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THE COMBINED EFFECTS OF FLOW REGULATION AND AN ARTIFICIAL FLOW RELEASE ON A REGULATED RIVER

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ABSTRACT

Damming and regulating the flow of rivers is a widespread issue and can have a significant impact on resident biota. The Tongariro River, central North Island, New Zealand, has a flow regime that is regulated by two hydroelectric dams along its length, and it has been suggested that 'flushing flows' would assist benthic communities by removing 'nuisance' periphyton growth forms that typically occur in autumn. We assessed whether (i) damming has altered periphyton and macroinvertebrate communities downstream of the Rangipo Dam and (ii) whether the release of a flow pulse equivalent to 50 times the baseflow is sufficient to (a) move the substrate in the section of river downstream of this dam and (b) impact benthic periphyton and macroinvertebrate communities. Downstream macroinvertebrate communities were impacted by the presence of the dam, but periphyton was not. No movement of substrate occurred downstream of the dam as a result of the flow release, which was likely because of naturally high embeddedness and armouring of substrate. Periphyton biomass and macroinvertebrate density were not affected by the release indicating that larger releases would be required to have any effect on benthic communities downstream of this dam. This study highlights the importance of considering natural bed structure and sediment dynamics when using flow releases downstream of dams to control periphyton. Copyright © 2013 John Wiley & Sons, Ltd.

KEY WORDS: algae; artificial flow release; complementary flows; dams; flow regulation; flushing flow; macroinvertebrate; periphyton

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INTRODUCTION

The natural flow regime has long been considered crucial for maintaining the ecological integrity of rivers worldwide (Poff *et al*., 1997). Damming and controlling flow regimes can have severe effects on downstream benthic communities through a variety of factors depending on the management regime (Vinson, 2001; Bunn and Arthington, 2002). These impacts depend on the size of the dam and may reflect changes in water temperature, fluctuating depth and velocity, deposition or removal of silt and changes to food supply/periphyton (Munn and Brusven, 1991; Ligon *et al*., 1995; Brandt, 2000; Tonkin *et al*., 2009). To alleviate these effects, dam removal has been increasing in recent times (Bednarek, 2001; Hart *et al*., 2002; Lejon and Nilsson, 2009; Hurst *et al*., 2012).

The Tongariro River in the central North Island of New Zealand has two dams regulating the flow regime, and previous studies have suggested that flow regulation has altered macroinvertebrate communities (Dedual and Collier, 1995; Collier, 2002; Tonkin *et al*., 2009). The main reason postulated for these shifts in macroinvertebrate communities is changes in periphyton biomass downstream of the dams because of altered flow regimes (Quinn and Vickers, 1992). Consequently, 'flushing flows' have been suggested as a potential means of removing these nuisance periphyton growths (Quinn and Vickers, 1992), as has been advocated elsewhere around the world (e.g. Robinson, 2003; Robinson *et al*., 2004a). Tonkin *et al*., (2009) found clear differences in periphyton biomass and macroinvertebrate drift between three sections of the Tongariro River with contrasting flow regimes indicating an effect of the hydroelectric scheme on benthic communities.

Complementary flows, which satisfy multiple needs, such as recreational and environmental, are a potential answer to many issues with regulated river management. Currently, there are 'recreational' flow releases from both dams situated on the Tongariro River, but no flushing flows. These 'recreational' flows could potentially be developed for maximum ecological impact such as flushing flows for reducing periphyton blooms. It is important to have an understanding of environmental flow requirements on individual rivers as they are likely to differ because of their physical characteristics. This study investigates the impacts of flow regulation and an artificial (recreational) flow release 50 times the

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baseflow on periphyton and benthic macroinvertebrate communities downstream of the Rangipo Dam on the upper Tongariro River. More specifically, we examine whether (i) the dam has altered periphyton and macroinvertebrate communities downstream and (ii) whether the flow release is sufficiently large to (a) move the substrate in the section of river downstream of this dam and (b) to impact corresponding benthic periphyton and macroinvertebrate communities. We expected the effects on benthic flora and fauna to be the greatest immediately downstream of this dam and to lessen progressively downstream because of the provision of water from tributaries, as proposed by the serial discontinuity concept (Ward and Stanford, 1983; Stanford and Ward, 2001).

METHODS

Study sites

The Tongariro River drains the Kaimanawa Range in the east and the Tongariro National Park volcanic plateau in the west and is the largest tributary (catchment area of 772 km^2) of Lake Taupo, central North Island, New Zealand with a mean annual rainfall in the upper catchment of 2097 mm (Figure 1). Catchment geology consists of primarily greywacke with ash deposits in the Kaimanawa Range and primarily andesite conglomerate in the west. Vegetation consists of southern beech forest (*Nothofagus* spp.) or tussock grassland above c. 500 m a.s.l. and some *Pinus radiata* plantations and pasture in downstream sections.

