

Sites (e.g., *Aoteapsyche* spp. and Oligochaeta) (Table 8). Optimum velocities for total chironomid numbers (both curve calculation techniques) and for abundances of *A. neozelandica* and Oligochaeta (Lowess curves only) were higher at TP and TT than at the upper two sites (Appendix 3). In contrast, optimum depths for *Aoteapsyche* spp. and *A. neozelandica* (Lowess curves only) were lower at TP and IT than at the upper two sites. Velocity optima for *Deleatidium* spp., *Z. furcillatus*, *Aoteapsyche* spp., Hydrobiosidae and *A. neozelandica* were always greatest at TT, which had the most stable baseflow compared with other sites (Appendix 3). Depth optima for *Deleatidium* spp. were also highest at TT, but the position of this site amongst depth preference curves for other taxa varied depending on the method used to calculate the curves.

Overall, taxonomic richness, chironomid biomass and densities of most invertebrate groups were greatest at depths of 0.1-0.4 m, although this was variable at different sites for some taxa perhaps reflecting differences in the size of the data sets. Taxonomic richness, *Aoteapsyche* spp., Hydrobiosidae, Oligochaeta and chironomid biomass had limited depth optima at all sites using both techniques (Table 8). The range of depths sampled at site TP was lower than at other sites (maximum depth = 0.68 m), but omission of this site from the calculation of generalised Lowess depth preference curves significantly altered the optimum only for *Z. furcillatus* (from 0.1 m to 0.4 m). Therefore, this site did not introduce any bias for most taxa.

Taxonomic richness and abundances of *Deleatidium* spp. and *Aoteapsyche* spp. were greatest in fast water ( $>1.0 \text{ m.s}^{-1}$ ) when data from all sites were combined, whereas abundances of total invertebrates, *Z. furcillatus*, Chironomidae and Oligochaeta were greatest overall where water velocity was  $<0.5 \text{ m.s}^{-1}$ . In contrast to abundances, generalised velocity optima for total chironomid biomass was  $1.8 \text{ m.s}^{-1}$ , although this differed widely between sites perhaps reflecting differences in velocity optima between taxa (see next section). Generalised optimum velocities for Hydrobiosidae and *A. neozelandica* ranged from 0.6-1.0 and 0.6-1.2  $\text{m.s}^{-1}$ , respectively, depending on the technique used to calculate preference curves. Velocity and depth optima for different size classes of Hydrobiosidae and *Deleatidium* spp. are discussed in Section 5.

The methods used here to estimate optimum depths or velocities provide an indication of where maximum abundance, biomass or taxonomic richness was likely to occur. However, preference curves for some taxa were shallow and did not extend below values of 0.5 (an arbitrarily selected value which indicates approximately where half the maximum density of a taxon occurred). This indicates that these taxa were found over a wide range of conditions and had broad preferences. None of the preference curves calculated using the exponential polynomial method for taxonomic richness and abundances of total invertebrates, chironomids and elm mid beetles extended below preference values of 0.5 in the range of depth and velocity conditions sampled for any site (Appendix 3B). The polynomial preference curves for chironomid biomass also did not fall below preference values of 0.5.

### 3.4 Validation Sampling

Replicate sampling of "slow", medium" and "fast" flowing habitats (see Table 6 for velocities) was carried out at Site TJ (see Fig. 1) in December 1992 to verify

