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SHORT-TERM CHANGES IN WATER QUALITY AND BENTHIC INVERTEBRATE FAUNAS FOLLOWING POST-HARVEST MANIPULATION OF WOODY DEBRIS IN SOME WHIRINAKI STREAMS

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by

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1. INTRODUCTION

Woody debris can perform important functions in streams by increasing habitat diversity, providing substrates and cover for invertebrates and fish, and by enhancing the ability of streams to conserve energy and nutrient inputs (Wallace & Benke 1984). There is considerable interest amongst forestry companies and environmental management agencies in the effects and fate of wood deposited in stream channels after pine forest harvesting (e.g., Baillie 1996). In particular, managers are interested to know whether wood needs to be removed from the stream channel following harvesting, and if so, how much wood is too much in an ecological context.

In the light of current interest in how best to manage wood inputs following harvesting, Forestry Corporation and NIWA (through the Public Good Science Fund; FRST Contract no. CO4505) have been conducting studies into the effects of different post-harvesting wood treatments in three first order streams in the Whirinaki area of the central North Island. This area was selected for study because the stable flow regime is unlikely to move the wood, allowing evaluation of the effects of different wood treatments over the medium-long term. The study began in November 1995 and is planned to continue over three years; to date one pre-harvesting and two post-harvesting trips have been conducted. Two more trips are planned in the summers of 1996/97 and 1997/98. This report presents the preliminary results of the first three sampling trips in order to keep project participants informed of progress.

2. METHODS

Physicochemical and benthic invertebrate data were collected before and after pine forest harvesting and wood manipulations at 3-4 sites (see Tables 1 and 2). The pre-harvest data were intended to establish a baseline against which post-harvesting wood manipulation effects could be evaluated. Additional physicochemical baseline data were collected at the Te Rake Road site which was in mature pine forest.

Sampling reaches ran from the tributary confluences upstream for 100 m at Site 1, or for approximately 60 m at Sites 2A and 2B at which point these streams became ephemeral. Channel widths in the three sampling reaches prior to harvest averaged between 0.65 and 0.85 m. Twenty evenly-spaced transects were established for measurements of wood volume (November 1995 and April 1996 only), substrate composition, and for invertebrate sampling (every second transect). Water samples, temperature and dissolved oxygen measurements were taken at the bottom of the reaches above the tributary junctions. A summary of techniques used for the physicochemical analyses and invertebrate sampling is provided in Table 3.

Sites 2A and 2B were harvested over a 5 week period beginning in mid-January 1996. All the slash was removed from above the wetted channel of Site 2A ("all wood removal " treatment) within three weeks of harvesting, while on the adjacent stream (2B) only merchantable pieces of timber were removed (>10 cm diameter and 2-3 m long; "large wood removal" treatment). No wood was removed after harvesting from the channel at Site 1 ("no wood removal" treatment).

Table 1: Names and locations of the sampling sites

	Name of parent stream	Compartment	Map. ref. (NZMS 260 V18)
1 ("no wood removal")	Otutakahiao	159	268772
2A ("all wood removal")	Mangamingi	157	264783
2B ("large wood removal")	Mangamingi	157	264784
Te Rake Rd	Waimurupuha	150	284797

Table 2: Dates on which different physicochemical data and invertebrate samples were collected at the three experimental sites (1, 2A and 2B; ✓) and at the Te Rake Road site (*). Symbols in parentheses indicate samples that are in storage but have not yet been analysed.

Date	Spot water temperature	DOC	Nutrients	Dissolved oxygen	Wood volume	Substrate composition	Invertebrates
27/29-Nov-95	✓	(✓)	(✓)	✓	✓	✓	✓
28-Dec-95	✓*	✓(*)	(*)				
3-Jan-96	✓*	✓(*)	(*)				
10-Jan-96	✓*	✓(*)	(*)				
17-Jan-96	✓*	✓(*)	(*)				
HARVESTING AND WOOD MANIPULATION							
4-Apr-96	✓	✓	✓				
12-Apr-96	✓	(✓(*))	(✓(*))				
22-Apr-96	✓*	(✓(*))	(✓(*))				
29/30-Apr-96	✓*	✓(*)	✓(*)	✓*	✓	✓	✓
8-May-96	✓*	✓(*)	✓(*)	✓*			
15 -May-96	✓*	✓(*)	✓(*)	✓*			
22-May-96	✓*	✓(*)	✓(*)	✓*			
19-Jun-96	✓*	✓(*)	✓(*)	✓*			
25-Jul-96	✓*	✓(*)	✓(*)	✓*			
26/28-Aug-96	✓*	✓(*)	✓(*)	✓*		✓	✓(*)

Table 3: Details of methods used for sample collection and analysis.