The Tongariro River is subject to flow regulation by a hydroelectric scheme comprising two dams (Rangipo Dam and Poutu Intake). This system is part of the Tongariro Power Scheme, which was commissioned in 1973. Water is diverted into the Tongariro River at Rangipo Dam from Lake Moawhango in the Kaimanawa Ranges. This study focuses on the effects of flow releases from the Rangipo Dam and thus effectively deals with two section of the river: upstream of Rangipo Dam, which is called the Waipakihi River (main tributary) and has an unregulated flow regime, and the Rangipo Reach, which is the section below the Rangipo Dam. Water captured by the Rangipo Dam is diverted for power generation to the nearby Rangipo Power Station via a tailrace tunnel. This water is then returned to the Tongariro River immediately upstream of the Poutu Intake further downstream. The mean flow of the Waipakihi above Rangipo Dam is approximately 10 m^{3}s^{-1}, whereas the Rangipo Dam releases a minimum flow of 0.6 m^{3}s^{-1} into the river downstream, although this figure has varied because the scheme was commissioned. This section of river receives two flow releases per year of 30 m^{3}s^{-1}, equivalent to 50 times the minimum flow, designed to provide extra flow for recreational river users for a period of 8 h through daylight hours.

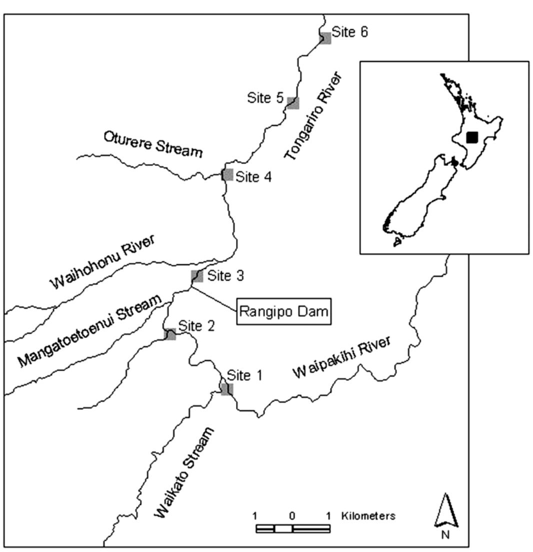

Figure 1. Location of six sites (grey squares) sampled on three occasions on the Tongariro River, New Zealand, in relation to the Rangipo Dam, September/October 2006

Six sites were selected for sampling over these two sections of river: sites 1 and 2 are upstream of the Rangipo Dam and thus represent an unimpacted section of river, and sites 3–6 are below the dam. These sites begin immediately below the dam and are spaced progressively downstream from there.

Physicochemical variables

Depth and water velocity were recorded with a Marsh-McBirney Flowmate current metre at the five Surber sampler locations at each sampling site. Conductivity and temperature were measured using a Eutech Instruments ECScan pocket meter (Eutech Instruments Pte Ltd, Singapore). Substrate size composition was assessed using the 'Wolman Walk' method where the β axis of 100 stones was measured at approximately 1-m intervals across a zigzag transect at 45° to the stream bank (Wolman, 1954). Percentage substrate composition of Wentworth scale classes was converted to a single substrate index by summing midpoint values of size classes weighted by their proportion (Quinn and Hickey, 1990). Bedrock was assigned a nominal size of 400 mm for use in the calculations.

Two methods were used to give an overall measure of substrate stability at each site. Firstly, the bottom component of the Pfankuch (1975) stability index was assessed to give a score for channel stability (low = stable) on the basis of rock angularity, brightness, packing, stable materials, scouring and vegetation. The bottom component of this index has been found to be relevant to stream invertebrates (Winterbourn and Collier, 1987). Secondly, we used painted

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tracer particles to assess whether the flow release was large enough to move the substrate downstream of the dam. Using tracer particles is common practise for freshwater ecologists and hydrologists alike (Schwendel *et al*., 2010); however, this often involves the removal of substrate from the river to apply paint and therefore leads to unnatural placement of substrate, especially where there is a high degree of embeddedness. In this study, we applied dyed wet curing epoxy-concrete (K273, Nuplex Construction Products, Hamilton, New Zealand) *in situ*. This was applied to 15 stones at each site at the first sampling date, which consisted of five stones from each of three size classes (D_{50}, D_{75} and D_{90}) determined from the 'Wolman Walk' (Wolman, 1954). Positions of these stones in the benthos were marked on the stream bank and were subsequently recorded as moved or not moved at the post-release sampling date.

