Changes in substrate and diet of blue duck on Tongariro River after the 1995 Mt Ruapehu eruption

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Summary

Sampling of three sites on the upper Tongariro River was carried out in summer (January) 1996 to evaluate impacts of the Mt Ruapehu eruption and subsequent flushings of accumulated sediment from behind Rangipo Barrage on substrate, periphyton, invertebrates and blue duck (*Hymenolaimus malacorhynchos*) diet. Levels of sand and gravels increased markedly in summer 1996 in blue duck feeding habitat at the head of a large island, while sand levels were low at the upstream reference site and immediately below Rangipo Barrage. Amounts of suspendable interstitial fine sediment in the middle part of Rangipo Reach were comparable to those at the upstream reference site, while directly below Rangipo Barrage there were extensive accumulations of fine volcanic silt in slow flowing areas.

The accumulations of volcanic silt below the barrage apparently smothered algae growing on stones in slow flowing areas, and may have contributed to higher (but non-significant) periphyton inorganic levels at this site. Periphyton biomass and inorganic content in the middle part of the reach were similar in summer 1996 to those at the upstream reference site. In contrast, there were marked reductions in the diversity, biomass and density of invertebrates at this site associated with the high levels of sand and gravels. Summer 1996 values for invertebrate richness, biomass and density were the lowest recorded at this site over a one year period, whereas at the upstream reference site summer 1996 values were not significantly different to those recorded on other dates.

There had been an increase in the relative abundance of Chironomidae on cobbles and gravels in the middle part of Rangipo Reach since the eruption, and there was some suggestion of a corresponding increase in the proportion of Chironomidae in the diet of blue duck. The inorganic content of blue duck faeces at this site also increased after the eruption, although it was within the range previously recorded elsewhere in the reach. Continued inputs of volcanic sediment to Rangipo Reach are likely to have adverse impacts on feeding habitat, food supplies and diet of blue duck, at least for birds feeding amongst boulders at the heads of islands. Two options for intercepting volcanic sediment delivered to Tongariro River are discussed:

1. Construction of sediment retention devices on tributary streams carrying high suspended sediment loads.

2. Continued use of Rangipo Barrage to trap sediment delivered to the river.

1. Introduction

On 18 September 1995 Mt Ruapehu erupted, and over the following months large amounts of volcanic ash were deposited within the catchment of the

Tongariro River. Most ash fell in a band across the Desert Road and Kaimanawa Ranges from 23 September and particularly between 11 and 12 October (H. Keys, DoC, Turangi, pers. comm.). Two streams, the Mangatoetoenui and Waihohonu, flow through the belt affected by the ash falls and most of the ash initially delivered to the Tongariro River was from these two tributaries, although there was also some input from upper Waikato Stream and tributaries flowing from the Kaimanawa Ranges. Other tributaries of the Tongariro such as Oturere Stream were relatively free of suspended sediments at the same time that the Mangatoetoenui and Waihohonu were carrying high loads (1460 and 900 g.m-3, respectively; Waugh et al. 1996). Secondary lahars have also been mobilised down Mangatoeteonui Stream (e.g., 28 October 1995) and, more recently, the Waihohonu (e.g., 10 February, 23 April 1996). As well as delivering the highest suspended sediment loads for longer periods, these tributary inputs have been been associated with changes to water conductivity and pH, although the Tongariro River at Turangi showed little change in pH during the eruption (Waugh et al. 1996).

Both the Mangatoetoenui Stream and Waihohonu Stream (via its diversion into the Waihohonu Tunnel) enter the Tongariro River above Rangipo Barrage, which trapped large amounts of sediment entering the river. Flushing of the barrage has been necessary to remove the accumulated sediment, and since the eruption (and up to May 1996) the barrage has been flushed on three occasions (G. MacCarthy, ECNZ, pers. comm.):

- 9-11 November 1995 - gates opened at 8.20 h and closed at 10.41 h.
- 23-26 December 1995 - gates opened 14.15 h and closed 13.42 h.
- 21-23 April 1996 - gates opened 02.56 h and closed 21.00 h.

These flushings have resulted in pulses of coarse sediment entering the Rangipo Reach of Tongariro River during high flows over the past few months, in contrast to the more constant delivery of volcanic sediment that might have been expected under natural flow conditions. A study commissioned by ECNZ into the effects of the TPD on substrate, periphyton, invertebrates and blue duck diet in the Rangipo Reach of Tongariro River was carried out between January and October 1995. This study included an evaluation of the impacts of a flushing of Rangipo Barrage carried out in August.

The Department of Conservation wishes to evaluate the ecological impacts of the high sediment input to Rangipo Reach in the light of the conditions prior to the September 1995 eruption as identified in the study for ECNZ. DoC posed the following questions which are dealt with in the present study:

1. What changes in substrate have occurred at three study sites above and below Rangipo Barrage since the previous investigations? Can these be attributed to the 1995 eruption?

2. What impact have these changes or other effects of the eruption (e.g., water chemistry) had on algae and aquatic invertebrates at the study sites, and how does this relate to blue duck diet?

3. On the basis of available information, what are appropriate options for management of sediment in Rangipo Barrage which could be used to mitigate effects of the eruption?