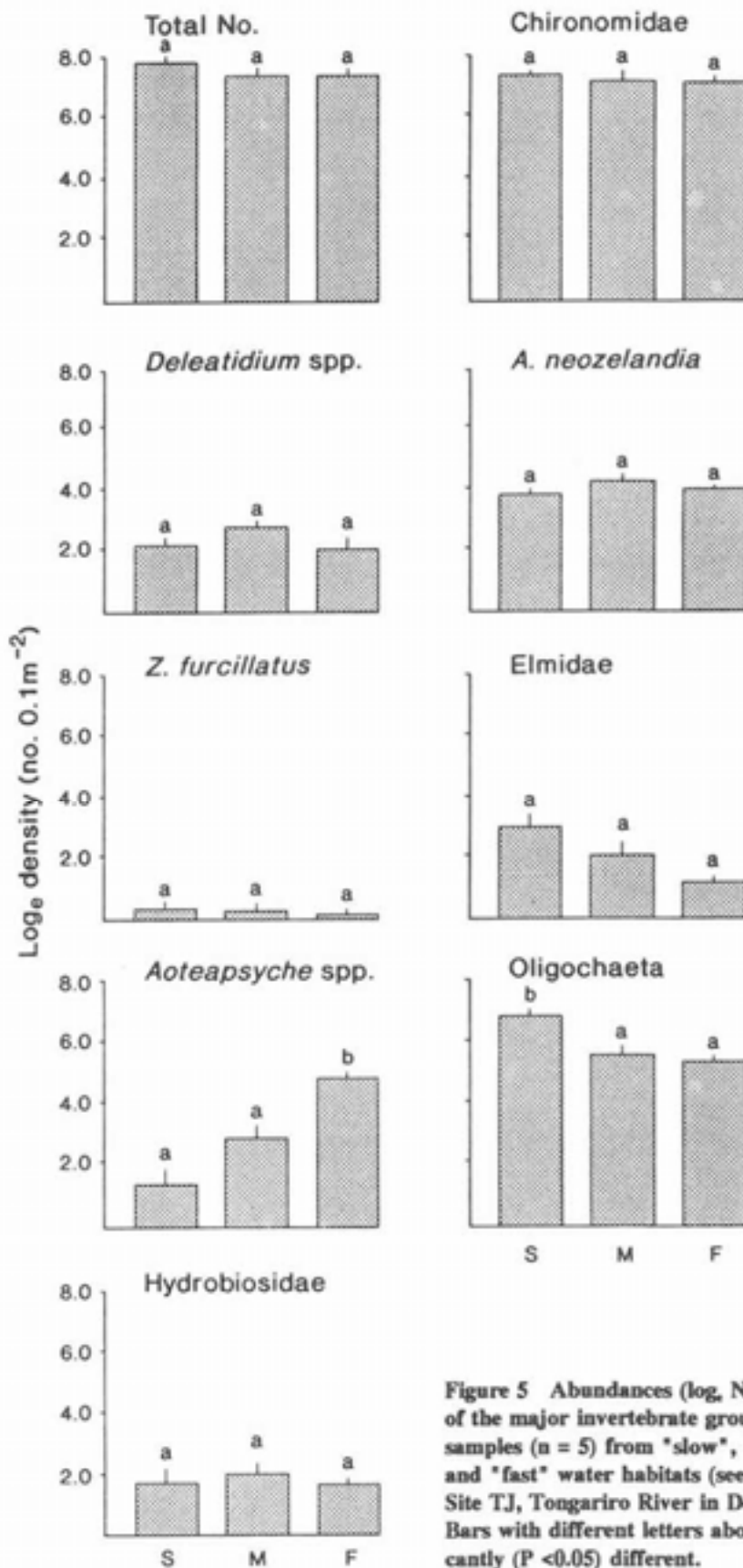


Figure 5 Abundances ( $\log_e N+1$ ,  $\bar{x} \pm 1SE$ ) of the major invertebrate groups in Surber samples ( $n = 5$ ) from "slow", "medium" and "fast" water habitats (see Table 6) at Site TJ, Tongariro River in December 1992. Bars with different letters above are significantly ( $P < 0.05$ ) different.

conclusions derived from preference curve analyses. Densities of total invertebrates, *Deleatidium* spp. and Hydrobiosidae (all size classes combined), *Z. furcillatus*, Chironomidae (all taxa combined), *A. neozelandica* and Elmidae were not significantly ( $P < 0.05$ ) different between the different habitat types (Fig. 5). This result is in general agreement with the preference curve analyses (see Table 8) which indicated broad velocity preferences for most of these invertebrate groups. Densities of the stonefly *Z. furcillatus* were low at TJ in December 1992 and conclusions regarding the slow velocity preference of this taxon could not be verified.

Significant differences in abundances of the uncased caddisfly *Aoteapsyche* spp. and oligochaetes were detected between habitats (Fig. 5). Densities of *Aoteapsyche* larvae increased with mean velocity and were significantly higher in the "fast" flowing habitat (mean =  $1.15 \text{ m.s}^{-1}$ ) than in the "slow" or "medium" flowing habitats. In contrast, densities of oligochaetes were significantly higher in "slow" flowing habitats (Fig. 5). This result confirms that optimum velocities for *Aoteapsyche* and oligochaetes in the Tongariro River are  $>1.0 \text{ m.s}^{-1}$  and  $\leq 0.2 \text{ m.s}^{-1}$ , respectively (see Table 8).

#### 4. FLOW PREFERENCES OF CHIRONOMID TAXA

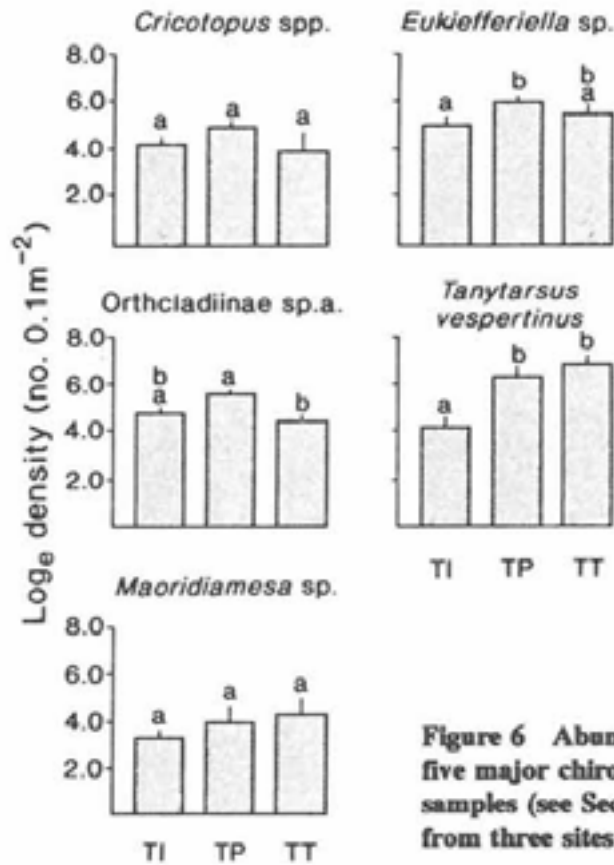
##### 4.1 Site-related Differences

Significantly higher densities of *Eukiefferiella* sp. and *Tanytarsus vespertinus* were found at one or both of the lower two sites on the Tongariro River (Fig. 6). Fewer Orthocladiinae sp.a were found at TT than at TP, but no significant differences in abundances of *Cricotopus* spp. and *Maoridiamesa* sp. were found between any of the three sites examined in this analysis.

**Table 9** Coefficients of multiple regression analyses for the 5 major chironomid taxa using uncorrelated physical variables for all sites combined (see Table 3). Abundance data were  $\log_e(N+1)$  transformed. The percent variance accounted for ( $r^2$ ) by the whole regression is given. Astericks indicate probability levels of t statistic associated with the coefficients.

Coefficients					
Taxon	Depth	Velocity	Embeddedness	Periphyton	$r^2$
<i>Cricotopus</i> spp.	-0.08	0.84 *	0.07	0.36	0.11
<i>Eukiefferiella</i> sp.	-1.16 **	0.75 **	0.20	-0.30	0.39
Orthocladiinae sp. a	-1.75 ***	-0.51 *	-0.14	0.29	0.46
<i>T. vespertinus</i>	-1.23	-1.94 ***	0.94 ***	0.07	0.48
<i>Maoridiamesa</i> sp.	-0.49	2.64 ***	0.34	0.23	0.60

\* =  $P < 0.05$ ; \*\* =  $P < 0.01$ ; \*\*\* =  $P < 0.001$ .



**Figure 6** Abundances ( $\log_e N+1$ ) of the five major chironomid taxa in subsets of 9 samples (see Section 2.4 for explanation) from three sites down Tongariro River.

#### 4.2 Factors Affecting Distribution

The uncorrelated variables depth, velocity, substrate embeddedness and periphyton cover (see Table 3 for correlation coefficients) accounted for between 11% (*Cricotopus* spp.) and 60% (*Maoridiamesa* sp.) of the variation in abundances of five chironomid taxa (Table 9). Water velocity was a significant factor explaining abundances of all major chironomid taxa, whereas depth was important in the multiple regression analysis for *Eukiefferiella* sp. and Orthocladiinae sp.a. Embeddedness was a significant factor affecting abundances of *T. vespertinus* only, and periphyton was not a significant factor for any chironomid taxon (Table 9). Depth and velocity flow preference curves were calculated for all taxa.