Benthic macroinvertebrates and periphyton

Sampling was conducted on three occasions based around 17 September 2006 flow release (15 and 19 September and 1 October 2006) to have a pre flow (two days prior release), immediately post flow (two days) and two weeks post flow release (Figure 2). Five benthic macroinvertebrate samples were taken at each site using a 0.1-m^2 Surber sampler (250-μm mesh) from random locations in riffle habitats of approximately 50 m in length. Samples were preserved in 10% formalin. In the laboratory, the samples were washed through 0.5- and 1.0-mm Endecott sieves before being

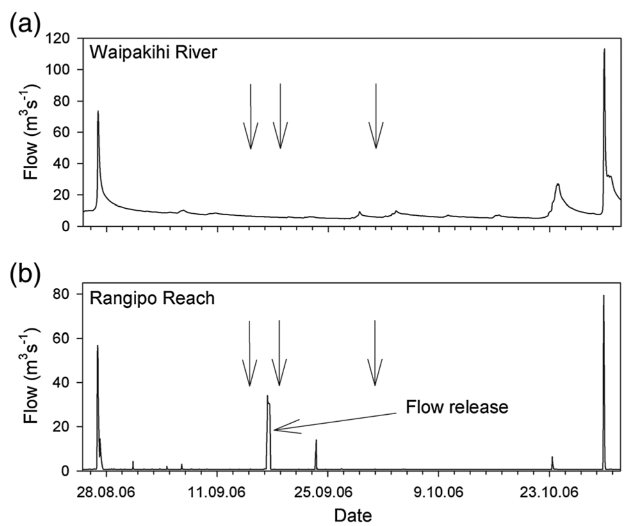

Figure 2. Hydrographs at (a) the unregulated Waipakihi River section and (b) the regulated section immediately below the Rangipo Dam on the Tongariro River between August and November 2006. Arrows denote the three sampling occasions in this study (15 and 19 September and 1 October 2006); the artificial flow release date is indicated on 17 September 2006. Data sourced from Genesis Energy Ltd., Turangi

identified and enumerated to the lowest possible taxonomic level using available keys (e.g. Towns and Peters, 1996; Winterbourn *et al*., 2000). Periphyton biomass was estimated from pigment analysis of five stones (mean area: 60 cm^2) collected randomly from each site, which were kept cool and dark before being frozen. Chlorophyll *a* and phaeophytin were extracted using 90% acetone at 5°C for 24 h in the dark and absorbances read on a Varian Cary 50 Conc UV-Visible Spectrophotometer (Varian Australia, Mulgrave, Australia) and converted to pigment concentration following Steinman and Lamberti (1996). Stone surface area was estimated following Graham *et al*., (1988) and then halved to correct for the proportion of the stone available for periphyton growth.

Data analysis

Benthic macroinvertebrate mean density (individuals 0.1 m^{-2}), number of taxa, Margalef's richness index (d) (Clifford and Stephenson, 1975), and Pielou's evenness index (J') (Pielou, 1975, 1984) were calculated for each site. To determine whether periphyton biomass and macroinvertebrate metrics differed between above and below the dam and between the three sampling occasions (pre-release, immediately post-release and two weeks post-release), we performed a multiple before-after, control-impact analysis using a multi-factor mixed model analysis of variance in PASW Statistics 18 (IBM SPSS Inc, 2009). The two main factors were Dam (control-impact; two sites above and four sites below) and BA (before-after the flow release; one sampling before and two after). Sites were nested within Dam, and time was nested within before-after. Dam, BA, and time were treated as fixed factors, and site was treated as a random factor as we did not sample all potentially impacted sites. The final analysis of variance model consisted of the following terms: Dam, BA, Dam × BA, Time (BA), Site (Dam), Dam × Time (BA) and BA × Site (Dam). This model assesses any effect associated with the dam or flow release.

To visualize the relationship between communities in two-dimensional space, non-metric multidimensional scaling ordination (Kruskal and Wish, 1978) was performed on log(x + 1) transformed data using Bray–Curtis similarities in PRIMER v6 (Clarke and Warwick, 1994). To assess differences in community structure above and below the dam and before and after the release, two-way crossed analysis of similarities (ANOSIM) was carried out in PRIMER v6 (Clarke and Warwick, 1994). ANOSIM is a nonparametric procedure that determines whether average similarities between samples within groups are closer than the average similarities of all pairs between groups (Clarke and Warwick, 1994). Taxa contributing to any differentiation between these treatments were determined using a two-way crossed similarity percentages analysis (Clarke, 1993) in PRIMER v6 (Clarke and Warwick, 1994).

