New Zealand Freshwater Research Report No. 3

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National Institute of Water & Atmospheric Research Ltd
Te Tari Taiharo Nukurangi

Aquatic fauna survey of Duffers Creek catchment (Grey River), February 1990, following cessation of alluvial gold mining and channelling

G.A. Eldon
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ISSN 1171-9842

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Report to: Department of Conservation

Freshwater Division
NIWAR
Christchurch

January
1993

NEW ZEALAND FRESHWATER RESEARCH REPORTS

This report is one of a series issued by the Freshwater Division of the National Institute of Water and Atmospheric Research Ltd. (NIWAR).

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The Publications Officer
Freshwater Division
NIWAR
PO Box 8602
Riccarton, Christchurch
New Zealand

ISBN 0-478-08304-1

Edited by:
C.K. Holmes

The studies documented in this report have been partially funded by the Department of Conservation

National Institute of Water & Atmospheric Research Ltd
Te Tari Taiharo Nukurangi

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SUMMARY

The purpose of this work was to determine the effects of stream bed channelisation for flood control and restoration after alluvial gold mining, on the aquatic fauna of Duffers Creek, a tributary of the Grey River. Eight sites were surveyed during February 1990.

Invertebrate communities throughout Duffers Creek catchment indicated good water quality, with the marginal exception of a highly modified previously mined reach. There were, however, considerable differences in the communities between sites, reflecting the type of habitat modification resulting from mining, forestry and channelising practice.

Eight species of fish were recorded. Brown trout and longfinned eels were recorded from all sites. Dwarf galaxias were recorded from five sites, being abundant at the only wholly unmodified one, and common at a second site not recently disturbed; they were absent from a third natural, but small volume, high altitude site. Shortfinned eels were scarce at four sites, and redfinned bullies were at the two lowest altitude sites. The distribution of upland bullies (three sites) and lamprey ammocoetes (four sites) had no apparent pattern. A single torrentfish was recorded from the most downstream site.

Biomass of fish per unit of wetted area was very similar in the five mid-river and downstream sites, despite differences in water volume, depth and other habitat features. The two highest altitude sites had greatly reduced biomass, which may have been partly the result of stream works impeding upstream migration by trout. Numbers and biomass of trout were clearly influenced by the quantity of instream and bankside cover, and the paucity of cover may also have limited eel stocks. However, limitation of trout may have been advantageous to smaller indigenous fish. Trout numbers were reasonably high at a channelised site with low water quality, and four native species were also present there, but biomass was low.

It is concluded that channelisation per se had not affected fish production, but the loss of cover which accompanied channelisation had affected production, particularly of trout and eels, and the loss of habitat variability may have affected fish species diversity.

1. INTRODUCTION

Fisheries managers have long expressed concerned over the impacts of alluvial gold mining, both in New Zealand (McDowall 1990, p 499) and overseas (Pain 1987). Most effects seem to be short-term, extending little beyond the life of the mining operation, and careful compliance with water right conditions should limit impacts to acceptable levels during the operation. However, inadequate or unsuitable stream restoration processes can result in provision of poor, degraded fish habitat. In a previous study on the Big Hohonu River (Eldon *et al.* 1989), it was found that in a violently flood-prone river, the effects of channelisation were short-lived. However, it was felt that in more stable waters, the effects of channelisation would be more profound and long lasting.

The Department of Conservation (DOC) has for some years been funding the Freshwater Fisheries Centre (FFC) (from July 1992 part of the Freshwater Division, National Institute of Water and Atmospheric Research) to study the effects of mining and stream diversion. A major obstacle to such research has been the problem of finding potential study areas where an adequate control stream was available.

The Duffers Creek catchment has a long history of alluvial gold mining, dating from the last century to as recently as 1983-1989. Recent miners, upon exhausting each claim, were required by the Westland Catchment Board (WCB) - now incorporated into the Westland Regional Council (WRC) to realign the creek to the Board's specifications. Following mining, the stream was confined to a direct course at the side of its valley to ensure minimum obstruction to flow. Consequently there was little cover for aquatic life, except where boulder drops had been created to prevent scouring. The WCB was understood to consider the result as a model of stream restoration. In its lower reaches, Duffers Creek was channelised by the WCB in 1983-1984, to enhance grazing land and alleviate flooding.

In 1987, Tony Tweed, former field officer to the West Coast Acclimatisation Society (WAS - now the Westland Fish and Game Council), carried out a trout survey in the lower Duffers Creek catchment, and found that numbers in two channelised reaches were only a tenth of numbers in two unchannelised reaches. Tweed's unpublished field notes included presence of native fish species, but there were no real quantitative data for these.

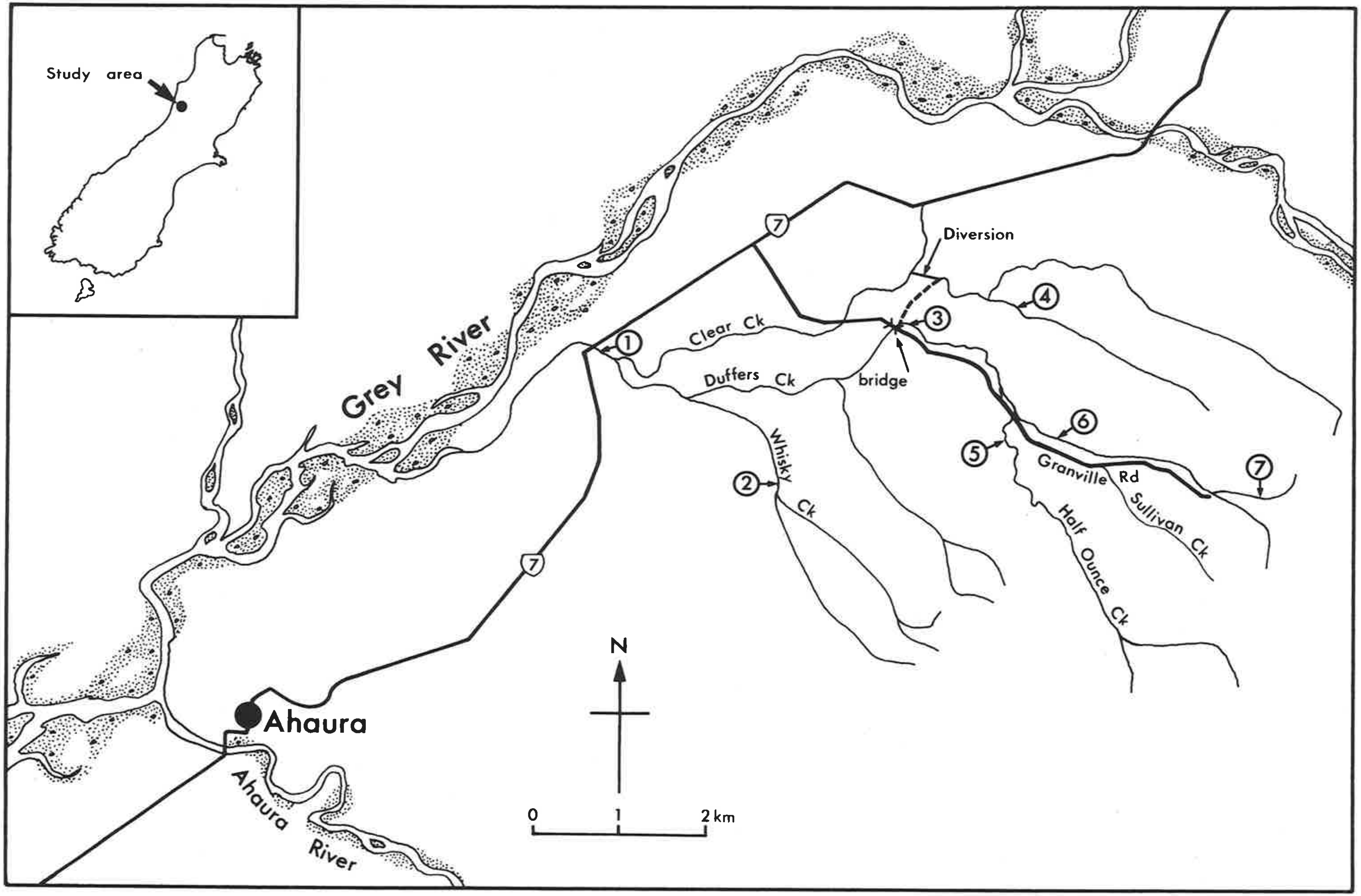

FIGURE 1. Duffers Creek catchment, Grey River system, showing sample sites surveyed, February 1990.