2. Methods

2.1 SAMPLING SITES AND DATES

A site above Rangipo Barrage (TDW), a site immediately below the barrage (TOR) and a site in the middle part of Rangipo Reach (TBTG) were sampled (see Table 1 for map references) on 18-19 January 1996. Site TBTG was in blue duck feeding habitat at the head of a large island, which the ECNZ study suggested was more sensitive to the effects of sediment inputs as the leading ends of islands serve as sediment deposition zones. Mangatoetoenui Stream and Waihohunu Tunnel, which carried most of the sediment from the eruption to the Tongariro, entered the river between sites TDW and TOR. Although TDW received some input of volcanic ash from tributaries in the Kaimanawa Ranges and upper Waikato Stream, levels were much lower than those that entered the Tongariro from Mangatoetoenui or Waihohonu Streams. Thus, for the purposes of this study, TDW served as a "control" site whereas TOR and TBTG were expected to be impacted by volcanic sediment inputs compared to the control.

Results from the summer 1996 sampling were compared with data collected previously on five occasions as part of the ECNZ study. The other samples were collected on:

- 16-19 January 1995 (Summer)
- 26-28 April and 3 May 1995 (Autumn)
- 2-4 August 1995 (Winter (pre-flush))
- 15-17 August (Winter (post-flush))
- 24-26 October 1995 (Spring).

Mt Ruapehu erupted 36 days before the spring sampling. Sediment flushing of Rangipo Barrage occurred 7 and 37 days before visits to TBTG by Dr M. Scarsbrook of NIWA, and 26 days prior to the late summer (18 January) 1996 sampling described in this report. Between 14 and 5400 tonnes of sediment per day were estimated to have travelled down the Mangatoetoenui Stream between the spring and summer 1996 sampling trips (Waugh et al. 1996).

Table 1 Locations of sampling sites.

Site code	Map reference (NZMS260)	Comments
TDW	T20 500 160	2.5 km above Rangipo Barrage
TOR	T20 498 177	50 m below Rangipo Barrage
TBTG	T19 527 228	200 m below Waikoko Stm confluence

2.2 SAMPLING AND ANALYTICAL METHODS

Study reaches at each site were 50-70 m long and encompassed the wadeable width of the river. The variables measured at each site and the methods used are described in Table 2.

One-way analysis of variance (ANOVA) followed by Tukey's post-hoc test was used to determine statistically significant differences between summer 1996 conditions following two flushings of volcanic sediment from Rangipo Barrage, and the other sampling dates for each of the three sites. Thus, the summer 1996 data for the two sites below the barrage reflect changes brought about by the transport of fine volcanic silt suspended in the water column and travelling through the barrage gates under normal flow conditions, and the pulses of sediment released by the barrage flushings during floods. In contrast, the spring data presented from the ECNZ study for the two downstream sites partly reflect the effects of fine volcanic silt carried below the barrage in the first few weeks following the eruption as well as any longer term impacts of the winter barrage flushing. The upstream site (TDW) experienced the floods associated with the barrage flushings but was not subject to the release of sediment from behind the barrage.

All data were log (count data) or arcsine-square root (proportional data) transformed before analysis to minimise heterogeneity of variances. The probability level (P) at which significant differences were determined was set at $P < 0.05$. These analyses were carried out for interstitial suspendable inorganic sediment levels, periphyton biomass and inorganic levels, and taxonomic richness, biomass and density of aquatic invertebrates in Surber samples as five replicate samples were collected at each site on each date for these parameters. For the other parameters single or composite samples were collected, and statistical analyses of differences between dates were not carried out.

Table 2 Details of methods used for analyses.

Analysis	Method	References
Surficial substrate size composition	Random walk through reach to determine size class of ≥100 substrate particles using standard divisions ranging from sand to bedrock (see Figure 1).	Wolman (1954) Minshall (1984)
Interstitial suspendable inorganic sediment levels	At 5 random locations, fine sediments within the bed enclosed by a metal cylinder (0.36 m diameter) stirred and suspendable sediments (mostly fine sand and silt) collected in 1 L bottle. Depth of water in cylinder measured at 10 points. Dry weight (105°C) and ash-free dry weight (450°C for 6 hrs) of sediment measured. Values adjusted for volume of water in cylinder.	APHA (1989)
Periphyton biomass and inorganic levels	At 5 random locations, 5 stones (large gravel-small cobble) collected and scrubbed in 120 ml water with stiff nylon brush. Removed material collected and stored in dark on ice. Analysed for chlorophyll *a* (a measure of live algal biomass) spectrophotometrically following extraction in 90% acetone. Total dry weight and ash-free dry weight (a measure of live and dead algae + other organic matter) measured as above. Axes (a, b & c) of stones measured and converted to surface area.	APHA (1989) Dall (1979)
Diversity, biomass, density and composition of invertebrate food supplies	At 5 random locations, 0.1 m^2 Surber sample (250 mm mesh net) collected in typical blue duck feeding habitat. Boulder brushing from submerged surfaces of exposed boulders (10 x 10 sec) also collected using 250 mm mesh net. Invertebrates counted and identified using standard keys, and biomass measured after drying at 60°C for ≥24 hrs (stony cases of caddisflies excluded). Values adjusted for subsampling where appropriate.	Winterbourn & Gregson (1989)
Invertebrate composition and percent inorganics in blue duck diet	Faecal samples collected from exposed boulders and frozen. Thawed, dispersed with stirrer and detergent, and first 100 diagnostic fragments identified to taxonomic group. Dry weight and ash-free dry weight of remainder of sample measured as above.	APHA (1989) Wakelin (1993)

3. Results

3.1 SURFICIAL SUBSTRATE SIZE COMPOSITION

The results of the substrate size analysis at three sites between summer 1995 and summer 1996 are shown in Figure 1. For sites TDW and TBTG, additional data collected on 15/12/95 by Dr Mike Scarsbrook of NIWA are also shown ("early SU" in Figure 1).