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RESULTS

Physicochemical variables

Mean conductivity ranged from 51 to 109 μScm^{-1}, with a rise from 51 to 98 μScm^{-1} below the dam (Table I). Temperature increased downstream from 8 to 10.7°C, velocity was greater in the upper sites of the river ranging from 0.6 to 1.22 ms^{-1}, and pH remained relatively circumneutral at all sites (Table I).

Substrate size indexed averaged 145 mm and was larger in the downstream (165 mm) than upstream (104 mm) section (Table I). No marked tracer particles of any size class were moved during the flow release either above or below the dam. The most stable site according the bottom component of the Pfankuch index was site 3 directly below the Rangipo Dam with all sites ranging from moderate to unstable (Table I).

Periphyton

Periphyton biomass, assessed as chlorophyll *a*, was similar throughout all sites with the lowest values recorded at the downstream sites 4 and 5 (Figure 3). Chlorophyll *a* ranged from 0.12 to 0.83 μg cm^{-2}, with the exception of the first sampling of site 4, which had a biomass of 3.17 μg cm^{-2} (Figure 3). Biomass did not change between the three occasions, nor did it between the upstream and downstream sites (Table II; Figure 3). However, there was a significant BA x Site(Dam) interaction indicating a differential effect of the release between individual sites (Table II), which likely reflects the spike at site 4 on the before-release sampling (Figure 3).

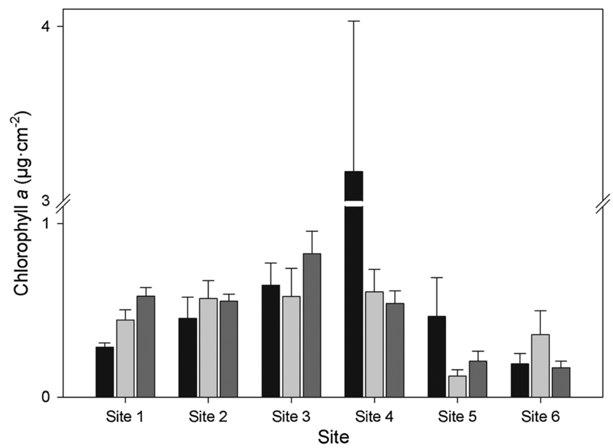

Figure 3. Mean (± 1 standard error) periphyton biomass, assessed as chlorophyll *a*, at six locations sampled on three occasions on the Tongariro River over September/October 2006. Black bars = pre flow release, light grey bars = 2 days post flow release, dark grey = 2 weeks post flow release. Site 1–2 = upstream of Rangipo Dam, Site 3–6 = downstream of Rangipo Dam

Macroinvertebrates

Taxonomic richness was higher at sites below Rangipo Dam (mean = 11 taxa 0.1 m^{-2}) than above the dam (mean = 7.6 taxa 0.1 m^{-2}; Table II; Figure 4). There was no difference in the mean number of individuals per sample between the two sections (u/s = 140, d/s = 141; $F_{1,\ 16} = 0$, $p = 0.98$; Figure 4). Sites below the dam had greater Margalef's index scores (2.1) as opposed to those upstream (1.4; Table II; Figure 4), although evenness did not differ between the sections (Pielou's index: u/s = 0.46, d/s = 0.61; Table II; Figure 4). None of the community metrics changed over the three sampling occasions, nor were there any interactive effects between sampling location and time (Table II; Figure 4).

Mayflies (Ephemeroptera) tended to be present in higher proportions in the upper section, and chironomids (Diptera) showed the opposite pattern regardless of time (Figure 5). Six species contributed 50% to the difference between the upper and regulated sections of river including two orthoclad midges of which one favoured each section, one species of Chironominae midge and the chironomid *Maoridiamesa* sp. (both only present downstream of the dam), the swimming mayfly *Nesameletus ornatus* (more abundant in the upstream section) and the elmid beetle *Hydora* sp. (four times higher density downstream of the dam) (Table III).

The three taxa contributing the greatest to differences before and after the flow release were chironomids, followed by the stonefly *Zealandoperla* spp., the leptophlebiid mayfly *Deleatidium* spp. and the elmid beetle larvae *Hydora* sp.