DOC's concern is centred on the indigenous fauna, and as Tweed's 1987 report provided no information on how this was affected by channelisation, FFC mounted this survey to:

(a) determine the distribution and abundance of invertebrates and fish in Duffers Creek;

(b) assess the impacts on the fauna of channelisation after gold mining;

(c) recommend means by which any adverse impacts could be reduced in the future.

2. STUDY AREA

The Duffers Creek catchment (Fig. 1) had an area of approximately 40 km^2, and although mining ceased in 1989, types of stream modification were diverse. They included:

(a) an unnamed stream, diverted in its lower reaches to Clear Creek, but with much of its course in pristine condition in untouched beech forest;

(b) Half Ounce Creek, a tributary mined long ago but not recently, subjected to limited deforestation and replanting with exotics, and showing considerable signs of erosion;

(c) Whisky Creek, a tributary with its upper catchment under forestry management but showing little adverse effect from this;

(d) the main stem, mined heavily both last century and in recent times, with channelised reaches in both bush and pastoral country.

The main stem rose at an altitude of 400 m asl, in beech forested hills between the Grey and Ahaura catchments. It followed a course of approximately 13 km to join the Grey River 10 km to the west, and approximately 40 km from the sea. Duffers Creek collected 12 tributaries during its course, two of the largest being Whisky and Half Ounce Creeks.

Only 0.5 km from its source, Duffers Creek emerged from the beech forest (Site 8, Fig. 2a) into a narrow valley opened up by gold mining (Site 7, Fig. 2b). From there, downstream for several kilometres, the creek had been channelised. It was confined to the true left of the valley, and provided with a series of steep

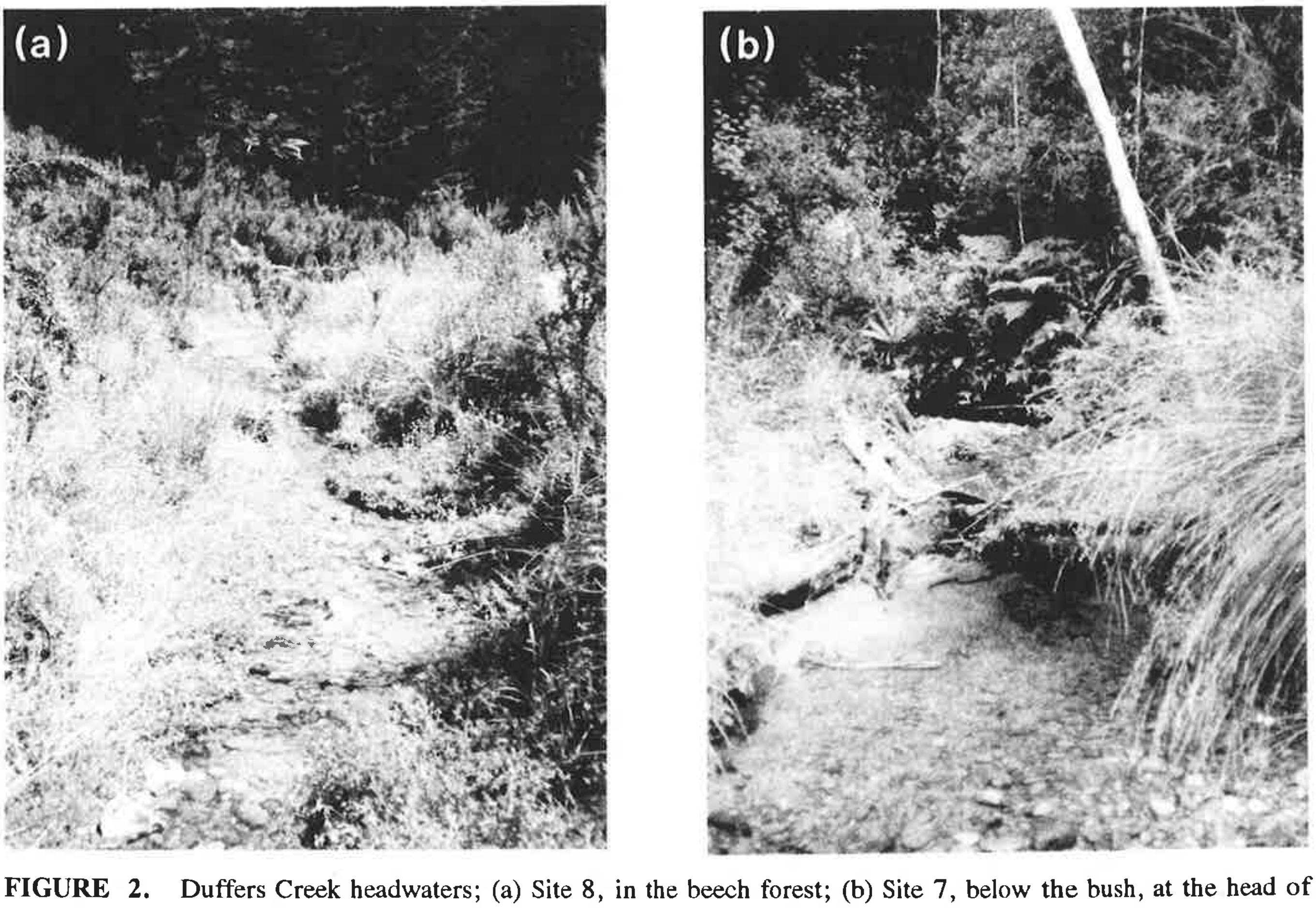

FIGURE 2. Duffers Creek headwaters; (a) Site 8, in the beech forest; (b) Site 7, below the bush, at the head of the mined reaches.

boulder drops to prevent scouring. The valley floor was mainly bare of vegetation, but the hills were bush-clad except for an area of recent clear-felling in the vicinity of Sullivan Creek.

The condition of the main stem in this upper reach was disappointing. Our understanding was that machine activity had ceased and that the stream was recovering, but this proved to be erroneous. A length of the valley upstream of the confluence of Half Ounce Creek had recently been furrowed by bulldozer, presumably for exotic forestry, and although there had been little direct interference with the actual stream channel, trained to the true right there, the flood bed had been stripped (Site 6, Fig. 3). The stream substrate at this point was heavily coated with a bright orange flocculence which appeared to be the result of mining activity having exposed an iron pan (R. Griffin pers. comm.).
The Half Ounce tributary (Site 5, Fig. 4) had a history of gold mining during the last century, when it was diverted through a tunnel, and a long dry oxbow created. The stream had not been mined recently, but much of the catchment was under exotic forest, and there was evidence of considerable erosion which may have been induced by logging activity. The channel upstream of the sampling site had been filled with silt, causing the stream to bifurcate into an extensive delta where the valley broadened out.