Analysis	Method	References
Water quality	Measured instream (temperature and dissolved oxygen) or on 60 ml water samples filtered through 0.45 µm millipore filters and then frozen.	
•temperature	YSI Model 55 meter	
•dissolved oxygen	YSI Model 55 meter	
•dissolved organic carbon	UV photo-oxidation with alkaline persulphate oxidant and determined as CO_2 by IRGA after acidification	APHA (1989)
•NO_3-N	Automated hydrazine reduction column followed by diazotization with sulphanilamide and NEDDE.	APHA (1989)
•DRP	Automated molybdenum blue/ascorbic acid reduction colorimetry	APHA (1989)
Wood volume	Diameters of wood pieces intersecting 20 evenly-spaced transect lines throughout sampling reach were measured. Data were converted to wood volume using standard equation.	van Wagner (1968)
Surficial substrate composition	Substrates on the stream bed were measured at 5 points across 20 transects through each reach to determine substrate type and size class using standard divisions (Wentworth scale) ranging from sand to bedrock for inorganic particles and large wood (>10 cm diameter) or small "wood" (<10 cm including needles and other coarse organic material).	Wolman (1954) Minshall (1984)
Density and composition of invertebrates	Ten 0.04 m^2 Surber sample (250 µm mesh net) were taken at regular intervals up the sampling reaches. Samples were sorted live and invertebrates were counted and identified using standard keys.	Winterbourn & Gregson (1989)

3. RESULTS AND DISCUSSION

3.1 Wood volumes and instream changes

Wood volumes at Sites 1, 2A and 2B prior to harvest ranged from 168-335 $m^3.ha^{-1}$ with most of this (65-80%) being above the wetted stream channel (Table 4). Following harvesting, wood volumes increased by 477-736 $m^3.ha^{-1}$; total volumes were lowest at the "all wood removal" site (2A). The "large wood removal" (2B) and "no wood removal" (1) treatments had post-harvest volumes of 967 and 829 $m^3.ha^{-1}$, respectively, although the volumes measured instream at the latter site are underestimates due to difficulties in accessing the stream bottom. Bearing this caveat in mind, measured volumes of instream wood were similar at all sites after harvesting (Table 4). Post-harvest volumes of wood above the wetted channel and on the floodplains were similar at Sites 1 and 2B following harvest, but at Site 2A above channel wood volumes were low and floodplain wood volumes were high reflecting the removal of wood from over the stream and its transfer to the edges. In addition to underestimating instream wood volumes at the "no wood removal" site, another reason for the lower volume estimate compared with the "large wood removal" site is that, although there were more pieces of large wood, it was patchily distributed such that sections of the channel in the study reach remained open. At the "large wood removal" site, the channel was covered by logging debris throughout the entire study reach.

Channel widths increased after harvesting by 2m at the "no wood removal" site (1), by 1 m at the "large wood removal" site (2B), and by 0.1 m at the "all wood removal" site (2A). The increase in channel width at Site 1 probably partly reflected damage to banks which occurred during harvesting. In April, growths of algae were noted to be forming at the "all wood removal" site, while at the "no wood removal" site algal growths on wood were becoming extensive in areas of open channel. By August, algae were abundant at these sites, and there were extensive accumulations of fine particulate organic matter on the bed at the "all wood removal" site.

Table 4: Measured volumes of wood ($m^3.ha^{-1}$) on the floodplains, above the wetted channel and in the stream at the three sites before and after harvest *, wood volumes underestimated due to difficulty reaching the stream bottom.

	Floodplains	**Above wetted channel**	**Instream**	**Total**
PRE-HARVEST				
Site 1	22.2	268.0	44.8	335.0
Site 2A	30.1	109.3	28.6	168.0
Site 2B	13.8	166.8	50.3	230.9
POST-HARVEST				
Site 1 ("no wood removal")	254.6	362.3	212.4*	829.3*
Site 2A ("all wood removal")	361.5	81.7	201.56	644.8
Site 2B ("large wood removal")	277.6	433.9	255.1	966.6

3.2 Water quality

3.2.1 Dissolved organic carbon and nutrients

Dissolved organic carbon (DOC) is leached from decomposing organic matter or aquatic plants; concentrations in streamwater in cool temperate climates are typically around 2 $g.m^3$ (Thurman 1986). Pre-harvest DOC concentrations were low at Sites 1, 2A and 2B (<1 $g.m^{-3}$), but increased markedly following harvesting and wood manipulation in the order "no wood removal" (9.4 $g.m^{-3}$), "all wood removal" (7.1 $g.m^{-3}$) and "large wood removal" (4.3 $g.m^{-3}$) (Figure 1). The high DOC levels at the "all wood removal" site in the first post-harvest sample may have been caused by leaching of organic matter from chips, needles etc transferred to the stream during wood removal. The peak in DOC concentrations was followed by a general decline and a secondary peak (3.3-4.9 $g.m^{-3}$) in May. By August, approximately 6 months after harvesting, DOC levels were similar at all sites although still above pre-harvest levels (1.6-2.0 $g.m^{-3}$). Moore (1989) also found that organic debris in stream channels can be a major source of DOC.

Dissolved reactive phosphorus (DRP) and NO_3-N are the main nutrients responsible for aquatic plant growth; they may enter the water column from drainage waters or by leaching from organic material in the stream channel. Periphyton growth appears to reach a maximum around 15-30 mg DRP m^{-3} (Perrin *et al.* 1987, Bothwell 1989, Horner *et al.* 1990, Stanley *et al.* 1990), and dissolved inorganic nitrogen (NO_3 + NH_4) values below around 0.04-0.10 g m^{-3} limit algal growth (Stockner and

Shortreed 1978, Grimm and Fisher 1986, Lohman *et al.* 1991). Post-harvest/wood manipulation DRP and NO3-N levels are shown in Figure 1. The DRP data suggest a higher concentration of DRP at the "all wood removal" site in the first post-harvest sampling (74 $mg.m^{-3}$), but similar levels at all sites after that (14-43 $mg.m^{-3}$) which were within the range thought to result in maximum periphyton growth. Post-harvest concentrations of NO3-N exceeded the levels for maximum periphyton growth at all sites but did not seem to be related to the catchment treatment; concentrations were highest at the "large wood removal" site (1.95-2.46 $g.m^{-3}$) and lowest at the "no wood removal" site (0.04-0.94 $g.m^{-3}$) (Figure 1). Analysis of post-harvest nutrient levels in samples from the unharvested Te Rake Road site would assist with interpretation of these results (see Table 2).