Levels of sand and gravel above Rangipo Barrage and Mangatoetoenui Stream (site TDW) varied between 3-9% and 21-48%, respectively, throughout the study. Directly below the barrage (TOR), there was a marked increase in sand and gravel associated with the winter sediment flush, with levels of sand declining through spring and summer 1996 and gravels remaining relatively constant over this time (37-39% of surficial substrates; Figure 1).

In the middle part of Rangipo Reach (site TBTG) there was also an increase in surficial sand associated with the winter flush (from 2 to 19%), but this had declined substantially by spring (9%). Rangipo Barrage was flushed again for approximately two days beginning on 9 November; on 16 November at 13.00-14.00 h the site was visited by Dr Mike Scarsbrook of NIWA. At that visit, he noted that "the bed comprised about 95% shifting sand with many invertebrates drifting in the water. I walked down the thalweg of the river from the confluence of the tributary to the island and did not get wet above my knees except when I sank into soft sand."

During another visit to TBTG one month later sand and gravel levels were 32% and 23%, respectively, of the substrate on the riverbed ("early Su" in Figure 1). By late summer (18 January 1996) and following a second flushing of Rangipo Barrage, sand levels had declined to 19% of surficial substrate elements and gravel levels had increased to 38%, much higher than the range of 10-13% recorded in the ECNZ study.

These results indicate that:

- the level of sand recorded at TBTG one month following the November flushing was the highest recorded during the study, but by January this had declined to levels comparable to that measured shortly after the winter flush of Rangipo Barrage.

- the level of gravel recorded at TBTG in January 1996 was the highest recorded at that site.

- continued inputs of volcanic sediment to Rangipo Reach are likely to result in sustained high levels of sand and increasing levels of gravel in blue duck feeding areas at the heads of islands.

3.2 INTERSTITIAL SUSPENDABLE INORGANIC SEDIMENTS

The mean weights of suspendable inorganic sediments (mostly fine sand and silt) within the riverbed adjusted to a square metre basis at the three sites on different sampling occasions are shown on log axes in Figure 2. In summer 1996, levels averaged 146 $g.m^{-2}$ at TDW, 255 $g.m^{-2}$ at TBTG and 5 347 $g.m^{-2}$ at TOR; for the latter site this was twice the average level recorded on any other sampling occasion.

At this time, the bed in slow flowing areas and along the water's edge at TOR was coated with thick deposits of fine silt, but this was not evident in faster flowing riffle areas. This fine silt was carried in water flowing through Rangipo Barrage rather than having originated from sediment flushing. The random assignment of sampling locations meant that suspendable sediment samples were collected across a range of velocity habitats resulting in wide variance in the data. The uneven distribution of these silt deposits appeared to be the main reason for a lack of statistically significant differences between summer 1996 and other sampling occasions (Table 3). At the other two sites, levels of suspendable sediments recorded in summer 1996 were significantly lower than those recorded over the winter and spring periods, and were not significantly different to those recorded in summer 1995.

These results suggest that:

- high levels of fine volcanic silt carried through the barrage were deposited downstream in slower flowing areas in summer 1996, but the distribution on and within the bed was patchy and reflected velocity conditions.

- levels of interstitial inorganic sediments at TBTG followed the same pattern as at the upstream reference site suggesting that inputs since spring had little impact on fine sediment levels within the bed at the heads of islands in that part of Rangipo Reach.

Table 3 Statistically significant differences (ANOVA followed by Tukey's test) in interstitial suspendable inorganic sediment levels between five sampling occasions in 1995 and summer 1996 (Su96) at three sites on Tongariro River. Sites TOR and TBTG received two flushings of sediment from Rangipo Barrage after spring. ", P < 0.01; "', P < 0.001; n.s. = not significantly different (P > 0.05).

	Summer	**Autumn**	**Winter (pre-flush)**	**Winter (post-flush)**	**Spring**
TDW	n.s.	n.s.	>Su96***	>Su96**	>Su96***
TOR	n.s.	n.s.	n.s.	n.s.	n.s.
TBTG	n.s.	n.s.	>Su96**	>Su96***	>Su96**

3.3 PERIPHYTON

The mean weights of periphyton as chlorophyll *a* (live algae) and AFDW (all organic material including live and dead algae, fungi, trapped organic matter) adjusted to a square metre of riverbed, and the percentage of inorganic material in periphyton at the three sites on different sampling occasions are shown in Figures 3-5. Chlorophyll *a* levels were low at all three sites in summer 1996 (0.62-3.79 $mg.m^{-2}$; Figure 3), and they were not significantly different to levels recorded in spring at any site or to levels recorded in winter (post-flush) at TOR and TBTG (Table 4A). Chlorophyll *a* levels at TOR were significantly lower than those recorded in summer 1995, but this was also evident at TDW suggesting that this was not a result of volcanic inputs from Mangatoetoenui or Waihohonu Streams and the flushing of accumulated sediment from Rangipo Barrage.

In contrast to the pattern for chlorophyll, mean AFDW of periphyton at TOR in summer 1996 was the highest recorded during the study (14.1 $g.m^{-2}$; Figure 4), although as with suspendable inorganic sediment levels there was high variability such that no significant differences with most other sampling occasions were detected (Table 4B). The high average value and great variability presumably reflect the presence of dead algae caused by the coating of rocks with fine silt. At TBTG, AFDW of periphyton in summer 1996 was significantly lower than in summer 1995 but did not differ statistically from winter (post-flush) levels. This pattern was also apparent at the upstream reference site (TDW) indicating that the low summer 1996 values at TBTG could not be attributed directly to the recent sediment flushings of Rangipo Barrage.