#### 4.3 Flow Preferences

Greater resolution of chironomid flow preferences was achieved by calculating individual curves for the five dominant taxa (Appendices 4A and B). Optima of generalised preference curves indicated that most larvae of all taxa occurred predominantly in shallow water ( $\leq 0.6$  m deep; Table 10). When site TP, which was sampled over a narrower depth range than the other sites, was omitted from the analysis of Lowess preference curves, only the generalised depth optimum for *Cricotopus* spp.

was different (from 0.1 to 0.6 m). Thus, inclusion of this site did not introduce any bias for most taxa. Different depth optima were identified for some taxa depending on the site and the technique used to calculate preference curves (Table 10). These differences could partly reflect differences in sample size and in the sensitivity of the techniques used.

When data from all sites were combined, optimum velocities ranged from  $<0.4 \text{ m.s}^{-1}$  for Orthoclaadiinae sp.a and *T. vespertinus*, to  $>1.0 \text{ m.s}^{-1}$  for *Cricotopus* spp., *Eukiefferiella* sp. and *Maoridiamesa* sp. (Table 10). Velocity optima occurred over a wide range at different sites for *Cricotopus* spp. and Orthoclaadiinae sp.a ( $0.1\text{-}1.8 \text{ m.s}^{-1}$ ), but over much narrower ranges for *T. vespertinus* ( $0.1\text{-}0.6 \text{ m.s}^{-1}$ ) and *Maoridiamesa* sp. ( $1.0\text{-}1.8 \text{ m.s}^{-1}$ ). Velocity optima for *Eukiefferiella* sp. at different sites ranged from  $0.6\text{-}1.5 \text{ m.s}^{-1}$  (Table 10).

The methods used here to estimate optimum depths or velocities provide an indication of where maximum abundance is likely to occur. However, preference curves for some taxa were shallow and did not extend below values of 0.5 (an arbitrarily selected value which indicates approximately where half the maximum density of a taxon occurred). This indicates that these taxa were found over a wide range of conditions and had broad preferences. None of the preference curves calculated using the exponential polynomial method fell below preference values of 0.5 for *Eukiefferiella* sp. (depth and velocity), Orthoclaadiinae sp.a (velocity), and *Cricotopus* spp. and *Maoridiamesa* sp. (both depth) in the range of conditions sampled at a site (Appendix 4B). This occurred because these taxa were found over a wide range of conditions at all sites, suggesting that they had broad depth and/or velocity preferences.

**Table 10 Optimum water depths (m) and velocities ( $\text{m.s}^{-1}$ ) for 5 chironomid taxa over the range of conditions sampled at 3 sites on the Tongariro River. Optima were derived from maxima of locally weighted smooth curves (Lowess) and exponential polynomial curves (Polynomial) (see Appendix 4). Optima are for generalised curves (data from all sites combined: no parentheses) and for curves from each site (range given in parentheses).**

Taxon	Depth		Velocity	
	Lowess	Polynomial	Lowess	Polynomial
<i>Cricotopus</i> spp.	0.1 (0.1-0.6)	0.5 (0.1-0.9)	1.8 (0.3-1.8)	1.2 (0.1-1.5)
<i>Eukiefferiella</i> sp.	0.6 (0.1-0.6)	0.4 (0.1-0.6)	1.8 (0.6-1.5)	1.2 (0.7-1.5)
Orthoclaadiinae sp. a	0.2 (0.1-0.6)	0.1 (0.1-0.4)	0.3 (0.3-1.8)	0.1 (0.1-1.5)
<i>T. vespertinus</i>	0.1 (0.1-0.6)	0.1 (0.1-0.2)	0.3 (0.1-0.6)	0.1 (0.1)
<i>Maoridiamesa</i> sp.	0.2 (0.1-0.2)	0.1 (0.1-1.2)	1.8 (1.0-1.8)	1.6 (1.1-1.7)

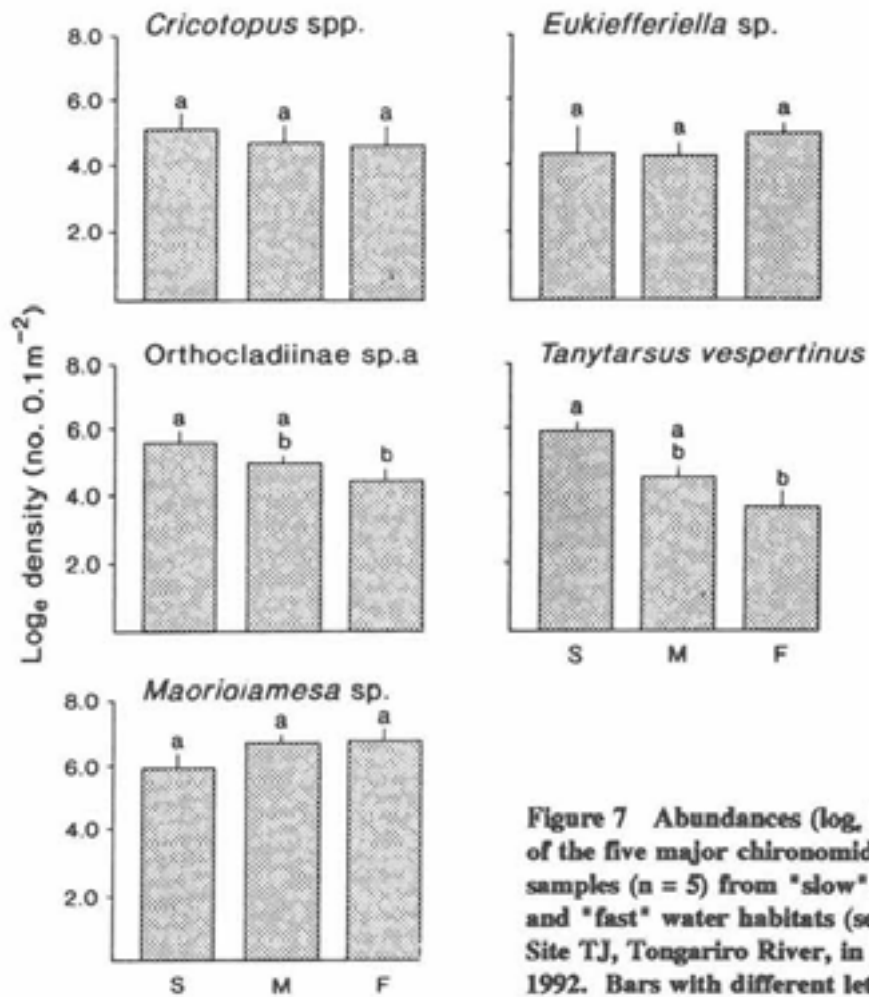


Figure 7 Abundances ( $\log_e N+1$ ,  $\bar{x} \pm 1SE$ ) of the five major chironomid taxa in Surber samples ( $n = 5$ ) from "slow", "medium" and "fast" water habitats (see Table 6) at Site TJ, Tongariro River, in December 1992. Bars with different letters above are significantly ( $P < 0.05$ ) different.