3.2.2 Water temperature

Spot water temperatures recorded during the course of the study are shown in Figure 2 for four sites including the unharvested Te Rake Road site. Summer and Autumn temperatures (December-May) were similar both before and after harvest at all sites (10.3-12.3°C), followed by a marked drop in June which was most extreme at the Te Rake Rd site. These results indicate that harvesting and removal of wood at Site 2A had little effect on Autumn water temperatures; this may partly reflect the predominantly groundwater source of streamflow, the small size of the stream, and shading of the channel by banks and valley walls. Any effects of harvesting and wood removal at this site may become more apparent over the forthcoming summer when air temperatures and solar radiation will increase. It is planned to monitor water temperature continuously using data loggers at the study sites during summer to provide additional information on daily temperature variation.

3.2.3 Dissolved oxygen

Due to problems with the dissolved oxygen (DO) meter, limited data are available prior to harvesting and soon after wood manipulation (Table 2). In November 1995, Sites 1, 2A and 2B had DO levels around 10 $g.m^{-3}$, similar to post-harvest values recorded at the Te Rake Road site (Figure 3). On 30 April 1996, DO at the harvested sites had declined to 7.1-7.8 $g.m^{-3}$ equivalent to 60-70% saturation. DO at the "all wood removal" site (2A) increased to 9 $g.m^{-3}$ soon after and remained around this level until August. The "large wood removal" site (2B) showed a continued decline in DO until June followed by a steady increase until August when DO was similar to the "all wood removal" site (2A). At the "no wood removal" site, DO remained around 6.1-7.7 $g.m^{-3}$ until August.

Dissolved oxygen concentrations below 5 $g.m^{-3}$ are generally considered adverse for some fish species, and the Third Schedule of the Resource Management Act (1991) recommends a dissolved oxygen saturation of 80% for fish spawning. Although saturation levels were lower than this after harvesting of the Whirinaki sites, concentrations did not fall below 6 $g.m^{-3}$ on any of the monitoring dates. Further monitoring of DO over summer when water temperatures are higher and microbial activity may be greater should provide further insights into the relationship between post-harvesting wood treatment and dissolved oxygen.

3.3 Surficial substrate

The pre-harvest analysis of surficial substrate composition at Sites 1, 2A and 2B (November 1995) showed that the beds of all these sites were comprised predominantly of inorganic particles (c. 90%) in the sand to small gravel range (<8 mm) (Figure 4). This size fraction remained at similar levels at the "all wood removal" site (2A) in April, but declined in relative terms at the "large wood removal" (2B) and "no wood removal" (1) sites to 72% and 34%, respectively, of surficial substrate elements. At this time, the majority of substrate at the "no wood removal" site comprised small wood with about 10% large wood. To some degree this reflected the fact that we were not able to access the stream bottom at this site because of the increased depth; the majority of substrata within reach was mostly wood in the water column. Wood levels remained high at this site in August, but increased markedly at both the "large wood removal" and "all wood removal" sites at this time to around 65% of surficial substrate elements (Figure 4). At the "large wood removal" site this is thought to reflect "woody" material (including sticks, needles and other organic matter) falling into the stream from material suspended across the channel, while at the "all wood removal" site this is thought to be due to material that had been washed into or had fallen into the channel. In August, the "all wood removal" site also showed an increase in small-medium gravels which were beginning to accumulate amongst the wood.