Similarly, the percentage of periphyton that comprised inorganic material in summer 1996 was not significantly different to that recorded in spring, winter (post-flush) or summer 1995 at any site (Figure 5, Table 4C) suggesting that the recent sediment inputs had no detectable effect on this at the time of sampling. At TOR where there was high biomass of apparently dead algae and accumulations of silt on stones in slower flowing areas, 95% of periphyton was, on average, composed of inorganic material in summer 1996. This was the same as that recorded in spring (soon after the eruption of Ruapehu) but higher than that recorded in other months at this site (78-91%). This suggests that waterborne ash from the eruptions may have contributed to high inorganic levels in periphyton at this site, but this was probably mainly in slower flowing habitats. The variable range of velocity habitats sampled probably partly accounts for the lack of a statistically significant difference in periphyton inorganic content at this site.

These results suggest that:

- deposition of waterborne volcanic silt below Rangipo Barrage was associated with high levels of apparently dead algae in summer 1996, and may have contributed to higher periphyton inorganic content in slower flowing habitats.

- differences in levels of chlorophyll, AFDW and percent inorganics in periphyton detected at TBTG in summer 1996 did not seem to be attributable to the recent inputs of sediment.

Table 4 Statistically significant differences (ANOVA followed by Tukey's test) in periphyton chlorophyll *a*, ash-free dry weight (AFDW) or % inorganics between five sampling occasions in 1995 and summer 1996 (Su96) at three sites on Tongariro River. Sites TOR and TBTG received two flushings of sediment from Rangipo Barrage after spring. *, P < 0.05; **, P < 0.01; ***, P < 0.001; n.s. = not significantly different (P > 0.05).

A. Chlorophyll *a*

	Summer	Autumn	Winter (pre-flush)	Winter (post-flush)	Spring
TDW	>Su96**	>Su96**	n.s.	n.s.	n.s.
TOR	>Su96***	>Su96***	>Su96**	n.s.	n.s.
TBTG	n.s.	>Su96***	>Su96***	n.s.	n.s.

B. AFDW

	Summer	Autumn	Winter (pre-flush)	Winter (post-flush)	Spring
TDW	>Su96**	>Su96*	>Su96*	n.s.	n.s.
TOR	n.s.	n.s.	n.s.	<Su96**	n.s.
TBTG	>Su96*	>Su96***	>Su96***	>Su96***	0.004

C. % inorganics

	Summer	Autumn	Winter (pre-flush)	Winter (post-flush)	Spring
TDW	n.s.	<Su96**	<Su96***	n.s.	n.s.
TOR	n.s.	<Su96*	<Su96**	n.s.	n.s.
TBTG	n.s.	<Su96*	n.s.	n.s.	n.s.

3.4 INVERTEBRATE COMMUNITIES

The mean taxa richness (number of taxa), biomass and density of benthic invertebrates, and the relative composition of the main taxonomic groups collected in Surber samples (adjusted to a square metre of riverbed) or boulder brushings are shown in Figures 6-11. Mean taxa richness in Surber samples in summer 1996 was the lowest recorded during the study at TOR and TBTG (9 and 4 taxa, respectively; Figure 6), but at TDW summer 1996 richness was not significantly different to that on any other date. In contrast, invertebrate richness at TOR and TBTG was significantly lower than on all dates except spring (Table 5A). Taxonomic richness of invertebrates in boulder brushings increased in summer 1996 at TDW, remained at a similar low level to that recorded on most other dates at TOR, and was comparable to the richness recorded in spring at TBTG (Figure 7).

The mean biomass (weight) of invertebrates in Surber samples was higher in summer 1996 than the preceeding two sampling occasions at TDW and remained at a constant low level at TOR (Figure 8). Indeed, there were no significant differences between summer 1996 and other sampling dates at these sites (Table 5B). In contrast, mean biomass at TBTG was the lowest recorded during the study in summer 1996 and this difference was statistically significant for all dates except autumn. A similar pattern was apparent for invertebrate biomass from boulder brushings (Figure 9).

The mean density of invertebrates at TDW in summer 1996 was not significantly different to that recorded on other dates, while at TOR densities were similar to those recorded in winter and spring but significantly lower than those recorded in the preceeding summer and autumn (Figure 10, Table 5C). At TBTG, mean densities in summer 1996 were the lowest recorded during the study; they were significantly lower than densities recorded in spring, winter (pre-flush) and autumn but were not significantly different to densities recorded in winter (post-flush) or the preceeding summer. The low densities at TBTG in summer 1996 appeared to reflect substantially lower densities of Leptophlebiidae (mean = 36 m^{-2} cf 228-554 m^{-2} on other dates) and cased caddis (8 m^{-2} cf 54-998 m^{-2}); densities of these taxa were significantly ($P < 0.01$) lower in summer 1996 than on any other date. Numbers of invertebrates collected from boulders were also lowest at TBTG in summer 1996 (Figure 11).