Upstream of Granville Road bridge, Duffers Creek emerged from the mining area into grazing land, the banks at first scrub-clad but later changing to pasture (Site 3, Fig. 5). The substrate here still showed evidence of erosion from Half Ounce Creek, and probably from mining of the main stem. The stream bed had aggraded, and a stop bank had been raised to prevent the stream spreading out over the pastureland. The channel still followed a meandering course and good riparian fish cover was present.

Downstream of Granville Road bridge, Duffers Creek received the waters of several tributaries, including Whisky and Clear Creeks. So far as we are aware, Whisky Creek had not been mined in recent times. Its headwater catchment was under exotic forestry, but we saw no evidence of the erosion problems prevalent in the Half Ounce catchment. Site 2 (Fig. 6) was situated on Whisky Creek 1.5-2 km upstream of the confluence with the main stem. Here the creek followed a natural course over a coarse substrate between scrub-covered banks in grazed country. A bankside gorse infestation had been sprayed with herbicide.

Clear Creek received the waters of an unnamed tributary stream which had been diverted into it. The unnamed stream originally entered Duffers Creek, above Granville Road bridge (Fig. 1). Site 4 (Fig. 7) was situated in a branch of this stream, which apartfrom the diversion, was in its natural condition, having never been mined; the sub-catchment was still under native forest and there was no farm stock.

From about 1 km above the main road bridge, to the confluence with the Grey River, Duffers Creek was again channelised, following a canal-like course between dairy pastures. There was no riparian fish cover, and the banks were not continuously fenced to exclude stock. Site 1 (Fig. 8) was established immediately upstream of the main road bridge. The substrate in this lower reach was good; heavy silt had dropped out further upstream, and the water velocity was sufficient to carry fine sediment through.

3. METHODS

Field work was carried out by four FFC staff over the week of 12-17 February 1990. The first day was spent on travel from Christchurch to Ahaura, and on a reconnaissance of the Duffers Creek catchment. Local knowledge was obtained for relevant historical data on past mining areas and access, and the study sites were selected (see Section 2; Table 1; Figs. 2-8), including a control site (4) which had no history of mining or logging (Fig. 7).

3.1 Physical parameters

Water clarity was measured with a 200 mm black disc (Davies-Colley 1988). Conductivity was measured with a Hannah HI 8333 meter. Spot water temperatures were taken with a standard hand-held thermometer, and a max-min thermometer was set over three days at one site.

Each sampling site was divided into sections based on the visual appearance of flow type, e.g., run, riffle, etc. Each site was measured longitudinally, and the width of each flow type recorded at one, two or three points according to its length. At each point, depth and velocity (measured with a Gurley Pygmy flow meter) were recorded at 0.25, 0.5 and 0.75 of the width. Substrate composition for each third of the transect was estimated by eye, using the following categories: sand (<2 mm), fine gravel (2-20 mm), gravel (21-60 mm), small cobbles (61-125 mm), large cobbles (126-260 mm) and boulders (>260 mm). For each site a substrate index was calculated, based on Bovee (1982) as modified by Eldon *et al.* (1989). Weighted mean

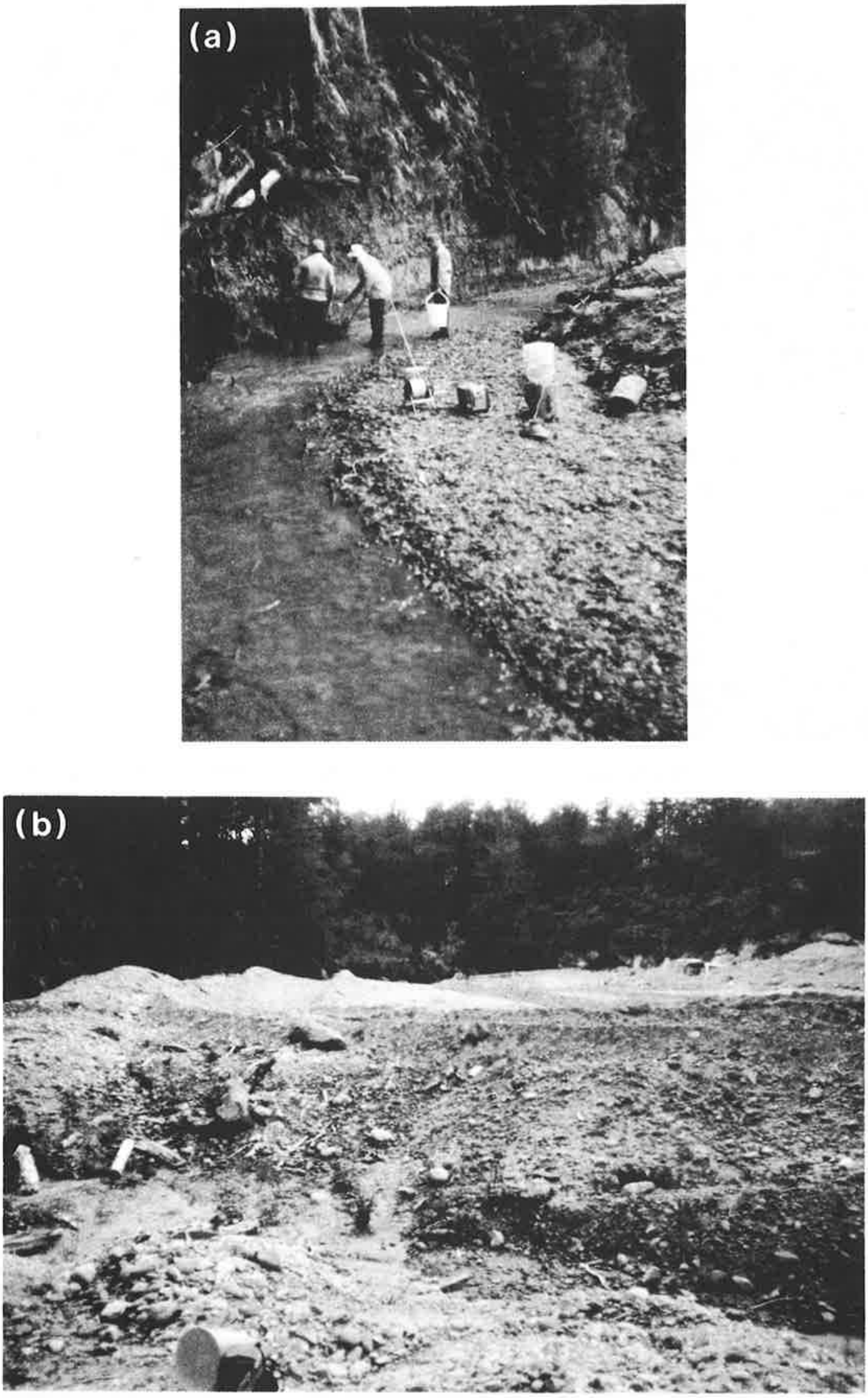

FIGURE 3. Site 6, a channelised upper reach of Duffers Creek mainstem. (a) electric fishing the channel; (b) the "moonscaped" valley adjacent to (a); the channel is behind the heaps of gravel to the left.

FIGURE 4. Site 5, Half Ounce Creek.

FIGURE 5. Site 3, Duffers Creek mainstem.

FIGURE 6. Site 2, Whisky Creek looking upstream. Flow gauging is in progress.

FIGURE 7. Site 4, unnamed tributary.

depths and widths were derived from flow-type, length and area data.