#### 4.4 Validation Sampling

Replicate sampling of "slow", "medium" and "fast" flowing habitats (see Table 6 for velocities) was carried out at TJ (see Fig. 1) in December 1992 to verify conclusions derived from preference curve analyses. Densities of *Eukiefferiella* sp. and *Maoridiamesa* sp. were highest in "fast" flowing habitats, supporting conclusions derived from the preference curve analyses (Fig. 7). However, differences in densities of these taxa between replicate samples at TP were not significantly different, indicating that there was considerable variability between replicates. Some of this variability seemed to stem from the collection of replicate "slow" water samples from the main channel of the river and from a side channel. Densities of *Maoridiamesa* were considerably higher in "slow" flowing habitats in the side channel (703-794 0.1 m<sup>-2</sup>) than in the main river (116-382 m<sup>-2</sup>), indicating that factors other than water velocity can have an effect on densities of this taxon in the Tongariro River.

Densities of *Orthoclaadiinae* sp.a and *T. vespertinus* were significantly higher in "slow" than in "fast" flowing habitats (Fig. 7). This supports conclusions derived from generalised preference curves that these taxa prefer velocities in the range 0.1-0.3 m.s<sup>-1</sup>.

Densities of *Cricotopus* spp. larvae were similar in the different habitats (Fig. 7), confirming the earlier finding that this taxon has broad velocity preferences (see Table 10).

## 5. INFLUENCE OF LARVAL SIZE ON FLOW PREFERENCES

### 5.1 Hydrobiosidae Preferences

Generalised depth optima were similar for each hydrobiosid size class (see Table 4) using both the Lowess and exponential polynomial curve calculation methods (0.1-0.4 m; Table 11). Depth optima for size classes II-IV were different at TG and TI using the exponential polynomial curve calculation technique (Appendix 5B). Thus, optima tended to be deeper (0.6-0.8 m) at TG than at TI (0.1 m).

There was a trend for velocity optima to increase with increasing larval size. Thus, larvae of size classes III and IV had generalised velocity optima of 1.5 m.s<sup>-1</sup> compared with optima of 0.3-1.0 m.s<sup>-1</sup> for size classes I and II, respectively. This trend was consistent for both curve estimation methods even though generalised optima were different for the smallest two size classes (Table 11). At least one of the exponential polynomial preference curves for both sites fell below 0.5 within the range of conditions sampled (Appendix 5B). Log linear analyses were not possible for the hydrobiosid data because of the small number of larvae present in many of the sampling cells.

Replicate sampling of "slow", "medium" and "fast" flowing habitats (see Table 6 for velocities) was carried out at TP (see Fig. 1) in December 1992 to verify conclusions derived from preference curve analyses. Densities of Hydrobiosidae larvae at the time of sampling ranged from 0 to 15 0.lm<sup>-2</sup> for all size classes combined. Densities of

**Table 11 Optimum water depths (m) and velocities (m.s<sup>-1</sup>) over the range of conditions sampled for 4 size classes of Hydrobiosidae at 2 sites on the Tongariro River derived from maxima of locally weighted smooth curves (Lowess) and exponential polynomial curves (Polynomial) (see Appendix 5). Optima are for generalised curves (data from all sites combined; no parentheses) and for curves from each site (range given in parentheses).**

Size Class	Depth		Velocity	
	Lowess	Polynomial	Lowess	Polynomial
Hydrobiosidae I	0.4 (0.2-0.4)	0.1 (0.1)	0.3 (0.3)	0.6 (0.6-0.7)
Hydrobiosidae II	0.1 (0.1-0.4)	0.1 (0.1-0.8)	0.6 (0.6-0.7)	1.0 (0.9-1.5)
Hydrobiosidae III	0.1 (0.1-0.4)	0.1 (0.1-0.7)	1.5 (1.5)	1.5 (1.5)
Hydrobiosidae IV	0.1 (0.1-0.4)	0.1 (0.1-0.6)	1.5 (1.0-1.5)	1.5 (1.2-1.5)

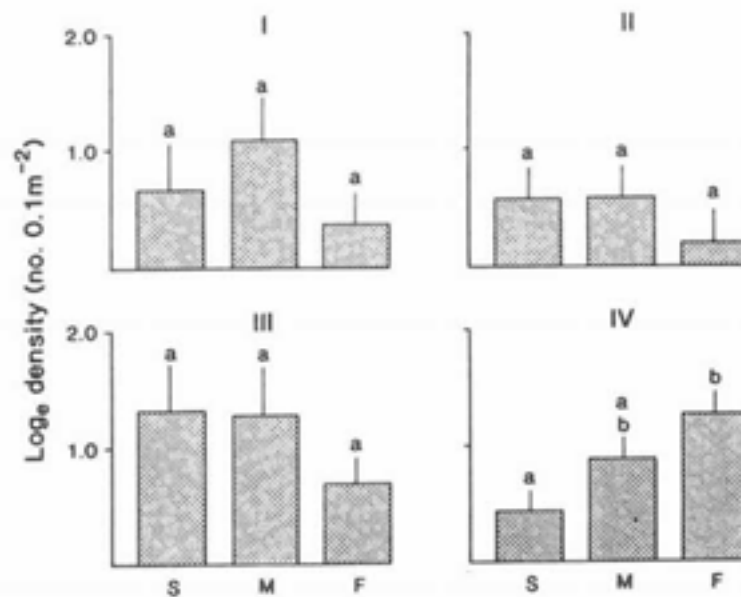


Figure 8 Abundances ( $\log_e N+1$ ,  $\bar{x} \pm 1SE$ ) of the four Hydrobiosidae size classes in Surber samples ( $n = 5$ ) from "slow", "medium" and "fast" water habitats (see Table 6) at Site TJ, Tongariro River in December 1992. Bars with different letters above are significantly ( $P < 0.05$ ) different.

larvae in size classes I-III were not significantly different in "slow", "medium" or "fast" flowing habitats, but a significant difference in the number of size class IV was detected (Fig. 8). Thus, densities of size class IV larvae increased with mean velocity and were significantly higher in "fast" than in "slow" flowing habitats. This supports the general conclusion from the preference curve analysis (Table 11), although the difference in size class III indicated by the preference curve analysis was not evident in the validation sampling.