In summer 1996, invertebrates on cobbles and gravels in Surber samples were dominated by Leptophlebiidae at TDW (48% of invertebrate numbers), Leptophlebiidae and Chironomidae at TOR (41% and 46%, respectively), and Chironomidae at TBTG (76%) (Figure 13). Chironomidae also dominated the invertebrate fauna numerically at TBTG in spring. Proportions of cased caddis and Leptophlebiidae at TBTG and cased caddis at TOR in summer 1996 were the lowest recorded during the study. In contrast, proportions of Leptophlebiidae at TOR and Coleoptera at TBTG and TDW were highest in Surber samples in summer 1996. The same pattern was evident at this time for proportions of cased caddis and Coleoptera on boulder brushings at TBTG, whereas at TOR there were no Leptophlebiidae collected on boulders and proportions of Plecoptera, cased caddis and Coleoptera were higher than on any other date (Figure 14).

Table 5 Statistically significant differences (ANOVA followed by Tuhey's test) in taxa richness, biomass and density of invertebrates in Surber samples between five sampling occasions in 1995 and summer 1996 (Su96) at three sites on Tongariro River. Sites TOR and TBTG received two flushings of sediment from Rangipo Barrage after spring. >, greater than; *, P < 0.05; **, P < 0.01; ***, P < 0.001; n.s. = not significantly different (P > 0.05).

A. Taxa richness

	Summer	**Autumn**	**Winter (pre-flush)**	**Winter (post-flush)**	**Spring**
TDW	n.s.	n.s.	n.s.	n.s.	n.s.
TOR	>Su96**	>Su96***	>Su96**	>Su96*	n.s.
TBTG	>Su96*	>Su96***	>Su96***	>Su96**	n.s.

B. Biomass

	Summer	**Autumn**	**Winter (pre-flush)**	**Winter (post-flush)**	**Spring**
TDW	n.s.	n.s.	n.s.	n.s.	n.s.
TOR	n.s.	n.s.	n.s.	n.s.	n.s.
TBTG	>Su96*	n.s.	>Su96***	>Su96**	>Su96**

C. Total density

	Summer	**Autumn**	**Winter (pre-flush)**	**Winter (post-flush)**	**Spring**
TDW	n.s.	n.s.	n.s.	n.s.	n.s.
TOR	>Su96***	>Su96***	n.s.	n.s.	n.s.
TBTG	n.s.	>Su96**	>Su96***	n.s.	>Su96*

These results suggest that:

- taxonomic richness of invertebrate communites was adversely affected by the eruption of Mt Ruapehu at both sites below Rangipo Barrage.

- invertebrate biomass and densities (particularly cased caddis and Leptophlebiidae) at TBTG declined to the lowest level recorded during this study following sediment inputs over summer 1995-96.

- the invertebrate community became dominated more by Chironomidae and there were relatively fewer cased caddis and Leptophlebiidae at TBTG following the eruption of Mt Ruapehu.

- the reduced food supply for blue duck at TBTG was probably due to the high levels of sand and the buildup of gravels between boulders and cobbles.

3.5 BLUE DUCK DIET

Blue duck faeces were only located at TBTG in summer 1996. The proportions of the eight main invertebrate groups in faeces on different dates from this site are shown in Figure 15 and changes in inorganic content are indicated in Figure 16. In summer 1996, diet comprised mostly Chironomidae (65%) followed by cased caddis (13%) and Coleoptera (11%). Chironomidae also the dominant component of blue duck diet at this site in spring (following the eruption) and autumn when there was high algal biomass, but this group did not make up the same large proportion of diet on other dates at this site. The summer 1996 diet contrasts with that recorded in summer 1995 when it comprised mostly cased caddis (Figure 15). This infers that that the eruption may have led to greater dominance by Chironomidae in the diet of blue duck at this site. However, further sampling is required to determine whether the suggested change in diet is consistent over time.

The faeces collected at TBTG in summer 1996 appeared grey in colour as if they contained large amounts of volcanic silt. There appears to have been an increase in the inorganic content of blue duck faeces at TBTG following the Mt Ruapehu eruption (55-65% compared to 33-41% on other dates; Figure 16), although inorganic content declined in summer 1996 compared to spring and the spring level was in the range recorded previously at other sites during the course of the ECNZ study (e.g., up to 81% at a site downstream of TBTG). This suggests that the response of blue duck diet to inputs of sediment may vary between sites on Rangipo Reach.

These results suggest that:

- the eruption of Mt Ruapehu appeared to be associated with increased dominance by Chironomidae in the diet of blue duck at TBTG.

- the inorganic content of blue duck faeces at TBTG increased following the eruption of Mt Ruapehu, but it was still within the range of that recorded at other sites on the river prior to the eruption.

4. Discussion

4.1 SUBSTRATE CHANGES

The eruption of Mt Ruapehu and the subsequent flushings of sediment from Rangipo Barrage were associated with sustained high levels of sand and the buildup of gravels between boulders in blue duck feeding habitat at the head of a large island in the middle part of Rangipo Reach (site TBTG). At the same time, levels of sand were low at the upstream reference site (TDW) and immediately below Rangipo Barrage (TOR), but at the latter site gravel levels had remained high since the winter sediment flushing. The two barrage flushings in November and December 1995 contributed an estimated total of 334,000 m^3 of sediment to Rangipo Reach, while in April 1996 200,000 m^3 are thought to have been flushed from the barrage (ECNZ estimates provided by DoC, Turangi).

Some of the gravel that had accumulated at TBTG over spring and summer 1996 was presumably derived from material transported to the river as a result of the eruption and subsequently flushed from the barrage. Many of the larger gravels probably originated from normal sediment transport processes upstream of Rangipo Barrage and were released following flushings during and prior to the last summer. Many of the gravels at TBTG had lodged in the interstices between cobbles and boulders, reducing the spaces in which blue duck often feed.