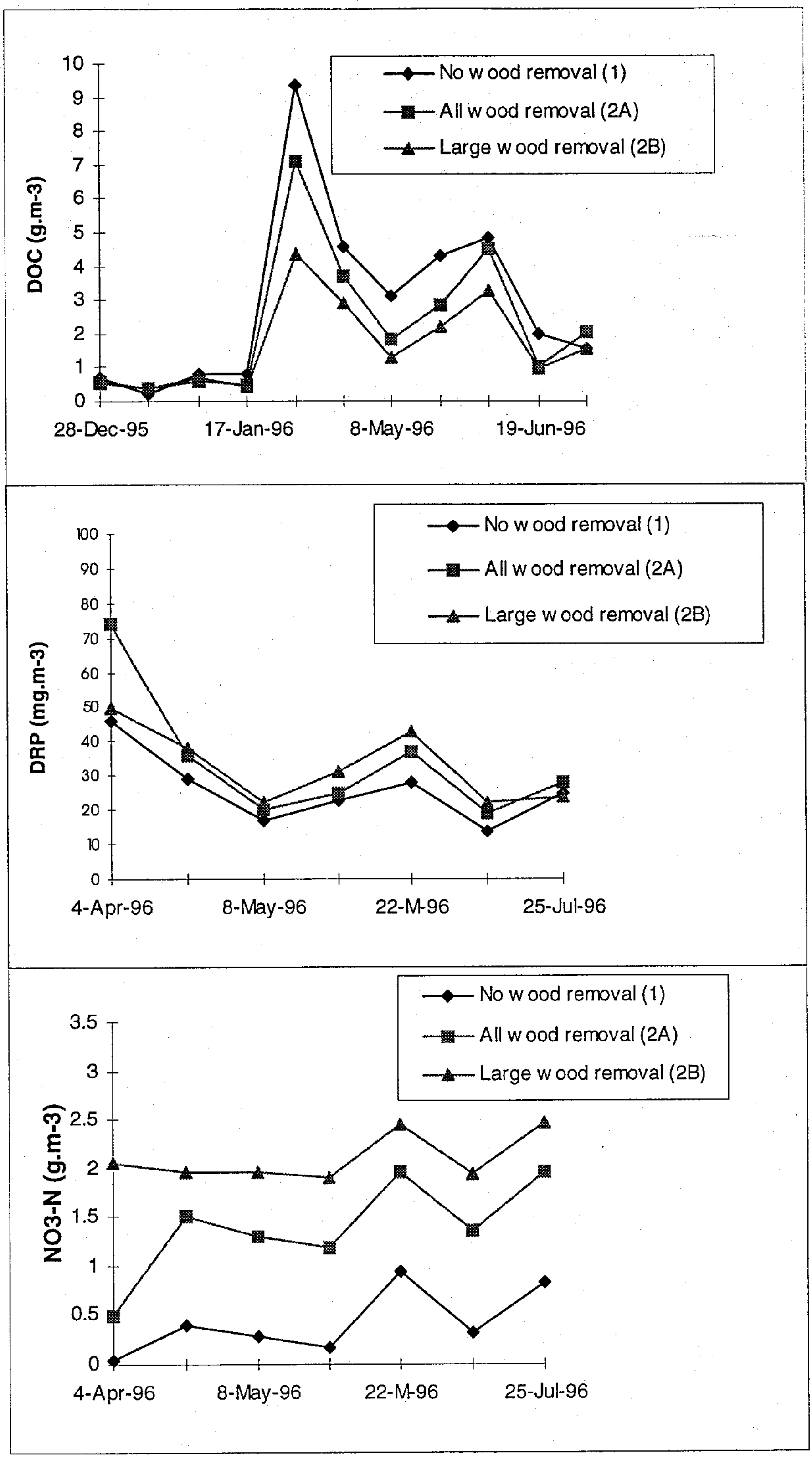


Figure 1: Concentrations of dissolved organic carbon (DOC), dissolved reactive phosphorus (DRP) and NO_3-N in water samples from three sites between December 1995 or April 1996 and August 1996.

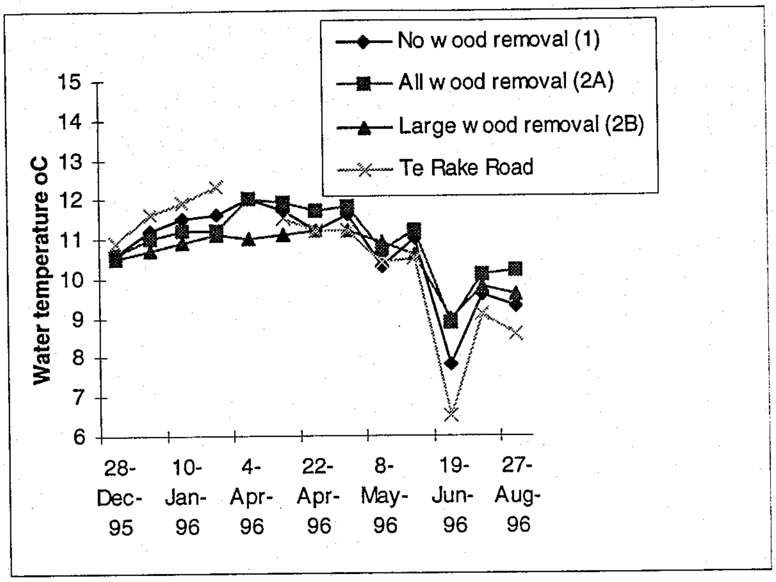


Figure 2: Spot water temperatures recorded at 3-4 sites between December 1995 and August 1996.