### 5.2 *Deleatidium* spp. Preferences

Generalised depth preference curves for different size classes of *Deleatidium* spp. indicated that the optimum depth for most nymphs was usually  $< 0.5$  m, although size class VI had a depth optimum of 1.5 m (Table 12, Appendices 6A and 6B). Both curve calculation methods suggested an increase in generalised velocity optima with increasing size up to final instar when velocity optima appeared to decrease. Each site showed this same general pattern, although it was more evident at 11 and the size of *Deleatidium* spp. nymphs at which the velocity optima seemed to increase was different (Appendix 6A and 6B). Generalised curves suggested an increase in velocity optima for nymphs above size class II ( $> 0.5$  mm head width).

The methods used here to estimate optimum depths or velocities provide an indication of where maximum abundance of different size classes is likely to occur. However, preference curves for some taxa were shallow and did not extend below



values of 0.5 (an arbitrarily selected value which indicates approximately where half the maximum density of a taxon occurred). This indicates that these taxa were found over a wide range of conditions and had broad preferences. Velocity preference curves calculated using the exponential polynomial method extended below preference values of 0.5 for all size classes of *Deleatidium* spp. in the range of conditions sampled (Appendix 6B). Because size classes IV-VII were abundant over the range of depths, preferences values did not fall below 0.5 at any site.

Log-linear modelling showed that interactions between site and size class were not significant, indicating that similar numbers of nymphs were present in the same size classes at both sites (Table 13). However, site-related interactions involving size class and depth or velocity were highly significant ( $P < 0.001$ ) suggesting that sampling site had a marked effect on sizes of *Deleatidium* spp. nymphs recorded in different sampling cells. Because significant site effects were detected for both size class analyses, the significance of the effects of depth and/or velocity were tested separately at each site. Effects of depth and/or velocity on numbers of *Deleatidium* spp. in different size classes were highly significant at each site, indicating that these factors affected the size distribution of nymphs (Table 14). Velocity had a stronger effect on

**Table 12 Optimum water depths (m) and velocities ( $\text{m}\cdot\text{s}^{-1}$ ) over the range of conditions sampled for 8 size classes of *Deleatidium* spp. at 2 sites on the Tongariro River derived from maxima of locally weighted smooth curves (Lowess) and exponential polynomial curves (Polynomial) (see Appendix 6). Optima are for generalised curves (data from all sites combined; no parentheses) and for curves from each site (range given in parentheses).**

	Depth		Velocity	
	Lowess	Polynomial	Lowess	Polynomial
I	0.1 (0.1-1.5)	0.1 (0.1-1.5)	0.6 (0.4-0.9)	0.9 (0.8-1.1)
II	0.1 (0.1-1.5)	0.1 (0.1-1.2)	0.6 (0.3-1.0)	0.9 (0.8-1.1)
III	0.1 (0.1-0.4)	0.1 (0.1-1.2)	1.5 (1.1-1.5)	1.2 (0.9-1.5)
IV	0.4 (0.1-0.4)	0.1 (0.1-0.5)	1.5 (1.1-1.5)	1.1 (0.8-1.5)
V	0.6 (0.1-0.6)	0.1 (0.1-0.7)	1.3 (1.1)	1.2 (1.1-1.3)
VI	1.5 (0.4-1.5)	1.5 (0.8-1.5)	1.5 (0.6-1.5)	1.2 (0.9-1.5)
VII	0.4 (0.1-0.4)	0.1 (0.1-1.2)	1.5 (1.5)	1.5 (1.5)
VIII	0.1 (0.1-0.4)	0.4 (0.2-1.5)	1.0 (0.7-1.0)	0.9 (0.8-1.0)

numbers in different size classes at TI than at TG (determined from the chi-square values in Table 14). However, the combined effect of depth and velocity was greater at TG.

Replicate sampling of "slow", "medium" and "fast" flowing habitats (see Table 6 for velocities) was carried out at TJ (see Fig. 1) in December 1992 to verify conclusions derived from preference curve analyses. Although densities of *Deleatidium* spp. nymphs were low at TJ ( $1-39 \text{ O.1m}^{-2}$ , all size classes combined), a general trend of greater densities in "fast" flowing water with greater larval size up to final instar was evident (Fig. 9). Differences between habitats were not statistically significant except for size class VII nymphs which reached significantly higher densities in "medium" and "fast" flowing compared with "slow" flowing water. In contrast, final instar nymphs were most abundant in "medium" and "slow" flowing water (Fig. 9) supporting the suggestion that final instars move in to slower flowing habitats, possibly in search of suitable emergence sites. This pattern may not be evident throughout the year as samples were collected in early summer when emergence is likely to be high.

**Table 13 Likelihood ratio chi-square statistics, degrees of freedom (d.f) and probability values (P) for site related effects on numbers of *Deleatidium* spp. in different size classes at two sites on Tongariro River. Size classes I & II, III & IV, V & VI and VII & VIII from Table 4 were combined for log-linear modelling (see Methods).**

Effect	Chi-square	d.f.	P
s*sc	7.4	3	>0.05
s*d*sc	113.4	16	<0.001
s*v*sc	141.3	16	<0.001

**Table 14 Likelihood ratio chi-square statistics, degrees of freedom (d.f) and probability value (P) for depth and velocity related effects on numbers of *Deleatidium* spp. in different size classes at two sites on Tongariro River. Conventions as for Table 13.**

Effect	TG			TI		
	Chi-square	d.f.	P	Chi-square	d.f.	P
d*sc	39.4	12	<0.001	43.8	12	<0.001
v*sc	27.1	12	<0.01	64.4	12	<0.001
d*v*sc	382.3	44	<0.001	300.2	44	<0.001