Continued volcanic inputs to Rangipo Reach are likely to result in sustained high levels of sand and the continued buildup of gravels in blue duck feeding habitat, at least at the heads of islands. Although pulses of sand can be expected to be damaging to aquatic biota, levels in the channel should change relatively rapidly as material is dispersed during flood events. This was evidenced by the changes in surfical sand levels at TOR and TBTG following the winter flushing of Rangipo Barrage. Furthermore, not all sand is deposited in the channel during flushing; some is deposited on islands or on the river's edge where water velocities slow down during floods and therefore does not directly affect instream habitat at baseflows. Gravels are less mobile than sand and may be a longer term feature of the surficial substrate in the channel if trapped in the interstices between larger substrate elements. As noted in the ECNZ report, blue duck feeding habitat at the heads of islands appears to be more sensitive to sediment inputs from flushing than areas of channel without islands, presumably because the leading ends of islands serve as sediment deposition zones. Levels of interstitial fine sediment at TBTG in summer 1996 were comparable to those at the upstream reference site (TDW), while directly below Rangipo Barrage (TOR) there were extensive accumulations of fine volcanic silt in slow flowing areas.

4.2 ECOLOGICAL CHANGES

The accumulations of volcanic silt below the barrage in summer 1996 apparently smothered algae growing on stones in slow flowing areas, resulting in low chlorophyll but high AFDW values, and may have contributed to higher (but non-significant) periphyton inorganic levels at this site. Periphyton biomass and inorganic content at TBTG in summer 1996 were similar to those at the upstream reference site indicating that downstream inputs to Tongariro River from the eruption had no detectable impact on these parameters at this time.

In contrast, there were marked reductions in the diversity, biomass and density of invertebrate food supplies of blue duck at TBTG in summer 1996 associated with high levels of sand and gravels. Indeed, values for these food supply indices were the lowest recorded at this site during the course of the study, whereas at the upstream reference site, summer 1996 values were not significantly different to those recorded on other dates. Taxa richness was also significantly lower immediately downstream of Rangipo Barrage in summer 1996 than on any other date, whereas biomass (which was usually low there) remained within the range previously recorded.

The abundance of Leptophlebiidae and cased caddis in particular had declined at TBTG since the recent sediment flushings and there appeared to be an increase in the relative abundance of Chironomidae on cobbles and gravels since the eruption in September. There was some suggestion that there was also a corresponding increase in the proportion of Chironomidae in the diet of blue duck at TBTG. Further sampling is required to determine if this suggested shift in diet persists. The inorganic content of blue duck faeces at TBTG increased after the eruption and was higher in summer 1996 than in the preceding summer suggesting that food quality as well as quantity had declined at this site. However, faecal inorganic levels were within the range previously recorded elsewhere within the reach during the ECNZ study.

Blue duck numbers on Rangipo Reach are unusually low at present, and some birds appear to have dispersed upstream or downstream (C. Speedy, DoC, Turangi, pers. comm.). Higher numbers of ducks have recently been noted by hunters in the Waipakahi valley and a male and female pair were seen below Rangipo Lodge in March 1996.

4.3 OPTIONS FOR MANAGING SEDIMENT

Continued inputs of volcanic sediment to Rangipo Reach are likely to have adverse impacts on the physical habitat, food supplies and diet of blue duck, at least for birds feeding at the heads of islands. This appears to be due principally to the deposition of high levels of sand on the bed and the accumulation of small gravels between larger sized substrate elements amongst which blue duck often feed. These impacts are likely to be most severe in blue duck feeding habitat at the leading ends of islands which seem to serve as sediment deposition zones.

There appear to be two main options for intercepting volcanic sediment delivered to Tongariro River:

1. Construction of sediment retention devices on tributary streams carrying high suspended sediment loads (e.g., Mangatoetoenui Stream).

2. Continued use of Rangipo Barrage to trap sediment delivered to the river.

4.3.1 Construction of sediment retention devices on tributary streams

Sediment retention devices on tributary streams would need to be cleaned out regularly. Waugh et al. (1996) estimated that 50 ten-tonne truck loads a day would be required to remove typical daily sediment loads recorded in Mangatoetoenui Stream following the eruption. Other issues associated with the construction of retention devices include the need to identify a suitable installation site with truck access, environmental effects of sediment trap and road construction, and the need to locate an acceptable site for disposal.

4.3.2 Continued use of Rangipo Barrage

Possible options for managing sediment trapped by Rangipo Barrage include:

a) allowing the long-term build up of sediment behind the barrage;

b) mechanical excavation of accumulated sediment;

c) continuing flushing of accumulated sediment during 100 cumec floods.

Issues associated with long-term retention of sediment behind the barrage include loss of generating capacity, long-term dam safety, ecological changes due to sediment accumulation, and future disposal problems. The same issues relating to disposal site location and sediment volume mentioned in Section 4.3.1 would also apply if material was excavated from behind Rangipo Barrage.

If flushing of Rangipo Barrage continues it should be carried out as frequently as possible (instead of only when it is full) during acceptably high flows so that smaller but more regular pulses of sediment are delivered to Rangipo Reach. The high rate of sediment accumulation behind the barrage means that this is currently being done. Sustaining artificially high flows by using Moawhango water should help to increase the rate at which released sediment moves through the reach. This needs to be balanced against the possibility of an extended shift in preferred blue duck feeding habitat to areas of bed that have been inundated by the higher flows and have little in the way of food supplies.

