26.2									
Chironomidae	17.8									
Empididae	1									
<i>Maoridiamesa</i>	3.2									
<i>Neolimnia</i>			1							
Orthoclaadiinae	3.2									
Simuliidae	7.4									
Tipulidae		5.2								
Trichoptera										
<i>Aoteapsyche</i>	2	12.8	6.2	3						
<i>Costachorema</i>	3.2									
<i>Hudsonema</i>	3.2		1	2	1					
Hydrobiosidae ¹		3.2								
<i>Hydrobiosis</i>	14.6	15.8	1							
<i>Neurochorema</i>	3.2	3								
<i>Olinga</i>	1	1								
<i>Oxyethira</i>	18.4									
<i>Plectrocnemia</i>	1									
<i>Psilochorema</i>	3.2	7.4	4.2	1						
<i>Pycnocentria</i>	30.4	6.4								
<i>Pycnocentrodes</i>	5									
Hemiptera										
Saldidae	1									
<i>Sigara</i>	2									
Neuroptera	2									
Annelida						1		2	1	
Nematomorpha										1
Platyhelminthes			1							
Mollusca										
<i>Physa</i>	3.2									
TOTAL	496.8	317	20.6	6	1	1	0	2	1	1

¹ Unidentified taxa – not included in taxa count.

Appendix 4. Counts (over all samples) of dusk drifting aquatic invertebrate taxa in 3 mm size classes for all sites combined (Mararoa River, April 2006).

Dusk aquatic drift taxa	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	27-30	222-225
Ephemeroptera										
<i>Deleatidium</i>	174.6	133.4								
<i>Oniscigaster</i>			1							
Plecoptera										
<i>Zelandoperla</i>	3.2									
Coleoptera										
Elmidae	71	29.8								
Hydrophilidae	1									
Diptera										
Anthomyiidae			3.2							
<i>Aphrophila</i>		3.2								
<i>Austrosimulium</i>	6.4									
Chironomidae	3.2									
Eriopterini										
<i>Maoridiamesa</i>	4.2									
Orthoclaadiinae	3.2									
Tipulidae	8.4	22.4	1	1						
Trichoptera										
<i>Aoteapsyche</i>		3.2	7.4							
<i>Costachorema</i>		3.2								
<i>Hudsonema</i>			3.2							
<i>Hydrobiosis</i>	8.4	12.8	2							
<i>Olinga</i>	1									
<i>Plectrocnemia</i>	3.2									
<i>Psilochorema</i>	9.6	16.8	2							
<i>Pycnocentria</i>	4.2									
Neuroptera	3.2									
Annelida	3.2									
Nematoda			3.2							
TOTAL	308	224.8	23	1	0	0	0	0	0	0