Table I. Mean physicochemical variables at six sites sampled on three occasions on the Tongariro River, New Zealand, September/October 2006

Site	Pfankuch	Conductivity (μScm^{-1})	Temperature (°C)	pH	Depth (cm)	Velocity (ms^{-1})	SI (mm)
1	48	53.7 (9.91)	8.2 (0.36)	7.0 (0.18)	32.1 (1.79)	0.89 (0.12)	93.3
2	48	51.0 (3.79)	8.0 (0.23)	6.1 (0.39)	28.2 (1.32)	1.22 (0.12)	114.9
3	34	97.7 (4.70)	8.7 (0.52)	6.6 (0.12)	38.9 (3.42)	0.60 (0.09)	176.9
4	54	112.0 (3.06)	9.7 (0.74)	6.9 (0.03)	13.1 (1.49)	0.74 (0.06)	99.0
5	39	94.0 (15.56)	9.9 (0.96)	6.9 (0.29)	53.4 (3.13)	0.68 (0.08)	212.0
6	44	109.0 (2.65)	10.7 (0.32)	7.1 (0.30)	28.2 (2.58)	0.56 (0.05)	173.4

Site 1–2 = upstream of Rangipo Dam; Site 3–6 = downstream of Rangipo Dam; Standard errors are given in brackets where appropriate; Pfankuch = bottom component of the Pfankuch stability index; SI = substrate size index.

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Table II. Multiple before-after, control-impact analysis of variance to test for changes in key macroinvertebrate metrics and chlorophyll *a*, above and below Rangipo Dam, before and after a flow pulse on the Tongariro River, New Zealand over September/October 2006

		N		*S*		*d*		*J*		Chlorophyll *a*	
Factor	*dF*	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*
Dam	1	0.00	0.991	11.54	**0.031**	9.35	**0.040**	1.20	0.335	0.22	0.665
BA	1	0.15	0.723	0.57	0.494	0.01	0.922	0.02	0.901	0.37	0.575
Dam × BA	1	0.17	0.704	1.60	0.274	3.90	0.119	1.48	0.290	0.80	0.423
Time (BA)	1	3.10	0.153	0.23	0.656	0.01	0.939	0.11	0.757	0.28	0.623
Site (Dam)	4	11.79	**0.017**	5.51	0.064	15.01	**0.011**	15.48	**0.011**	1.41	0.375
Dam × Time (BA)	1	2.43	0.194	1.75	0.257	2.22	0.210	2.61	0.181	0.08	0.786
BA × Site (Dam)	4	1.33	0.394	0.33	0.845	0.21	0.923	3.26	0.139	55.36	**0.001**
Residual mean square	4	999.5		1.85		0.06		0.001		0.02	

N = number of animals; S = taxonomic richness; d = Margalef's index; J = Pielou's evenness index; Dam = upstream/downstream of dam; BA = before-after flow release; Time = three sampling periods; Site = six sampling locations; Bold values indicate significance at $p = 0.05$.

(Table III). However, changes in abundance of these taxa were minor (Table III).

Community structure reflected univariate indices on macroinvertebrate communities with ordination splitting the unregulated (sites 1–2) and regulated (sites 3–6) sections of the river (ANOSIM $R = 0.98$, $p = 0.002$; Figure 6). Community structure was not affected by the flow release (ANOSIM $R = 0.24$, $p = 0.08$; Figure 6). Site 3, directly below Rangipo Dam grouped separately from the remaining downstream sites.

DISCUSSION

Spatial patterns

As predicted, the dam appears to be altering macroinvertebrate community structure at sites downstream. The main differences in communities between the two sections were largely because of several species of Chironomidae, which exhibited differing preferences for either upstream or downstream sites. Metrics used in this study also conflicted