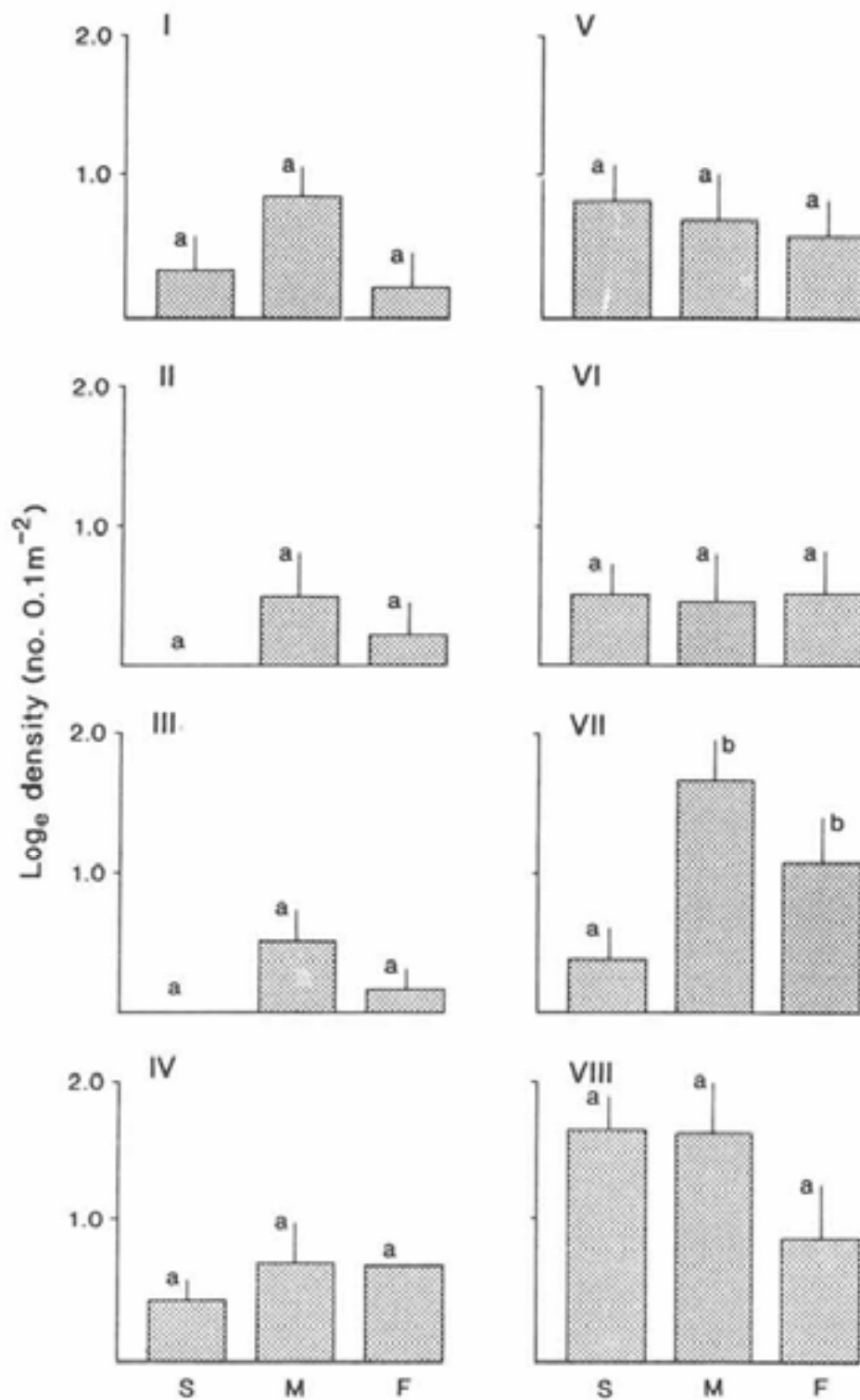


Figure 9 Abundances ( $\log_e N+1$ ,  $\bar{x} \pm 1SE$ ) of the 8 *Deleatidium* spp. size classes in Surber samples ( $n = 5$ ) from "slow", "medium" and "fast" water habitats (see Table 6) at Site TJ, Tongariro River, in December 1992. Bars with different letters above are significantly ( $P < 0.05$ ) different.

## 6. DISCUSSION

### 6.1 Sampling Protocol and Calculation of Flow Preference Curves

The number of samples collected at different sites ranged from 13 (TP) to 26 (TT). It was not possible to sample all cells in the pre-defined matrix of depth and velocity points, and few samples (12 at all sites) were collected in water >0.8 m deep. Thus, the probability of encountering high abundances, biomass or richness of the invertebrate fauna may have been greater in shallow water. However, a good range of velocity samples was taken at all sites (Table 1). The stratified sampling regime minimised the tendency for data to be dominated by a narrow range of depth or velocity conditions that may have prevailed at a specific site. As samples were collected over a narrow time frame (4 days in December), it was not possible to assess whether flow preferences were different in other months.

Both the Lowess and exponential polynomial methods of calculating preference curves yielded similar generalised depth and velocity optima for most invertebrate groups, although there were some differences. Small differences are probably not ecologically significant because of the variable height of different substrate elements influencing depth at a given point in the river, and because there is likely to be a diverse range of flow micro-environments amongst the substrate. However, the two techniques did yield relatively large differences in estimated depth and velocity optima for *Deleatidium* spp. (all sizes combined), depth optima for *Deleatidium* spp. size classes greater than II, and for velocity optima for *A. neozelandica*, *Eukiefferiella* sp. and *Cricotopus* spp. This may reflect the effects of variable sample sizes collected at different sites and the greater sensitivity of the Lowess technique to outliers.

### 6.2 Influence of Site Location

Site location was a significant factor affecting abundance of some of the invertebrate groups examined in the Tongariro River. Densities of all Chironomidae (midge) taxa combined were higher in the lower river sites TP and TT where they comprised 50-92% and 80-97% of total invertebrate numbers, respectively. Biomass of total chironomids, and abundances of *Eukiefferiella* sp. and *T. vespertinus* were also higher in the lower river. Chironomids appear to play an extremely important role in secondary production in the lower river, and this may be particularly so in summer when water temperatures are warmer and development rates are likely to be faster (e.g., Benke and Jacobi 1986). An understanding of the role of chironomids in the energetics of the Tongariro River, and of factors which affect their abundance is therefore important to the development of an ecologically desirable flow regime for the river.