Specific data for sampling sites are presented in Table 2.

3.2 Aquatic invertebrates

To minimise faunal differences due to variable substrate, benthic invertebrates (other than koura) were collected from riffles only. Three replicate benthic samples were collected using a 0.1 m² sampler (Waters and Knapp 1961) fitted with 350 micron mesh net. The substrate delineated by the sampler was brushed and/or stirred to a depth of about 10 cm. Samples were placed in containers and preserved in 4% formalin. At the laboratory the samples were sorted and identified under a stereomicroscope and later dried and weighed. Koura (freshwater crayfish) were not included in the invertebrate collections. They were seldom taken in invertebrate samples and their relatively great size biases comparative biomass .

A percentage similarity of community (PSC) index (Whittaker and Fairbanks 1958) was calculated between all combinations of sites (Stark 1985a) (Appendix I). Cluster analysis was also undertaken on the invertebrate

TABLE 1. Site localities and general description, Duffers Creek catchment, February 1990.

Site No.	Location	NZMS 260 K31 grid reference	Tweed's site No.	Figure No.
1	Mainstem immediately upstream of the main road bridge, channelised	938.765	1	8
2	Whisky Creek immediately upstream of track ford	952.759	3	6
3	Mainstem above Granville Road bridge	975.768	4	5
4	Unnamed tributary "virgin" stream apparently unmined and unlogged, but lower reach diverted; foot access only	986.771	-	7
5	Half Ounce Creek a short distance above its confluence with Duffers Creek; previously mined and logged and some erosion evident	987.756	-	4
6	Mainstem upstream of Half Ounce Creek, channelised and trained to the true right of the valley	993.754	-	3
7	Mainstem headwaters at emergence from beech forest to lately mined area, partially natural channel in forest and partially channelised to the true left of the valley	016.748	-	2
8	Mainstem just upstream of Site 7, following a natural course in beech forest	017.748	-	2

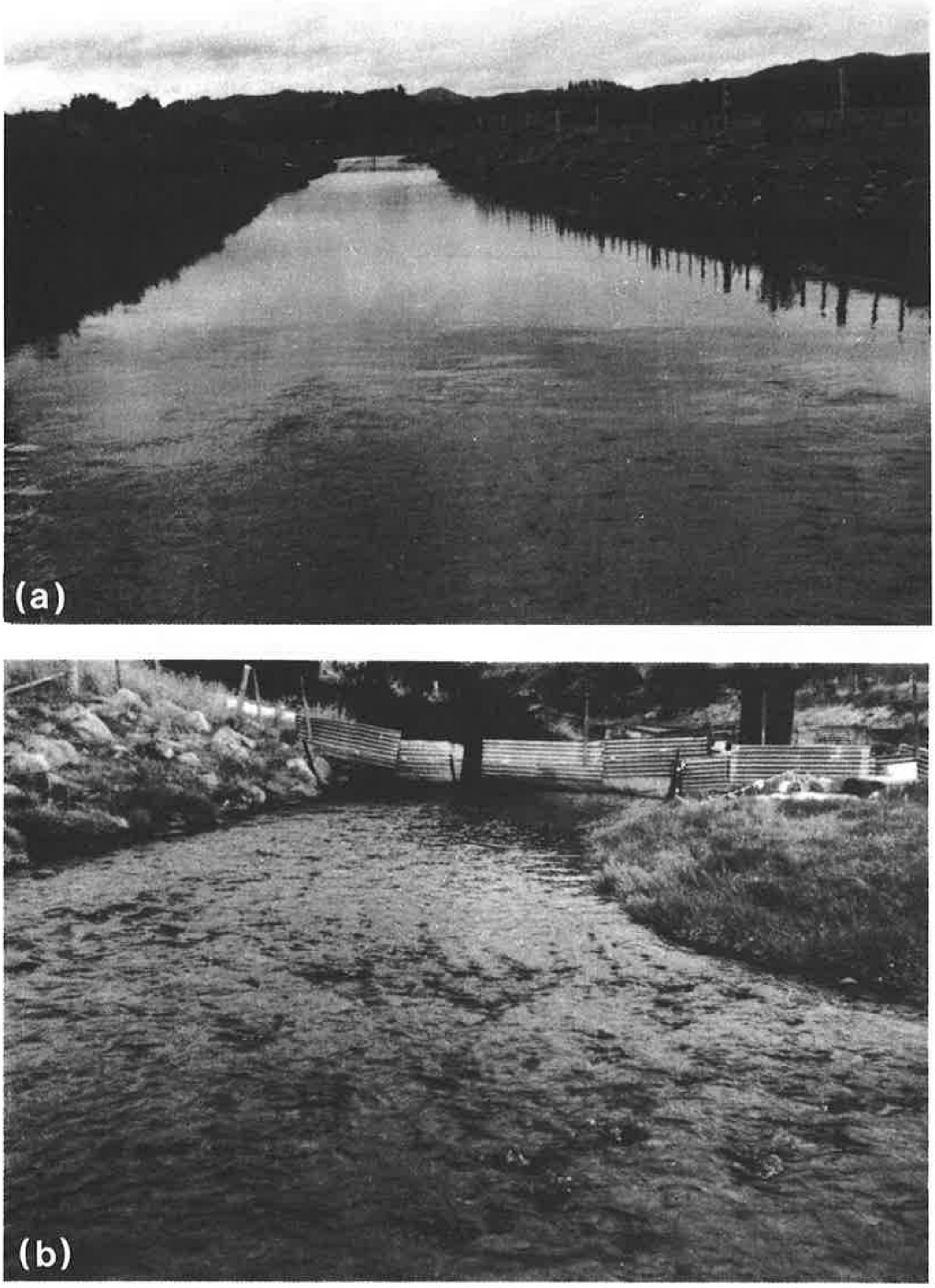

FIGURE 8. Site 1, channelised lower reach of Duffers Creek mainstem: (a) looking upstream at 70% of site containing few fish; (b) looking downstream over the riffle. 70% biomass caught from beneath boulders.

percentage compositions for all sites to provide an independent means of comparing faunal differences between sites (Stark 1985a) (Appendix II). We also produced macro-invertebrate community (MCI) values (Stark 1985b) from the data. This is an index of water quality based on the presence or absence of indicator species in the benthos.

3.3 Fish

Fish were collected using a generator-powered electric fishing machine, in conjunction with a hand-held stop net located 2-3 m downstream of the electrode, and a long stop net set across the entire width of the stream at the bottom of the site. Two or three sweeps were made, the long stop net being emptied at the end of

TABLE 2. Specific data on sampling sites in the Duffers Creek catchment, February 1990.