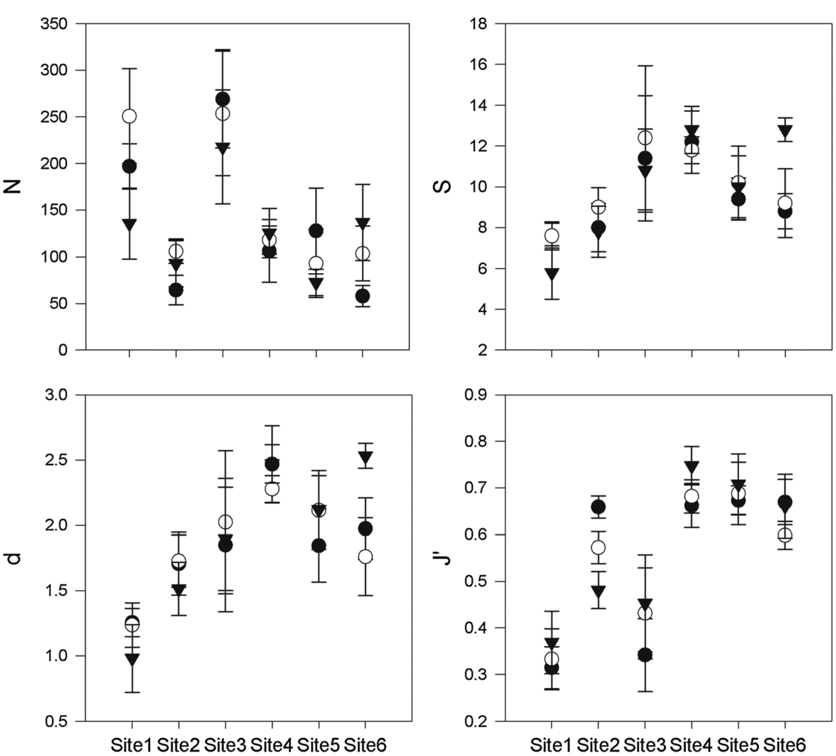

Figure 4. Mean (± 1 standard error) N = number of individuals, S = number of taxa, d = Margalef's index, J' = Pielou's evenness index at six sites sampled on three occasions on the Tongariro River over September/October 2006. Closed circles = pre flow release, open circles = 2 days post flow release, closed triangles = 2 weeks post flow release. Site 1–2 = upstream of Rangipo Dam, Site 3–6 = downstream of Rangipo Dam

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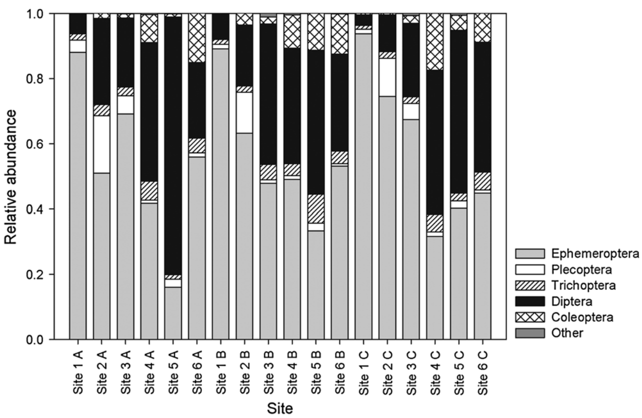

Figure 5. Relative abundance of six main macroinvertebrate groups at six sites sampled on three occasions on the Tongariro River over September/October 2006. A = pre flow release, B = 2 days post flow release, C = 2 weeks post flow release. Site 1–2 = upstream of Rangipo Dam, Site 3–6 = downstream of Rangipo Dam

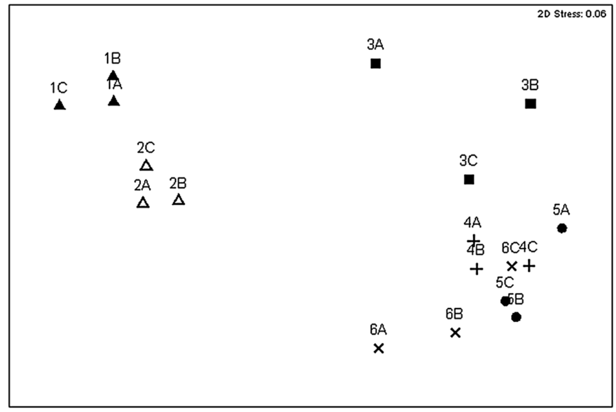

Figure 6. Non-metric multidimensional scaling ordination using Bray–Curtis distances on log(x + 1) transformed invertebrate data at six sites sampled on three occasions on the Tongariro River over September/October 2006. A = pre flow release, B = 2 days post flow release, C = 2 weeks post flow release. Site 1–2 = upstream of Rangipo Dam, Site 3–6 = downstream of Rangipo Dam

as to whether the effect was negative on the communities or not. The typical response of macroinvertebrate communities downstream of dams is negative with declines in taxonomic richness common (Bredenhand and Samways, 2009). Nonetheless, because of the nature of the study (upstream/downstream assessment), the effects of the dam on benthic communities downstream cannot be unequivocally drawn without replication at sites outside of this river system. Tonkin *et al*., (2009) found clear differences in periphyton biomass and the makeup of macroinvertebrate drift between the three different sections of the Tongariro River with regard to dam location. However, Collier (2002) also assessed whether there was a gradient of impact downstream of this dam but suggested that site-specific factors such as substrate composition and periphyton biomass (which may be secondarily altered by changes in the flow regime), and large scale factors such as natural longitudinal patterns and large floods were more important than reach scale factors in determining macroinvertebrate community structure.