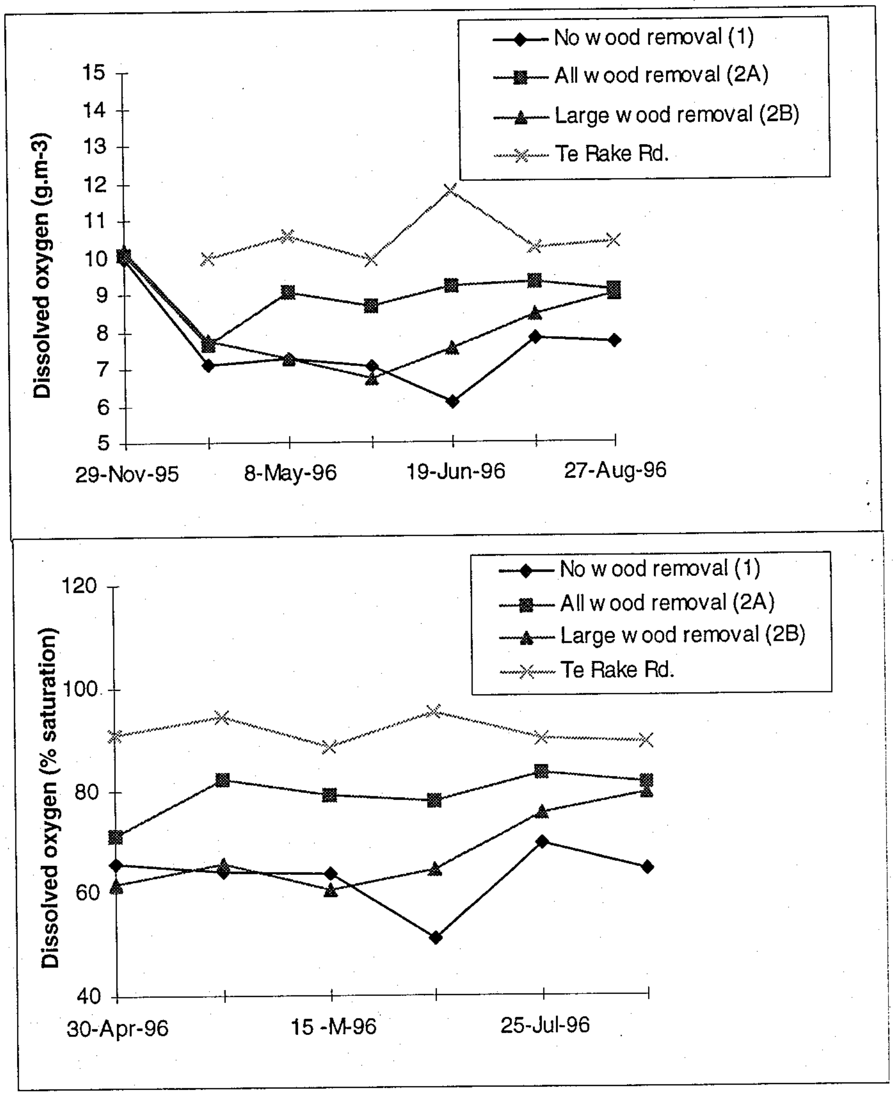
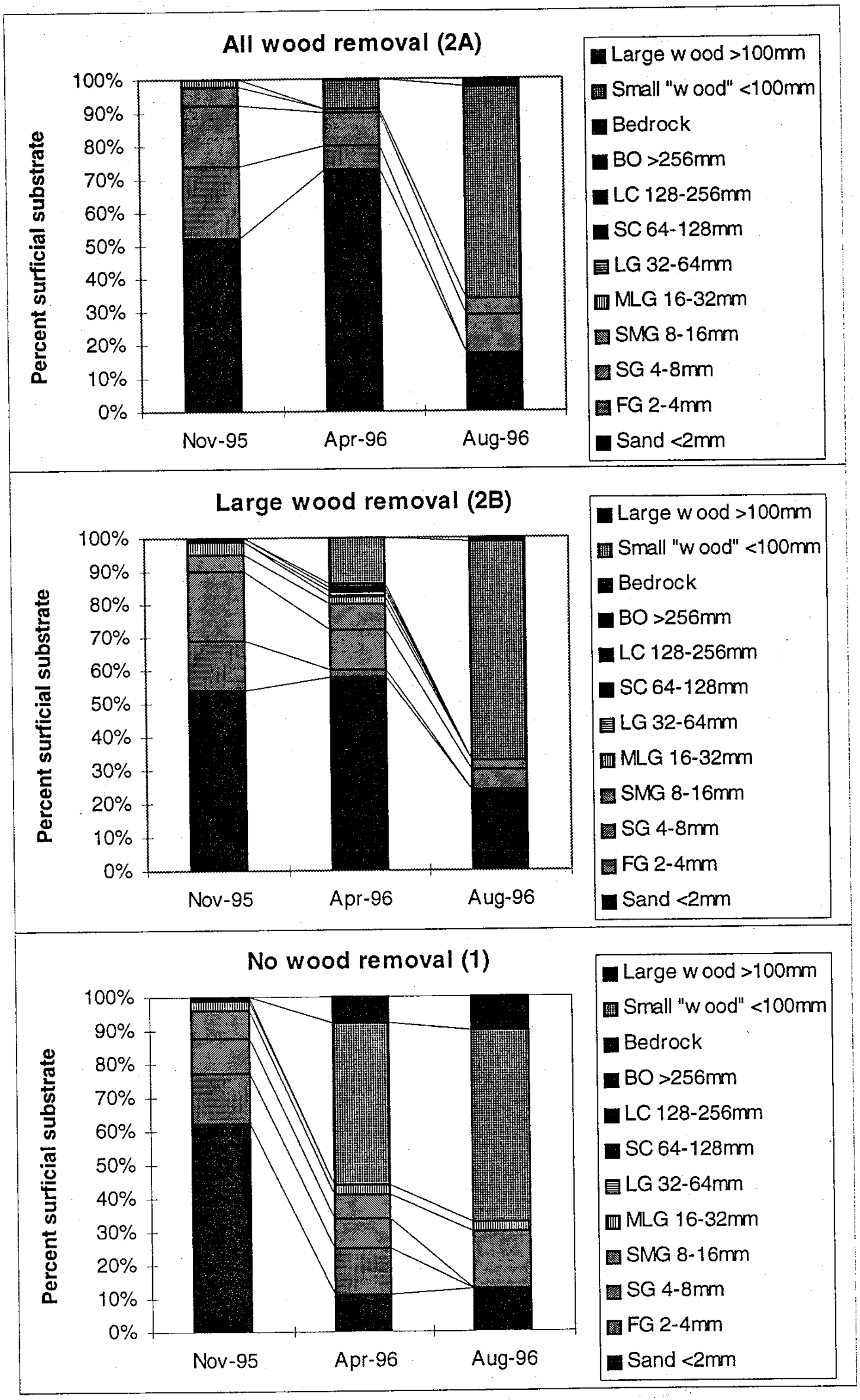


Figure 3: Concentrations and percent saturation of disssolved oxygen at 3-4 sites between November 1995 or April 1996 and August 1996.