	Site numbers							
	1	2	3	4	5	6	7	8
Distance inland (km)	43	45	46.5	48	48	48	51	51+
Altitude (m asl)	80	90	95	110	120	130	180	180+
Length of channel (m)	80	65	97	87	85	120	45	45
Area (m^2)	592	182	340	113	290	276	41	79
Weighted mean width (m)	7.4	3.0	3.5	1.2	3.4	2.3	0.9	1.8
Weighted mean depth (m)	0.3	0.16	0.16	0.1	0.17	0.09	0.1	0.05
Maximum depth (m)	0.43	0.5	0.52	0.35	0.52	0.2	0.2	0.35
Water clarity (m)	2.2	2.2	1.1	nd	3.4	0.8	1.4	nd
Conductivity (ms)	58	49.5	nd	40	46	58	nd	39.6
Spot temperature (°C)	20.2	16.6	9.5	16.5	15.6	16.0	nd	13.6
3-day minimum temperature	nd	nd	nd	nd	nd	13.0	nd	nd
3-day maximum temperature	nd	nd	nd	nd	nd	18.0	nd	nd
Volume (ls^{-1})	642	70	198	8	93	66	nd	7
Weighted mean velocity (ms^{-1})	.240	.032	.065	.005	.028	.028	nd	.004
Flow type % area								
riffle	0	60	38	48	10	0	0	0
run	100	31	47	30	73	95	90	95
pool	0	9	15	22	17	5	0	5
cascade	0	0	0	0	0	0	10	0
Weighted substrate %								
boulder	1	20	1	0	0	0	15	10
cobble	57	33	10	14	23	6	15	40
coarse gravel	24	27	44	62	48	67	35	40
fine gravel	15	10	29	23	23	27	35	10
sand	3	10	16	1	6	-	0	0
index value	5.32	5.55	4.77	4.95	4.91	4.9	5.24	5.45
Fish cover (other than substrate) %								
weed/algae	<5	12	0	0	4	0	<5	0
instream debris	0	6	7	8	6	5	0	<5
bank vegetation	0	45	26	26	0	0	45	0
undercut banks	0	0	0	10	16	<5	0	0
overhead shade	0	<5	21	14	20	0	5	80
other	4	0	0	0	0	5	0	0
Riparian vegetation %								
grass, herbs	100	45	0	0	0	0	50	0
gorse, scrub	0	50	80	50	80	0	50	0
bush	0	0	0	50	20	45	0	100
bare bed	0	5	20	0	0	55	0	0

nd = no data.

each one. The catch from each sweep was recorded separately.

Captured fish were anaesthetised with benzocaine and measured to the nearest mm. Fish were weighed in batches (species per sweep) to the nearest 0.1 g.

The fish population at each site was estimated by the removal method; fish numbers and biomass per linear m of channel and per m^2 wetted area were calculated.

Upstream of Site 8, spot fishing was carried out for some distance to verify the paucity of fish.

3.4 Physical and biotic associations

We explored a wide variety of possible associations of environmental and biotic factors. Chiefly, we examined fish and invertebrate biomass and numbers, relating them to each other, and to site altitude, substrate value, riparian vegetation, flow type, stream width, etc, and a combination of these values.

4. RESULTS

4.1 Benthic fauna

The invertebrate fauna, other than koura, recorded at each site, are depicted in Figure 9, and detailed data are presented in Appendix III; the mean number of each taxon, the total number of animals and total dry weight per sample are given. Also given are the same invertebrate data as percentage composition.

The PSC matrix (Table 3) shows a large spread of values, reflecting major differences in the composition of the benthic invertebrates. The benthic fauna of Sites 7 and 8 were similar (PSC 79.9), yet very different from those of other sites.

Also indicated as similar in faunal composition, were sites 2 and 6 (PSC 77.0). Chironomid larvae were important components of the fauna at both sites, but Site 2 had a better representation of taxa which indicate good water quality - Ephemeroptera and Plecoptera - and this site was far more productive than Site 6 (Fig.

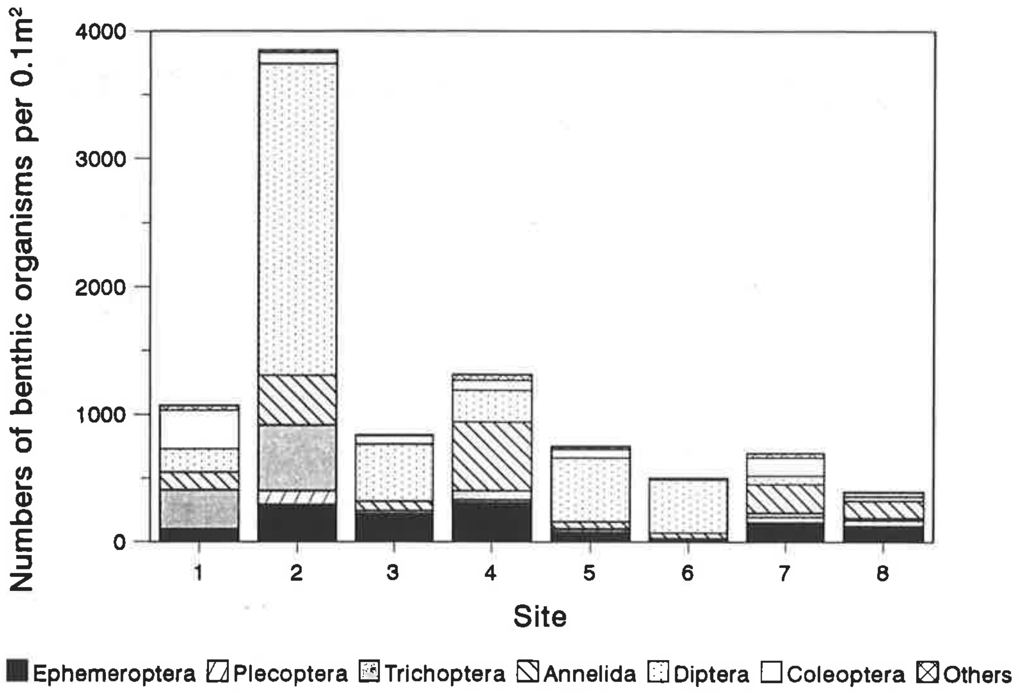

FIGURE 9. Numbers of major invertebrate taxa recorded from eight sites, Duffers Creek catchment, February 1990.

TABLE 3. Percentage similarity of community (PSC) index, Duffers Creek catchment, February 1990.

Site No.	1	2	3	4	5	6	7	8
1	////							
2	42.0	////				similar		
3	42.6	50.6	////		similar			
4	59.8	42.2	46.4	////				
5	43.2	46.4	74.5	42.1	////			
6	30.2	77.0	50.3	33.0	44.7	////	both very different	
7	50.7	34.6	51.4	67.1	40.2	23.8	////	similar
8	38.3	33.0	52.6	64.6	35.7	22.2	79.9	////

TABLE 4. MCI values for sample sites, Duffers Creek catchment, February 1990.

Site No.	1	2	3	4	5	6	7	8
Site score	140	138	124	140	110	73	130	122
Scoring taxa	23	23	22	22	19	14	21	19
MCI	121.7	120.0	112.7	127.3	115.8	104.3	123.8	128.4

9, Appendix III). Site 6 had a very low dry weight of invertebrates and lowest density (Appendix III); it also had a relatively low MCI value (indicating indifferent habitat quality) when compared with other sites (Table 4).

Sites 3 and 5 had particularly high simuliid counts, and a high PSC score (74.5) indicated a strong similarity in fauna. They also produced comparable overall numbers of benthos, though Site 5 had the greater biomass (Appendix III). Dissimilar benthic faunas were present at Sites 1 and 6, and at Sites 2 versus 7 and 8, while Sites 6 versus 7 and 8 had highly dissimilar faunas.

The dendrogram (Fig. 10) confirmed the findings of the PSC analysis. Although invertebrate numbers at Site 2 were 7.7 times greater than at Site 6, the fauna composition of these Sites were depicted as similar, and fundamentally different to all other sites. The difference was based on the high percentage of chironomids at Sites 2 and 6 (61% and 77% respectively), compared with other sites (8%-31%). Both these sites, but Site 6 particularly, were relatively poor in Ephemeroptera.

The sites with lower chironomid numbers (all sites except 2 and 6) fall clearly into two levels of simuliid representation; Sites 1, 4, 7 and 8 with very low numbers of simuliids, and Sites 3 and 5 with much higher numbers (Appendix III). Sites 4, 7 and 8, and Sites 3 and 5 group together in the dendrogram (Fig. 10), but Site 1 falls on its own between them. Site 1 was notable for a higher representation of Elmidae (riffle beetles) than any other site.