Increased 'nuisance' periphyton growths downstream of the dams on the Tongariro River have been postulated to be a result of regulation of flow and caused shifts in the macroinvertebrate community to less desirable species; consequently, flushing flows have been suggested as a possible

Table III. Differences in community composition between the (a) upstream (Waipakihi River) and downstream (Rangipo Reach) sections of the river in relation to Rangipo Dam and (b) before and after the flow pulse, sampled at six locations on three occasions on the Tongariro River, New Zealand, September/October 2006. Table shows similarity percentages showing the six taxa contributing to the greatest difference between treatments

Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
(a)	Upstream	Downstream				
Orthocladiinae sp. C	0.00	2.34	6.06	2.53	10.79	10.79
Orthocladiinae sp. A	2.42	0.56	4.80	2.80	8.56	19.35
Chironominae A	0.00	1.90	4.76	2.13	8.48	27.83
Hydora sp.	0.51	2.11	4.23	2.04	7.53	35.36
Nesameletus ornatus	1.64	0.05	4.12	2.25	7.33	42.69
Maoridiamesa sp.	0.00	1.62	4.06	3.57	7.23	49.92
(b)	Before	After				
Chironominae sp. A	0.60	1.60	2.59	1.30	8.44	8.44
Orthocladiinae sp. C	1.21	1.73	2.35	1.27	7.66	16.10
Orthocladiinae sp. B	2.30	1.91	2.33	1.94	7.60	23.70
Zealandoperla spp.	1.55	1.11	2.03	1.06	6.62	30.32
Deleatidium spp.	4.04	4.26	1.94	1.41	6.32	36.64
Hydora sp.	1.26	1.74	1.74	1.37	5.67	42.31

Av.Abund = average abundance; Av.Diss = average dissimilarity; Diss/SD = standard deviation of dissimilarity; Contrib% = % contribution; Cum. % = cumulative % contribution.

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solution (Quinn and Vickers, 1992). Tonkin *et al.*, (2009) suggested this was indeed occurring, with macroinvertebrate drift affected downstream of the dams on the Tongariro River because of increased periphyton biomass altering benthic communities present in the river. They found a marked increase in densities of chironomids and worms at downstream sites, and a decline in per cent Ephemeroptera, Plecoptera and Trichoptera taxa (but not densities of these taxa), which are associated with unimpaired rivers. This was not evident in the present study where periphyton biomass was low at all sites (above and below the dam) representing typical upland river characteristics of New Zealand with the exception of the first sampling occasion at site 4. This may reflect the fact that the dam has little storage capacity and thus operates as a run-of-river type dam where only small freshes are held behind the dam. Of course, this also means the dam has little influence on seasonality of the flow regime in this river. However, Wu *et al.*, (2008) found algal communities above and below a run-of-river dam differed significantly 2–3 years after its construction.

Communities at the site immediately downstream of Rangipo Dam (site 3) were different to those above the dam and those further downstream, which receive several large tributary inputs. Higher velocities are expected at this site during flood flows because of being situated within a gorge compared with the sites upstream with large floodplains (Quinn and Vickers, 1992). Consequently, benthic communities in this section are likely to be strongly affected by the presence of the dam because of the large fluctuations from the $0.6\,m^3s^{-1}$ baseflow; as has been found with macroinvertebrate drift (Tonkin *et al.*, 2009). However, flow regulation is not the only factor that may be influencing this site; a large volume of hypolimnetic water is diverted into Rangipo Dam from the Moawhango Dam, which may be impacting these communities. Hypolimnetic water tends to have low dissolved oxygen, as well as cooler and minimally fluctuating temperature, which has been shown to have an effect on macroinvertebrate communities downstream of dams (Saltveit *et al.*, 1994; Cereghino and Lavandier, 1998), although in this instance some oxygenation is likely at the point of discharge.

Flow release effects

No evidence was found in this study to indicate the recreational flow release was sufficient to move the substrate in the section of the Tongariro River below Rangipo Dam, with no change in periphyton biomass evident. However, one exception was a site-specific effect of the release on periphyton, which resulted from the much greater pre-release biomass at site 4 than all other sites. Despite the release of $30\,m^3s^{-1}$ being 50 times the baseflow of $0.6\,m^3s^{-1}$ at site 3 directly downstream of the dam, no effect was evident. There is much variation in the force required to entrain substrate in rivers depending on many factors such as substrate imbrication (Downes *et al.*, 1997; Schwendel *et al.*, 2010). Flushing flows are common management tools for regulated rivers (e.g. Patten *et al.*, 2001; Robinson, 2003; Robinson *et al.*, 2004a). Although the effects of flood events are clear on periphyton (Grimm and Fisher, 1989; Biggs, 1995), the specific magnitude of the release required to have an effect downstream is river specific and little research has assessed the long-term effects of flushing flow regimes (but see Robinson *et al.*, 2004b). Nonetheless, the frequency of flows three times the median flow (FRE3) has been found to be associated with reduced periphyton biomass in a widespread study of New Zealand rivers (Clausen and Biggs, 1997). More specifically, Biggs and Close (1989) found that flood events greater than six times preceding baseflow consistently scoured periphyton (ash-free dry weight), and smaller scale events had varied effects. Although these are much smaller magnitude increases than the 50 times in our study, both Clausen and Biggs (1997) and Biggs and Close (1989) were not assessing artificial releases but natural flow events on the basis of hydrographs, thus increased flow periods were likely often longer than the 8 h release in this study. Moreover, the $30\,m^3s^{-1}$ release is much closer to the pre-dam flow conditions through this section, as is indicated by the mean flow upstream in the Waipakihi River of ~$10\,m^3s^{-1}$.