All wood removal (2A)

Large wood removal (2B)

No wood removal (1)

Figure 4: Percent composition of different sized substrate elements at three sites in pre-harvest (November 1995) and post-harvest (April and August 1996) conditions.

3.4 Benthic invertebrates

3.4.1 Taxonomic richness

The number of invertebrate taxa collected in ten 0.04 m^2 Surber samples at three sites during the study is shown in Figure 5. Prior to harvest in November 1995, 28 and 26 taxa were collected at Sites 2A and 2B, respectively compared with 19 at Site 1. The composition amongst the main taxonomic groups was similar at all sites with Trichoptera (caddisflies), Plecoptera (stoneflies) and other Diptera (two-winged flies excluding Chironomidae (midges)) providing the most taxa (4-7 each). Total taxonomic richness increased in April and again in August at the "all wood removal" and "large wood removal" sites largely reflecting increases in the number of Chironomidae and Other Diptera taxa, and more Plecoptera taxa at the "all wood removal" site in August (Figure 5).

There was a marked decline in taxa richness at the "no wood removal" site in August, partly reflecting the fact that most of the substrate that could be sampled was wood in the water column. However, the number of taxa caught increased to 23 by August when some gravels had begun to accumulate amongst the wood (see Section 3.3). This increase in taxa was largely attributable to colonisation by Chironomidae species which were not recorded prior to harvest but had increased to 9 taxa by August. Harvesting at the "no wood removal" site was also associated with the disappearance of sensitive invertebrate taxa belonging to the Plecoptera and Ephemeroptera (Figure 5).

3.4.2 Invertebrate density and composition

The mean density of invertebrates collected in ten 0.04 m^2 Surber samples at three sites during the study is shown in Figure 6 and the relative abundance of the main groups is shown in Figure 7. Densities were not significantly different amongst sites prior to harvest in November 1995 (range 24-42 0.04 m^{-2}), when faunas were dominated numerically at all sites by Ephemeroptera, Plecoptera, Trichoptera (EPT taxa) and Coleoptera (each >10% of numbers at 2 or more sites).

Mean densities had declined at all sites by April following harvest and wood manipulation, but this was statistically significant only at the "no wood removal" site. At this time the "no wood removal" and "all wood removal" sites were dominated numerically by Other Diptera and Chironomidae with EPT percentages declining from 78% to 4% of numbers at the "no wood removal" site and from 54% to 13% at the "all wood removal" site. The "large wood removal" site also showed an increase in the percentage of Chironomidae (from 5 to 22%) while still maintaining relatively high numbers of EPT (from 74% to 55%) (Figure 7).

In August, invertebrate densities had increased markedly over pre-harvesting levels at the "all wood removal" and "no wood removal" sites reflecting relatively high numbers of Chironomidae at both

In August, invertebrate densities had increased markedly over pre-harvesting levels at the "all wood removal" and "no wood removal" sites reflecting relatively high numbers of Chironomidae at both sites, and Oligochaeta (worms) and Trichoptera (mainly the algal-piercing caddis *Oxyethira albiceps*) at the "no wood removal" site. This resulted in an increase in EPT at the "no wood removal" site to 14% compared with 12% at the "all wood removal" site. At the "large wood removal" site, August densities were similar to pre-harvesting densities, although there had been an increase in the proportion of Chironomidae (30%) and Other Diptera at this time. Nevertheless, percentages of EPT species continued to remain relatively high (45% of numbers).