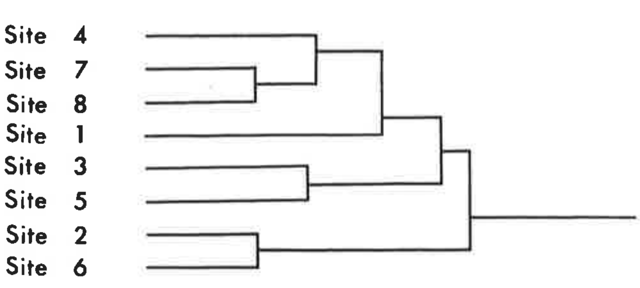

FIGURE 10. Dendrogram showing results of cluster analysis of invertebrates from Duffers Creek catchment.

4.2 Fish and koura

The estimated numbers and biomass of fish at the different sites are depicted in Figure 11. Actual numbers of fish and koura caught at each site are presented in Appendix III, as are the estimates from which Figure 11 is constructed. Longfinned eels, brown trout and koura were present at all sites; dwarf galaxias were present at five sites, shortfinned eels and lamprey at four, upland bully at three, redfinned bully at two, and torrentfish at one (Appendix III). The data show a decline in species diversity and fish biomass with increased altitude and distance from the sea. In this study, inland penetration and altitude increased fairly uniformly, although Sites 7 and 8 were at relatively greater altitude compared to distance from sea (Table 2).

Fish biomass was dominated by eels at all sites (Fig. 11), and eels constituted nearly 91% of all fish biomass in the study area. By contrast, dwarf galaxias dominated fish numbers at Site 4, but made a negligible contribution to biomass. Apart from a stray fish, dwarf galaxias and bullies were present together at only Site 5, where eels were in relatively low numbers (Fig. 11); even so, the combined biomass of dwarf galaxias and bullies was of little significance relative to that of the eels.

Most trout caught were apparently fish of the year (0+) or 1+ years; older fish, in excess of 180 mm, were recorded from Sites 1 (one fish), 2 (one), 3 (three), 8 (one) and from upstream of Site 8 (two). The mean length, range and standard deviation for small trout (age-class 0) are shown in Table 5.

4.3 Physical and biotic associations

There was a strong inverse relationship between fish biomass and altitude (Fig. 12) ($n = 8$, $r = 0.928$, $p = .001$). This reflected reduced habitat space provided by

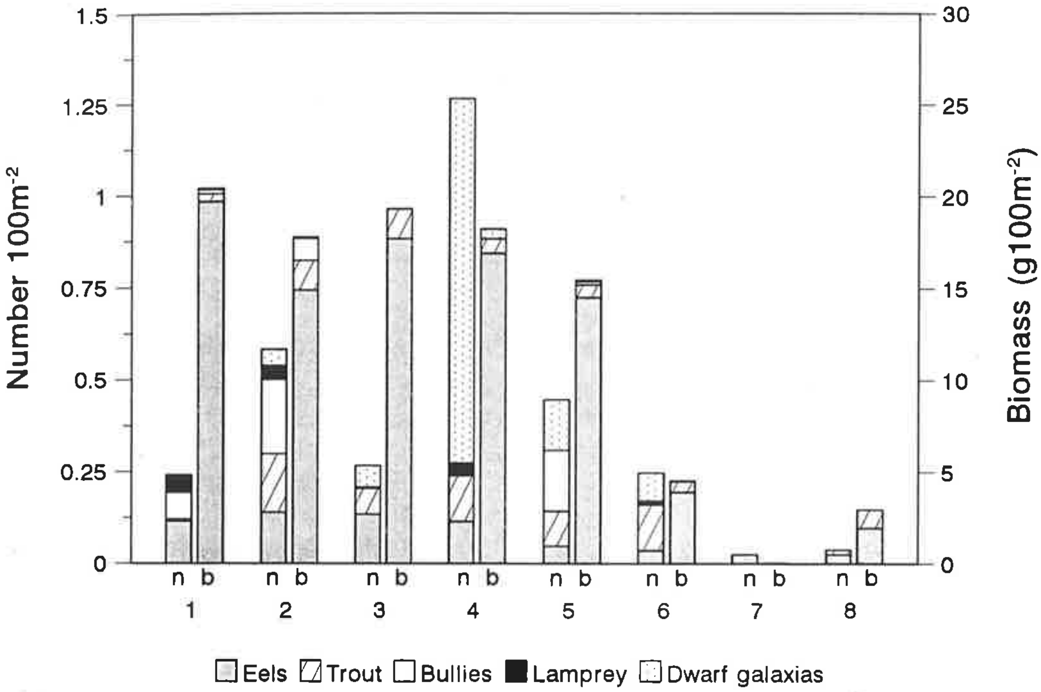

FIGURE 11. Relative occurrence, numbers and biomass of fish from eight sites, Duffers Creek catchment, February 1990.

TABLE 5. Mean length (mm), range and standard deviation of juvenile trout (age class 0) from Duffers Creek catchment, February 1990.

Site No.	n	Mean	Range	SD
2	28	90.6	67-111	13.7
3	21	95.9	80-127	11.2
4	14	79.6	70-91	8.0
5	25	86.1	74-114	8.6
6	34	73.1	59-86	7.4

reduced water volume higher in the catchment, as was to be expected. Once altitude was taken into account, MCI values were the only factor which showed a statistically significant relationship with biomass. The plot of fish biomass against MCI values (Fig. 13), shows Sites 7 and 8 to be poorer than should be expected, however, and it would appear that altitude, or some unmeasured factor (stream manipulation?), outweighs the importance of the plotted factor.

When numbers of fish per unit area were plotted, Site 4 was frequently shown to be highly favourable. However, numbers of fish per unit area were not significantly related to altitude, water volume or MCI values.

5. DISCUSSION

5.1 Inferences

The MCI indices (Table 4) indicated generally high water quality, with only Site 6 showing slight to moderate pollution under Stark's (1985b) criteria. This pollution was the result of a broken mineral pan, caused by mining excavation. Streams of similar appearance exist in old mine shafts in the Coromandel (Eldon pers. obs.). The pollution had a marked effect on the benthic fauna (see 4.1 above) and the visual appearance of the stream, but fish numbers (as opposed to biomass) appeared to be unaffected. The total fish number per unit area was very similar to that for the downstream mainstem sites, Sites 1 and 3. Here the effects of the pollution were diluted to the extent that there was no visual indication of it, and the benthic fauna was greatly improved. However, fish biomass at Site 6 was considerably less than that for Sites 1 and 3. As numbers of fish at Site 6 were not unduly low, altitude was not the sole cause of the low biomass. It may be attributable to poor habitat quality - uniformly shallow channel (Table 2), lack of major cover, and the blanketing effect of the flocculent - rather than poor water quality *per se*.