The lack of effect in this study is likely because of a high degree of armouring in this section of river, with extremely large floods and velocities required to entrain the bed, especially at site 3, directly downstream of the dam. With the Tongariro Power Scheme having been commissioned in 1973, the Rangipo Dam has been in operation for sufficient time to show the effects of armouring downstream. This type of armouring is common in regulated rivers, especially directly below dams because of reduced sediment supply (Benn and Erskine, 1994; Vericat *et al.*, 2006). In fact, greater substrate size was clearly evident at sites downstream of the dam in this study.

It is important to bear in mind that periphyton levels were low prior to the release, for two possible reasons. Firstly, a higher magnitude natural flow of nearly twice the size of the artificial release occurred approximately three weeks prior to the study commencement, which may have reduced pre-release periphyton biomass. Secondly, the study was performed during winter where biomass is typically lower than summer. Modelling the magnitude of flow releases required to move the substrate and reduce periphyton biomass could assist flow management on the Tongariro especially if recreational flows can be developed for maximum ecological benefit. Creating complementary flows, where they satisfy recreational needs but also maximize ecological benefits such as scouring nuisance periphyton growths (i.e. flushing flows), should be an area of focus in future river management in general. This would require a multidisciplinary approach to understand maximum usable flows for recreational purposes whilst ensuring an ecological benefit.

The artificial flow release had no effect on macroinvertebrate community structure or any of the univariate indices. This reflects the fact that the flow release was not sufficiently large enough to entrain substrate downstream of the dam, although scouring can occur through 'sandblasting' by entrained sand (Biggs *et al*., 1999; Webb *et al*., 2006). We expected the effects of the release would be the highest immediately downstream of the dam (site 3) and would decline progressively downstream because of several tributary inputs. The impacts of flow regulation (abstraction and flow releases) tend to lessen progressively downstream as discharge alterations are swamped by tributary input and higher baseflows (Ward and Stanford, 1983; Stanford and Ward, 2001). For macroinvertebrate communities to be strongly affected, entrainment of the substrate would likely be required (Lancaster and Hildrew, 1993; Bond and Downes, 2000), although where substrate is heavily imbricated, shear stress alone may be enough to influence the composition of macroinvertebrate communities (Schwendel *et al*., 2010). However, although there was a 'dam effect', there was no influence of the flow release on substrate, periphyton or macroinvertebrates in this study. Flow upstream of the dam was stable during this period indicating there were no other events, which may have overshadowed the effect of the artificial release downstream.

Conclusions

In the present study, we found no effect on either bed movement or macroinvertebrate communities of a small artificial flow release of $30\,\mathrm{m}^3\mathrm{s}^1$ downstream of the Rangipo Dam on the Tongariro River. Although, there was an interactive site-specific effect of the flow release on periphyton biomass, this was obscured by unusually high biomass at one site. Although periphyton biomass was not altered because of the presence of this dam, macroinvertebrate communities differed between the sections of river suggesting flow regulation has led to a change in these communities. Without comprehensive replication between regulated rivers of a similar nature this downstream change cannot be confirmed to be unequivocally because of the presence of dams and not because of other causes such as natural downstream changes. It is clear that significantly larger flow releases would be required to entrain the substrate, scour periphyton and in turn affect macroinvertebrate communities in this river. This highlights the importance of the physical structure of rivers in which flushing flows are desired as a dam management tool. It appears in this section of the Tongariro River that armouring of the substrate is sufficient enough to resist movement from all but severe floods. Thus, more targeted modelling is required to determine the magnitude of flow release to entrain substrate within this section of river. Furthermore, it would be beneficial to perform a similar study during a period (likely late summer/autumn) where periphyton biomass reaches 'nuisance levels'.

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