The feasibility and likely success of trapping gravels released during flushing while allowing sand to move downstream in sustained high flows could be evaluated. Sand deposited in the channel is likely to be mobilised and dispersed through the reach during high flows more readily than gravels, which may have longer term effects as they seem to lodge in the interstices between cobbles and boulders in blue duck feeding habitat. Material caught in gravel traps below the barrage would need to be excavated and disposed of appropriately.

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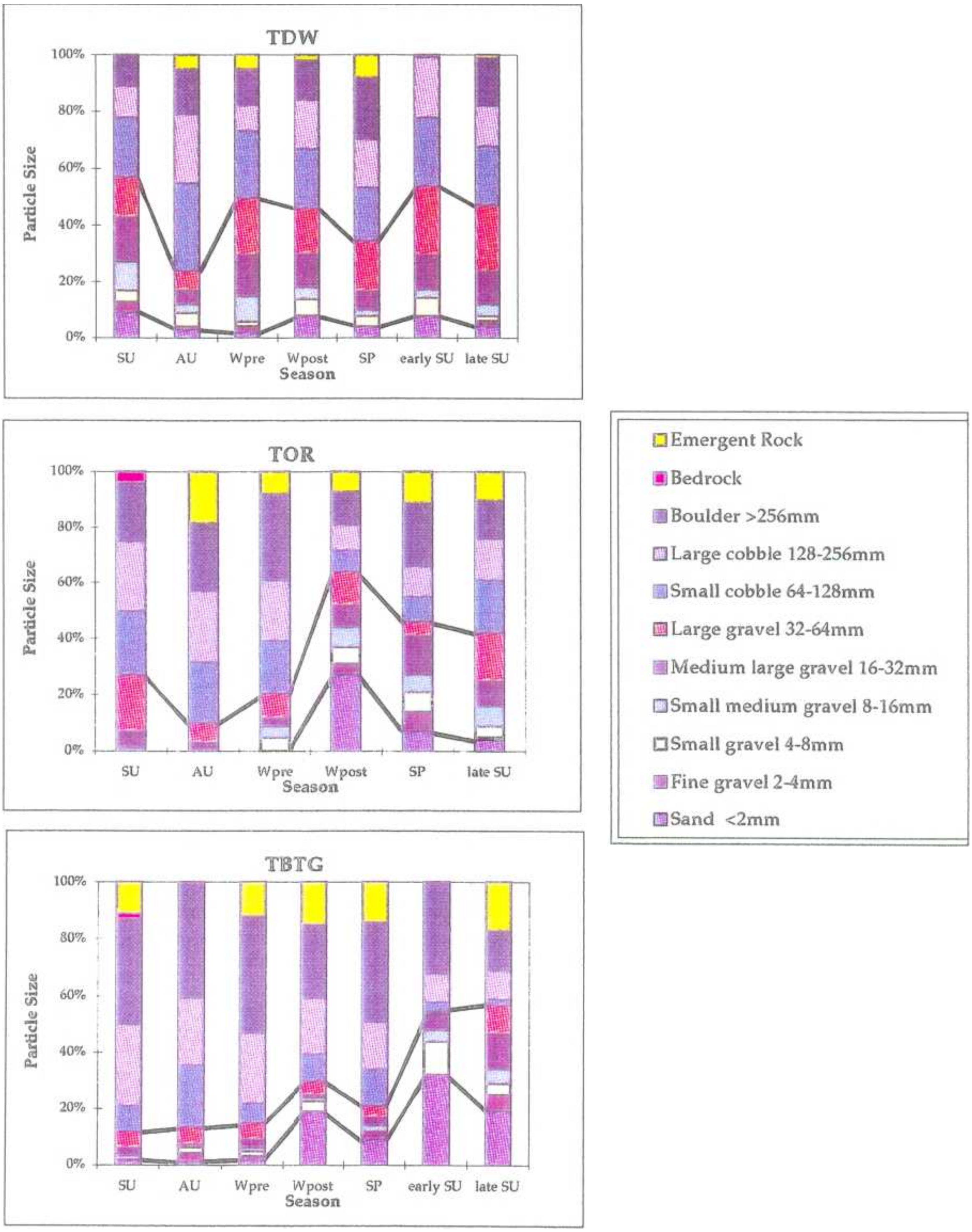

Figure 1 Percent substrate particle size composition of surficial bed materials at three sites along Rangipo Reach on six dates. SU=summer (January) 1995, AU=autumn, Wpre=winter (pre-flush), Wpost=winter (post-flush), SP=spring, early SU=December 1995, late SU=summer (January) 1996. Lines represent gravels (upper) or sand (lower).