The similarity in benthic fauna at Sites 2 and 6 (Fig. 10) is anomalous. Because both sites had very high

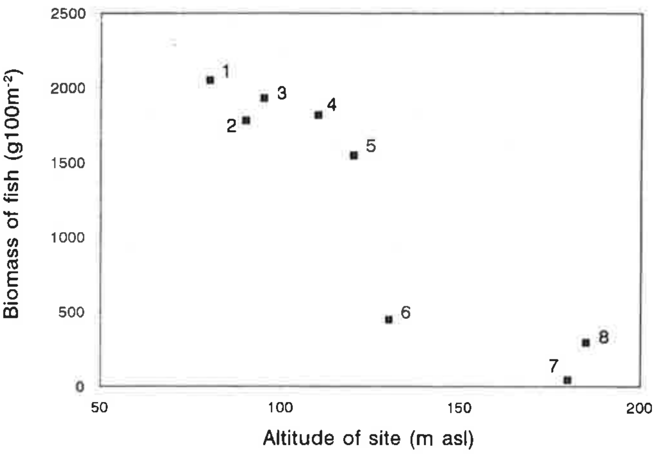

FIGURE 12. Biomass of fish plotted against altitude of sites, Duffers Creek catchment, February 1990.

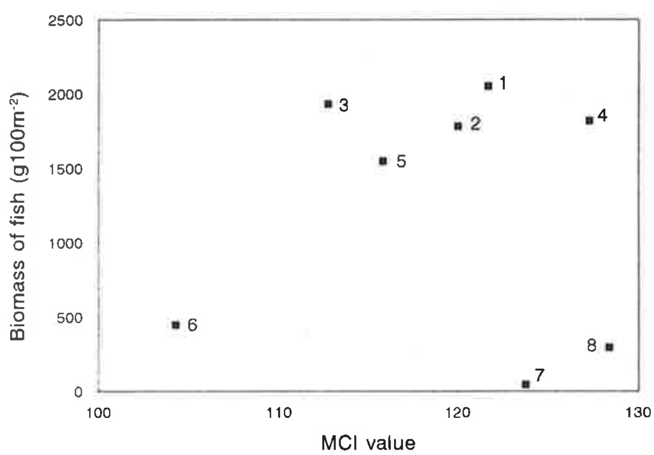

FIGURE 13. Biomass of fish plotted against MCI values for eight sites, Duffers Creek catchment, February 1990.

proportions of chironomids, with relatively small contributions from other taxa, the PSC index indicated similar faunas. However, inspection of absolute numbers (Appendix III) shows that Site 2 had much greater diversity of Trichoptera than Site 6, and a higher number of *Deleatidium*. Also, the dry weight of invertebrates at Site 6 was very poor (42.4 mg/0.1 m^2) versus 215.9 mg at Site 2.

The MCI values confirm the inferiority of Site 6, where there have been impacts from mining, channelisation and clear felling. Whisky Creek at Site 2 is apparently unaffected by any of these practices, though the headwaters of the catchment have been modified through forestry activity. The PSC index did not work for Site 2. Evidently low species diversity causes a loss in sensitivity in the PSC index.

Two other sites linked by the benthic analysis were Sites 3 on the main stem at 95 m asl (Fig. 5), and 5, a tributary, Half Ounce Creek, at 120 m asl (Fig. 4). Environmental factors they held in common were intermittent gravel and sand beaches, scrubby riparian vegetation and rather loose substrate resulting from catchment erosion.

A further three sites closely linked by benthic analysis were 4, 7 and 8. Two of these sites were the ones least modified by man. Site 4 and its upper catchment showed no signs of modification other than the chance invasion of some exotic riparian vegetation. Site 8 had not been modified. Site 7 had been channelled to the edge of the valley, but was probably close enough to the forest to have made a partial recovery.

In terms of fish number and biomass, Site 4 versus Sites 7 and 8 were widely divergent, a fact which may be accounted for in part by the difference in altitude - 110 m and 250 m respectively. The paucity of trout at Site 7 and 8 may have been the result of boulder drops in the channelised reach of this area being unsurmountable to migrants on spawning migration. Certainly there were no fish of the year (age-class 0) present - only a few older resident fish, for which there was very little holding water.

Site 4 had fish numbers and biomass probably in proportion to its dimensions. It contained by far the largest number of dwarf galaxias in the catchment, but also supported trout, longfinned eels and lampreys. Trout were small, but were as numerous (per m^2) as they were at most other sites. The distribution of native fish at this and other sites is discussed further, below.

The total biomass of fish per m^2 at all five lower sites was remarkably constant, as was the number of fish per m^1 for four of these sites (Appendix III). Under natural conditions (no channelisation; availability of instream and bankside cover) the biomass at Site 1 should have greatly exceeded other sites because of the volume of water and its proximity to the Grey River. The major cover available at Site 1 comprised the bank protection boulders placed on the true left bank at the approach to the bridge (see Fig. 8b). Some 70% of the site's biomass, mostly in the form of longfinned eels, was found concealed among these boulders. Had such cover been more plentiful, the production of eels would probably have been considerably greater, though not necessarily proportionally greater; other factors, such as food supply, might then be limiting. It has to be realised also, that eels may themselves limit the production of other fish by predation.

Although longfinned eels would probably have been more abundant at Site 1, given more cover, only the redfinned bullies seemed obviously under-represented among the native fish. Their biomass, given a less regimented habitat, should probably have at least equalled their biomass at Site 2. Upland bullies, by contrast, were somewhat more abundant than might have been expected. The most obvious anomaly at Site 1 was the paucity of trout, as demonstrated by Tweed (1987).

Site 1 held fewer trout and a lower biomass of trout than all other sites. In our view this was due to lack of instream and bankside cover, not to any shortage of food, for benthic fauna was more prolific at Site 1 than at Site 2. Trout production at Site 1 also compares unfavourably with that in other channelised streams with better cover. For example, a reach of the Styx River, near Christchurch (Eldon and Taylor 1990) which is very similar to Site 1 of Duffers Creek, had a trout biomass per km over six times greater.

In contrast with Site 1, the number of trout at Site 6 was considerably larger than we expected; indeed, the condition of Duffers Creek at this point was such that a total absence of trout would have been unremarkable. Biomass, however, was low, and trout were the smallest for their age class in the system (Table 5). Presumably they were leaving the area when outgrowing the limited cover left after channelisation - the vertical wall (Fig. 3a) and drop structures.

Unexplained results in the distribution of native fish were the intermittent occurrence of upland bullies (absent from Sites 2, 4, 6, 7 and 8), and the absence from Site 8 of dwarf galaxias. (The absence of dwarf galaxias from Site 1 was to be expected as it is not found in large, uniform, open habitats.) Neither mining activity, nor channelisation and diversion of lower reaches, would seem likely to have affected the presence or absence of either of these non-diadromous species. It can probably be assumed that the break in distribution was due to natural but unknown events, rather than due to man-induced habitat changes. The absence of these species from Site 8, however, may be related to the presence of a few adult trout in the vicinity.

It is worth noting that koura, while present at all sites, were most abundant at the sites least affected by farming and forestry - 4, 7 and 8. Recently koura were found to be plentiful in the catchments of the Whanganui Inlet, where man-induced modifications were few (Eldon and Ward 1991). In many waters these crustacea have greatly declined where they were once abundant. The recent discoveries of these creatures in large numbers in indigenous forest country tends to support speculation that bank erosion from land development and stock trampling, had contributed to the decline of crayfish elsewhere (Eldon 1981).

By far the largest number of fish per m² was at Site 4, the only site with no signs of human interference. Dwarf galaxias were abundant at this site, and were "in balance" with the small scale of the stream. However, they did not monopolise it, for juvenile trout, longfinned eels, lamprey ammocoetes and koura were all present.

5.2 Impacts

There is evidence that the paucity of vertebrate biomass in channelised streams may be due not to channelisation *per se*, but to the lack of cover which invariably, but not inevitably, goes with it.

The situation at Site 6, where juvenile trout were numerous but biomass low, emphasises the deleterious effect of channelisation. Small trout were tolerant of the water quality, and able to utilize the minimal cover, but there was no holding habitat (pools/cover) for larger fish.