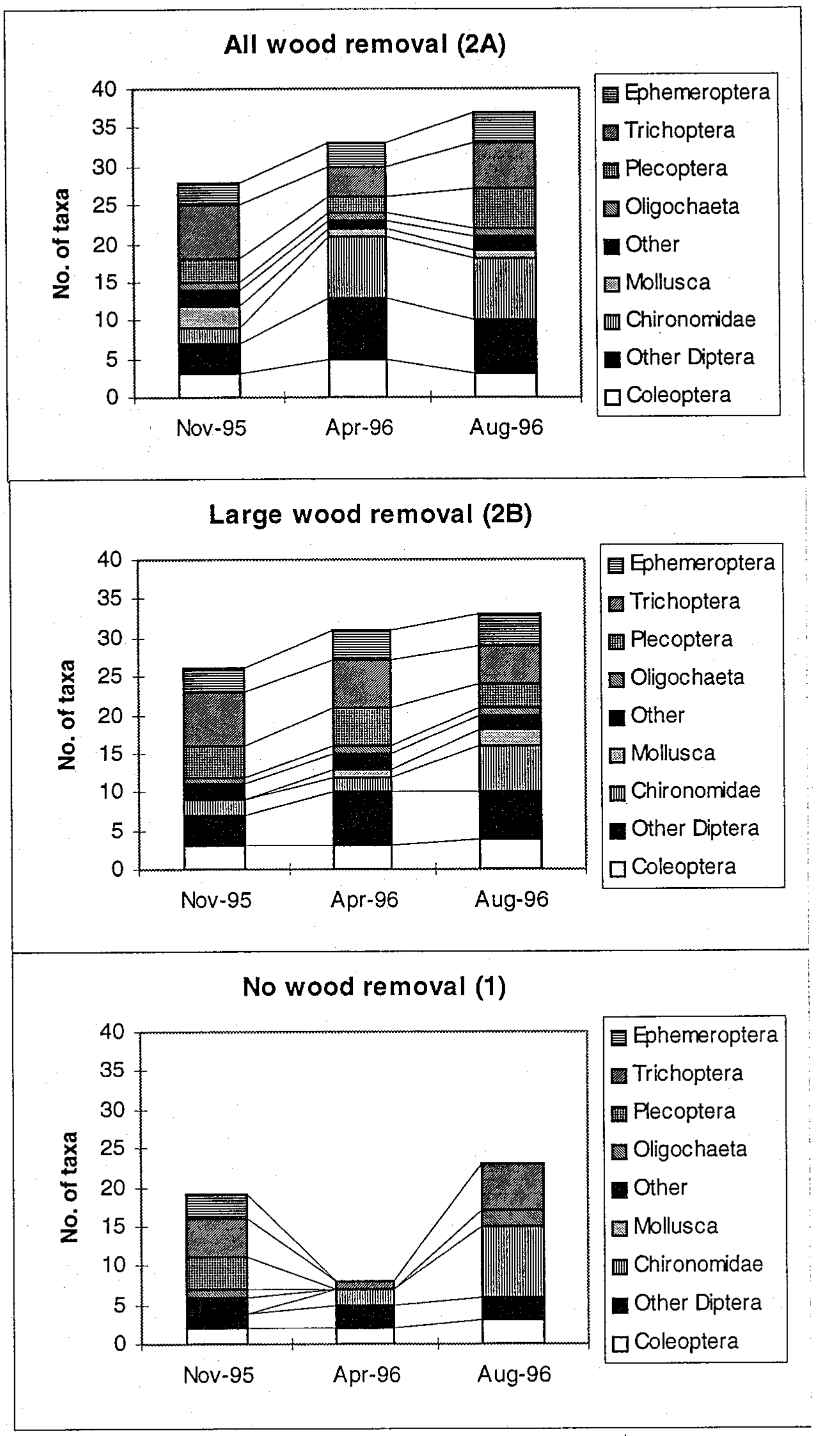


Figure 5: Number of taxa in the main invertebrate groups collected in ten 0.04m^2 Surber samples at three sites in pre-harvest (November 1995) and post-harvest (April and August 1996) conditions.

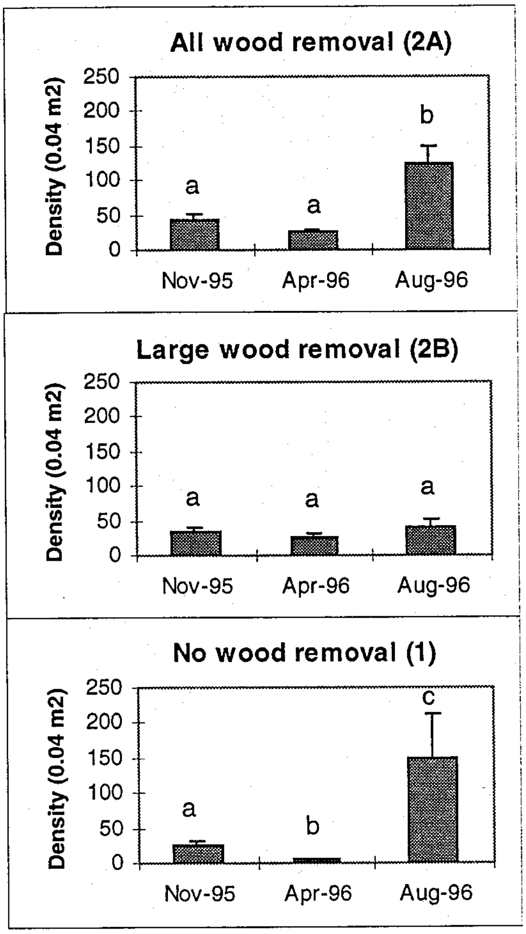


Figure 6: Mean densities (+1SE) of invertebrates collected in ten $0.04m^2$ Surber samples at three sites in pre-harvest (November 1995) and post-harvest (April and August 1996) conditions. Dates with the same letters above bars are not significantly different.