Abundances of total invertebrates, *A. neozelandica*, *Z. furcillatus* and Oligochaeta were also higher in the lower river, but these differences were significant only for the first two-named groups. In contrast, abundances of *Deleatidium* spp. decreased with distance down river. This finding for abundances of total invertebrates, oligochaetes, *Eukiefferiella* sp. and *T. vespertinus* is consistent with the findings of Quinn and Vickers (1992) in summer and in most other seasons at five sites down the Tongariro River (including three sites above TG).

The effect of site location was also evident when deriving site-specific preference curves for some invertebrate groups. For example, the estimated depth optima of total chironomid numbers covered the full range of conditions sampled, perhaps partly reflecting the broad taxonomic composition of this group. In contrast, site location appeared to have a minor effect on depth and velocity preferences of *Aoteapsyche* spp. *Z. furcillatus*, *Oligochaeta*, *Maoridiamesa* sp. and *T. vespertinus* which had similar optima at all sites. Factors leading to apparent site-related effects on flow preferences may include spatial differences in the composition of the taxonomically broader invertebrate groups (see later discussion), the prevailing flow regimes and changes in channel gradient down the river. Velocity optima were highest for several invertebrate taxa (see Appendix 3) at Site TT which had the most stable baseflow, suggesting that prevailing flow regime may have been important in explaining site effects.

### 6.3 Influence of Larval Size

Separation of the mayfly *Deleatidium* spp. and the uncased caddisfly group Hydrobiosidae into size classes provided greater understanding of flow preferences for these taxa which previously have been poorly defined. The finding that different size classes have different velocity optima is supported by the work of Jowett and Richardson (1990) who discovered that dry weights of *Deleatidium* spp. and “uncased caddisflies” (a combination of Hydrobiosidae and *Aoteapsyche* spp.) were positively correlated with water velocity. Water depth and dry weight were correlated positively for uncased caddisflies and negatively for *Deleatidium* spp. in that study, implying that larger caddis larvae occurred predominantly in deeper water and that larger mayfly nymphs were found more commonly in shallower water. Results of the present study suggest that final instar mayflies may move into slower flowing water, possibly in search of suitable emergence sites.

The finding that different size classes of some invertebrate taxa prefer different flow conditions has important implications for the management of invertebrate communities if the availability of suitable habitat is limiting populations. It implies that optimal flow conditions should include a range of water depths and velocities to accommodate different stages of larval growth. It may in fact be the high velocity conditions which are critical because slow water zones are likely to occur in backwaters or behind boulders even at high flows. Because most size classes of *Deleatidium* spp. are usually present in all seasons (Collier and Winterbourn, 1990; Scrimgeour, 1991; Towns, 1981; Winterbourn, 1974), diversity of flow conditions is desirable throughout the year, although sampling in other seasons should be carried out to determine the temporal generality these size-related differences.

### 6.4 Flow Preferences of Invertebrates

In general, taxonomic richness, the density of most invertebrate groups and chironomid biomass were highest in water <0.5 m deep when data for all sites were combined. This is consistent with other work overseas (Orth and Maughan 1983, Brusven 1984) and elsewhere in New Zealand (Jowett and Richardson 1990) which have found that depths around 0.4 m are optimal for most invertebrate groups. Nevertheless, depth did have a significant effect on the distribution of different size classes of *Deleatidium* spp. at TG and TI, and one size class (VI) had an estimated depth optimum of 1.5 m. Few data were collected from this depth though. Depth preference curves for taxonomic richness, and numbers of total invertebrates, total

chironomids, *Cricotopus* spp., *Maoridiamesa* sp., and *Deleatidium* spp. size classes IV-VII were relatively shallow suggesting broad preferences for those groups.

Velocity preferences were much more variable between sites than depth preferences. Taxa could be classified into one of four groups based on their apparent velocity preferences at the different sites determined using both curve calculation techniques (Table 15). Oligochaetes, *Z. furcillatus*, *T. vespertinus* and Hydrobiosidae size class I had slow velocity optima ( $0.1-0.7 \text{ m.s}^{-1}$ ) at all sites, whereas *Eukiefferiella* sp., Hydrobiosidae size class TT and final instar *Deleatidium* spp. consistently preferred "moderate-fast" water velocities (Table 15). "Fast" water taxa (optima  $>0.9 \text{ m.s}^{-1}$ ) included *Aoteapsyche* spp., *Maoridiamesa* sp., the two largest hydrobiosid size classes and most *Deleatidium* spp. nymphs larger than size class II. Validation sampling at site TJ provided support for velocity optima determined for oligochaetes, *Aoteapsyche* spp., *T. vespertinus* and large hydrobiosid larvae.

The two smallest *Deleatidium* spp. size classes were included in the group with "slow-fast" velocity optima ( $0.1-1.8 \text{ m.s}^{-1}$ ), although their estimated optima did not exceed  $1.1 \text{ m.s}^{-1}$ . Other taxa classified as having broad velocity preferences were *A. neozelandica*, *Cricotopus* spp. and Orthoclaadiinae sp.a (Table 15). Jowett *et al.* (1991) made similar conclusions for *A. neozelandica*, and also for oligochaetes and *Aoteapsyche* spp. The shallow exponential polynomial preference curves for taxonomic richness, total invertebrates and total chironomid numbers and biomass suggested that these groups were also relatively common over a wide range of velocity conditions, partly reflecting the broad taxonomic composition of these groups.

### 6.5 Implications for Juvenile Trout Diet

Stephens (1989) found that juvenile trout diet was dominated by chironomid larvae and contained minor proportions of other taxa during summer in Breakaway Pool (approximately 4 km below TP). Furthermore, the stomachs of trout fry were 6 times more full when caught in summer than in winter, indicating that they were feeding more intensively in summer. "Free-living" caddisflies (Hydrobiosidae and *Aoteapsyche* spp.) became important components of trout diet in autumn and winter. The chironomid taxa that were dominant and the size distribution of free-living caddisflies

**Table 15 Groups of aquatic invertebrates divided according to velocity preferences, based on optima at 2-4 sites and calculated using 2 techniques.**

Slow-moderate $0.1-0.7 \text{ m.s}^{-1}$	Moderate-fast $0.6-1.5 \text{ m.s}^{-1}$	Fast $1.0-1.8 \text{ m.s}^{-1}$	Slow-fast $0.1-1.8 \text{ m.s}^{-1}$
<i>Z. furcillatus</i>	<i>Eukiefferiella</i> spp.	<i>Aoteapsyche</i> spp.	<i>Deleatidium</i> I & II
Oligochaeta	Hydrobiosidae II	<i>Maoridiamesa</i> sp.	<i>A. neozelandica</i>
<i>T. vespertinus</i>	Final instar <i>Deleatidium</i> spp.	Hydrobiosidae III & IV	<i>Cricotopus</i> spp.
Hydrobiosidae I		Most III-VII <i>Deleatidium</i>	Orthoclaadiinae sp. a

in the diet of juvenile trout caught by Stephens (1989) are not known. A study of juvenile trout diet at Site TP was carried out in December 1992 and data are currently being analysed by DOC staff at Turangi.