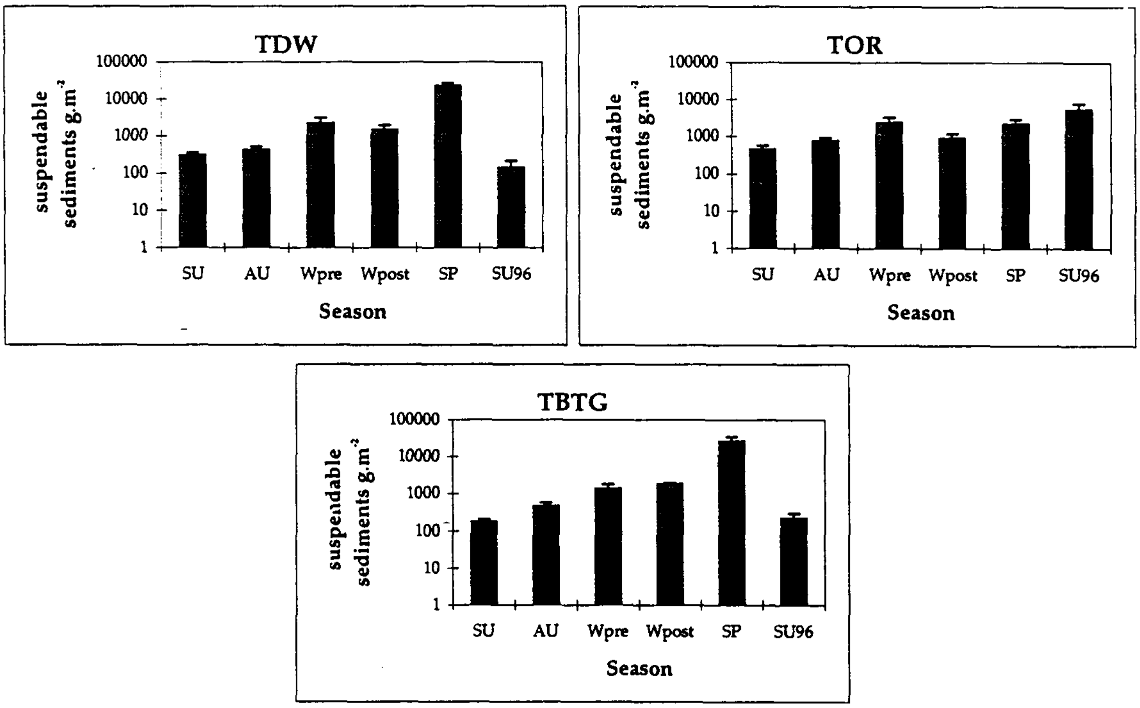

Figure 2 Mean (+ISE, n=5) weight of suspendable inorganic sediments in the bed at three sites along Rangipo Reach on six dates. SU=summer (January) 1995, AU=autumn, Wpre=winter (pre-flush), Wpost=winter (post-flush), SP=spring, SU96=summer (January) 1996.

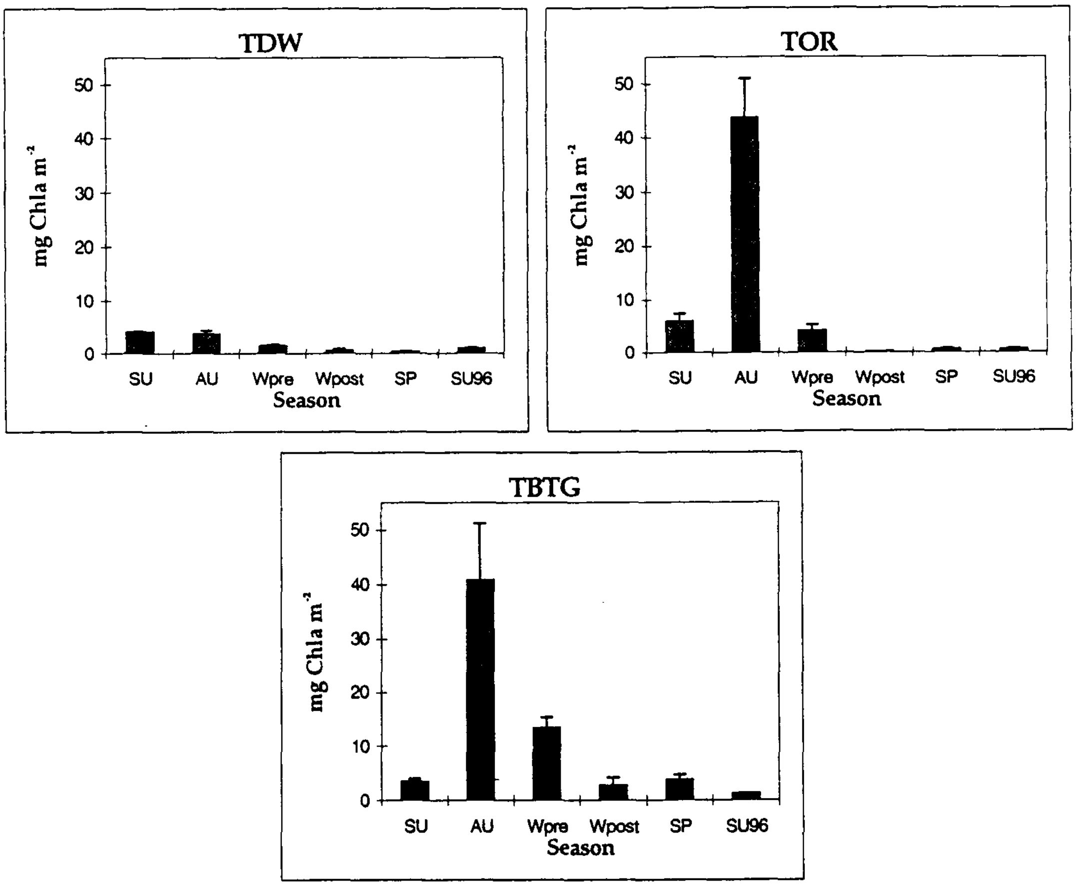

Figure3 Mean (+ISE, n=5) concentrations of chlorophyll *a* (an index of living algae) at three sites along Rangipo Reach on six dates. SU=summer (January) 1995, AU=autumn, Wpre=winter (pre-flush), Wpost=winter (post-flush), SP=spring, SU96=summer (January) 1996.

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