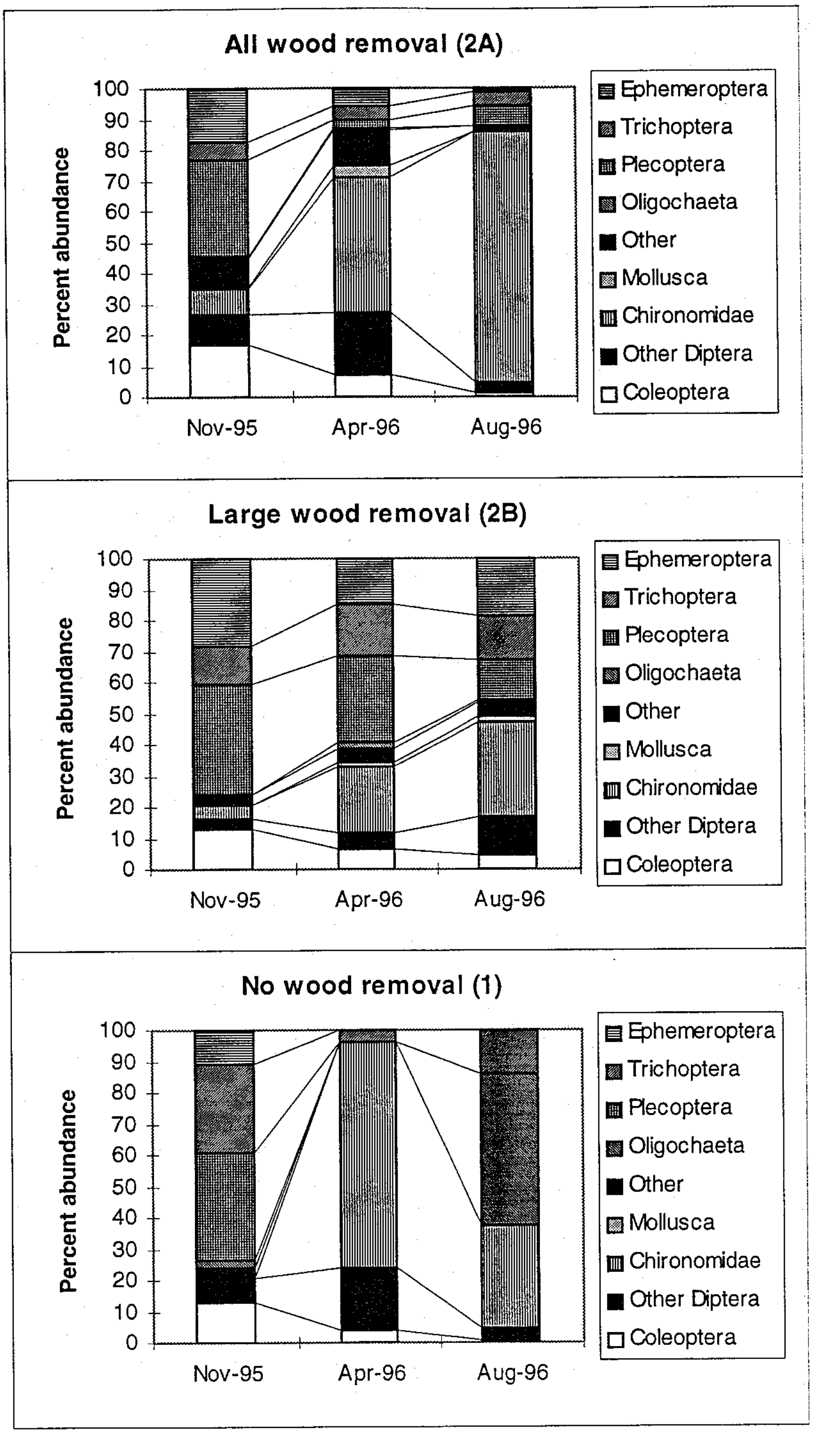


Figure 7: Percent composition of the main invertebrate groups collected in ten $0.04m^2$ Surber samples at three sites in pre-harvest (November 1995) and post-harvest (April and August 1996) conditions.

4. SUMMARY

- Wood volumes in stream channels increased by 477-736 $m^3.ha^{-1}$ after harvesting at the three study sites. Similar volumes of submerged wood were measured at all sites following harvesting. The "all wood removal" site had less wood above the channel and more wood on the floodplains than the other sites, however.

- Dissolved organic carbon concentrations increased from <1 $g.m^{-3}$ prior to harvest to 4.3-9.4 $g.m^{-3}$ in April when concentrations were highest at the "no wood removal" site. Concentrations were similar at all sites by August but were still above pre-harvest levels. Effects of wood treatment on water temperature and concentrations of DRP and NO_3-N should become clearer after summer sampling or analysis of stored samples from an unharvested reference site.

- Dissolved oxygen concentrations declined markedly from November levels (>10 $g.m^{-3}$) following harvest and remained relatively low (6.1-7.7 $g.m^{-3}$) at the "no wood removal" site until August. By this time dissolved oxygen concentrations at the "all wood removal" and the "large wood removal" sites were similar.

- Substrate analyses suggested that considerable amounts of coarse organic material had fallen or were washed into the stream channel of the "all wood removal" site by August so that the percent abundance of coarse organic material (excluding large wood) was similar to that recorded at the "large wood removal" site.

- Invertebrate taxa richness had increased from pre-harvesting levels at all sites by August, largely reflecting increases in the number of Diptera species. Densities had also increased by this time at the "no wood removal" and the "all wood removal" sites due to higher numbers of Chironomidae, Oligochaeta and algal-piercing Trichoptera, but remained similar to pre-harvest levels at the "large wood removal site". The percent abundance of sensitive EPT species declined from >50% of total numbers before harvesting to 12-14% by August at the "all wood removal" and "no wood removal" sites, but remained relatively high (45%) at the "large wood removal" site.

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