## 6.6 Implications for Blue Duck Diet

Wakelin (in press) examined the contents of seven blue duck faecal samples collected in December 1990 from sites above TG and down to TI on the Tongariro River. He found that, numerically, blue duck diet comprised 19-76% chironomids, 11-49% Trichoptera (a mixture of *Aoteapsyche* spp., Hydrobiosidae and various cased caddisflies), and 2-42% mayflies. *Eukiefferiella* sp. was the numerically dominant chironomid in the diet overall (11%), although *Cricotopus* spp. was relatively abundant in some samples (up to 19% of total invertebrates in the faeces). Chironomids tended to comprise a larger proportion of blue duck diet in samples below than above Tree-trunk Gorge.

The finding that blue duck on the Tongariro River consume a wide range of invertebrate taxa in varying proportions is consistent with the findings of studies on other rivers (Collier 1991, Veltman *et al.*: in prep.). This suggests that the best indicator of food supplies for blue duck may be total abundance and taxonomic richness of the invertebrate fauna. Optima of generalised depth preference curves for total invertebrates and taxonomic richness occurred in shallow water (<0.5 m deep), but velocity optima ranged from 0.1-0.3 and 1.2-1.8 m.s<sup>-1</sup> for total numbers and taxonomic richness, respectively. Nevertheless, preference factors for these groups tended to be high in most depth and velocity conditions sampled (see Appendix 3).

Recent work on Manganuiateao River indicates that blue duck may selectively consume large hydrobiosid larvae (K. Mason, Massey University, pers. comm.), suggesting that it may be necessary to consider larval size when determining flows that should optimise food supplies. If so, suitable habitat would need to be provided for young larvae to ensure that larger ones are recruited to the population. However, Hydrobiosidae represented only a small proportion numerically (7%, all samples combined) of invertebrates in the blue duck faecal samples from the Tongariro River examined by Wakelin (in press).

If total invertebrate abundance and taxonomic richness are the best indicators of blue duck food supplies and they are high over a wide range of flow conditions, as my results suggest, then it may be the area of suitable feeding habitat rather than the amount of food that is limiting blue duck populations on the upper Tongariro. Observations on Manganuiateao River have shown that blue duck feed predominantly in "ripply" or "ripply-white" water (Veltman and Williams 1990) which is probably equivalent to reasonably shallow water with moderately fast current velocities. Observations of blue duck feeding and follow-up measurements of physical conditions are currently being made to define the depth and velocity conditions at which most feeding activity occurs. As with juvenile trout, the influence of blue duck feeding activities on the distribution of invertebrate larvae in the river may also need to be considered when interpreting apparent flow optima for invertebrates.

## 7. CONCLUSIONS

1. In the Tongariro River in December 1990, water depth or velocity were important factors affecting the distribution of all invertebrate groups examined, except for elmid beetle larvae.

2. The different techniques used to estimate depth and velocity optima for invertebrates generally provided similar results. However, there were major differences between techniques for taxonomic richness, *Deleatidium* spp., *A. neozelandica*, *Eukiefferiella* sp. and *Cricotopus* spp. This may reflect the effects of variable sample sizes and the greater sensitivity of the Lowess technique to outliers.

3. Depth and velocity optima varied between sites for some taxa suggesting that other factors were also important in determining distribution. Optima were similar at all sites for the net-spinning caddisfly *Aoteapsyche* spp., the stonefly *Zelandobius furcillatus*, Oligochaeta (worms), and the midge larvae *Tanytarsus vespertinus* and *Maoridiamesa* sp.

4. Depths around 0.4 m are likely to provide suitable habitat for most benthic invertebrate groups and most size classes of Hydrobiosidae and *Deleatidium* spp. Other factors that could influence the decision on appropriate depth conditions in the river should include preferred feeding depths of blue duck, passage requirements of adult trout, and depth requirements for recreation and for stock barriers.

5. Velocity preferences of different taxa varied. Some clearly preferred "slow-moderate" (0.1-0.7 m.s<sup>-1</sup>) velocities (e.g., *Z. furcillatus*, Oligochaeta) whereas others preferred "fast" (1.0-1.8 m.s<sup>-1</sup>) water (e.g., *Aoteapsyche* spp.). Taxonomic richness, chironomid biomass, and abundances of total invertebrates, chironomids, and larvae of the crane fly *Aphrophila neozelandica* were relatively abundant over a broad range of velocity conditions.

6. Separation of chironomid (midge) larvae into major taxa provided considerable insight into the flow preferences of this group which can make up a large proportion numerically of the diet of juvenile trout and blue duck. All chironomid taxa were relatively abundant in shallow water, although *Eukiefferiella* sp., *Cricotopus* spp. and *Maoridiamesa* sp. were relatively abundant over a broad range of depth conditions. Some chironomid taxa showed distinct velocity preferences. *T. vespertinus* occurred predominantly at "slow-moderate" water velocities and *Maoridiamesa* sp. was found mainly in "fast" water. *Eukiefferiella* sp. occurred mostly at "moderate-fast" velocities (0.6-1.5 m.s<sup>-1</sup>) whereas *Cricotopus* spp. appeared to have broad velocity preferences.

7. Velocity preferences of Hydrobiosidae appeared to increase with increasing larval size. Larger *Deleatidium* spp. nymphs also seemed to prefer faster water, although final instar larvae appeared to move into slower water. This suggests that a range of



velocity conditions need to be provided to accommodate different life stages of some invertebrate taxa, at least in early summer.

8. A wide range of invertebrate taxa are eaten by blue duck in varying proportions suggesting that total invertebrate abundance and taxonomic richness may be the best indicators of blue duck food supplies. Total abundance and taxonomic richness were high over a wide range of flow conditions in this study. If these are appropriate indices of blue duck food supplies, then it may be the area of suitable feeding habitat rather than the amount of food that is limiting blue duck populations on the upper Tongariro. A study is currently investigating the water depths and velocities preferred by blue duck for feeding.

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