Although it is possible that trout had been concentrated into the reach by being displaced from elsewhere, no machine work had been carried out in the stream channel itself; therefore displacement of trout is problematical. Channelisation had, however, ensured a total lack of major cover, and large (age 1+) trout and large eels were absent.

Probably only Sites 1 and 3 would be of direct interest to anglers, as trout elsewhere were too small. The difference in trout numbers and biomass between these sites clearly confirms the superiority of the unchannelised reach, as shown by Tweed (1987).

It should be borne in mind that what is bad for trout may not be bad for small indigenous species. Indeed, factors which limit trout numbers may be good for the indigenous species, as large trout are efficient predators of small fish. However, numbers and biomass of small indigenous fishes were greater at Site 3 than at Site 1.

The evaluation of channelisation was complicated by recent ongoing forestry work. Despite this, there was clear evidence that channelisation (with its attendant lack of significant instream and bankside cover) had significantly degraded the lower reach as a trout habitat.

Whether channelisation of the lower reach had affected the indigenous fish fauna is less clear. What can be stated with regard to the indigenous fauna, is that the faunal association of the only totally unmodified lowland water (Site 4), was markedly different from all others. The abundance of lamprey ammocoetes, and of dwarf galaxias and koura in the presence of juvenile trout, was notable.

6. RECOMMENDATIONS

1. Restoration to hydraulically efficient regime channels should be avoided. Such channels lack suitable cover for all but the smallest fish, and lack habitat variability.

2. Where such channels already exist, means should be found to enhance fish habitat by installing cover, either by placing instream boulders/logs and/or planting the banks with suitable riparian vegetation which will provide overhanging cover.

3. Future studies of this sort should survey a larger number of study sites, to enable confident statistical evaluation of impacts to be carried out.

4. Given the amount of time required to sample invertebrates quantitatively, future studies should look at some subjective or sub-sampling technique.

7. ACKNOWLEDGEMENTS

This project was partially financed by the Department of Conservation. Preliminary work was carried out by Paul Lambert of the West Coast Acclimatisation Society, and Paddy Ryan of the Westland Regional Council took an interest. Malcolm Flain and Marty Bonnett took part in the field work. Colin Miskelly did the painstaking sorting of the invertebrates.

Special thanks are due for the assistance rendered by Messrs R.W. Griffin and R. Griffin Jr for supplying local knowledge and guidance. Site 4 could not have been accessed without the latter's assistance.

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APPENDIX I. PSC index.

The PSC Index (Stark, 1985a) is a measure of faunal similarity between two sites. The higher the number, the greater the similarity of fauna between the sites, with a theoretical maximum of 100.

The formula is:

$$PSC = 100 - (\tfrac{1}{2}\sum |A - B|)$$

where:

A = percentage benthos numbers of a taxon from site A,
B = percentage benthos numbers of the same taxon at site B.

APPENDIX II. Cluster analysis.

Cluster analysis is a technique which summarises the data from each site as a point in multidimensional space, where each dimension represents the relative abundance of a taxon. The geometrical distance between points provides a parameter for measuring differences in benthos composition.

This analysis established groups of sites with similar faunas, and also calculated how the groups differed from each other. Sites were classified into groups of sites with similar faunas, and the extent that each group differed from each other was determined.

These two properties were expressed graphically in the form of a dendrogram. Sites with similar benthic faunas occur together as a group, depicted by a vertical bar linking the sites. The length of the horizontal bar separating groups is proportional to their dissimilarity in fauna.

The degree of faunal similarity between groups is indicated in the order in which the groups are listed down the page. Thus, groups exhibiting some common features in faunal composition, are placed side by side, while groups with radically different benthic faunas are placed further apart. In this manner, sites with similar fauna composition are evident, and their degree of variation from other sites can be readily assessed.

APPENDIX III. Analytical data.

TABLE AIII.1. Mean numbers of benthic fauna per 0.1 m² at sampling sites in the Duffers Creek catchment, February 1990. Data are for the mean of three samples for all sites except Site 2.

	Site							
Taxa	1	2	3	4	5	6	7	7
PLATYHELMINTHES								
Trichadida	10	2	0	13.7	10.3	0.3	11	0.7
ANNELIDA								
Lumbricidae indet.	0	0	0	0.3	0	0	0	0
Oligochaeta indet.	140	391	74	536.3	53.3	43.7	224.3	132.7
GASTROPODA								
Potamopyrgus antipodarum	27	1	0.3	0	0	0	4	0.7
COPEPODA indet.								
Harpacticoid	0	2	0	1	0	0.7	0	0
EPHEMEROPOTERA								
Zephlebia versicolor	0	0	0	0	0	0	0	2
Coloburiscus humeralis	7.7	70	32	155.3	16	1.3	20	20.3
Nesameletus ornatus	0	2	0	1.7	0	0	7.7	2.3
Ameletopsis perscitus	0	0	0	0	0	0	0	0.7
Deleatidium spp.	92.7	224	184.7	145.3	61.3	8.7	128.3	103.3
Atalophlebioides	0	0	0	2.3	0	0	0	0
Ichthybotus	0	0	0	3.3	0	0	0	0
PLECOPTERA								
Stenoperla prasina	0.3	0	0.3	6	5.7	0	6.7	6
Austoperla cyrene	0.7	5	1.3	9.7	10	0	4.7	3.3
Zelandoperla agnetis	0.3	0	0	0	0.7	0	7	2.7
Zelandobius sp.	0	99	6.3	5	3	0.3	20	30.7
Spaniocerca zelandica	0	0	0	0	0	0	0.7	1.7
Spaniocercoides sp.	0	0	0	0	0.3	0.3	1	0
Megaleptoperla	0	0	0	2	0	0	0	0
Acroperla spiniger	0	0	0	0.3	0	0	0	0
Cristaperla fimbria	0	0	0	0.7	0	0	0	0
Neozephlebia scita	0	0	0	0	0	0	0.3	0
Hegaleptoperla diminuta	0	0	0	0	0	0	1	0
MEGALOPTERA								
Archichauliodes diversus	1.7	12	3.7	19	9	1.7	6.3	0
COLEOPTERA								
Hydraenidae indet.	1.3	10	0	0	2.7	0	0	0
Hydraenidae adults	0	0	7	60.3	0	0	26.3	3.3
Elmidae indet.	294	77	50.3	18.3	66.3	6.3	113	26
Elmidae adults	5.7	0	6.7	0	0	0.3	2	0.3
Scirtidae indet.	0.7	1	2	0	0	0	0.3	0
Ptilodacylidae indet.	0	0	0	0	0	0	0.3	0
Indet larvae	0	0	0	0	0.3	0	0	0.3
DIPTERA								
Chironomidae indet.	120.7	2300	228.3	218.3	192.3	340.3	52.7	29.7

Taxa	Site 1	2	3	4	5	6	7	7
Chironomidae indet. pupae	13.3	52	28.3	6.3	8.3	44.7	3	0.7
Ceratopogonidae indet.	0.3	7	1	15.7	4	3	7	1
Simuliidae	41	22	176.7	7.3	274.3	24	0.7	1.3
Simuliidae pupae	1.7	0	6	0	12.7	3.3	0	0
Empididae	0.3	46	2.7	2.3	2.3	2	3	0.7
Eriopterini	1	1	5	0.3	2.3	2	0.7	2
Hexatomini	0	0	0	0	0	0	0	0
Tabanidae	0.3	0	0.3	0	5.7	0	0.3	0
Tanyderidae	0.3	0	0	0	0	0	0	0
Limnophera	0	2	0	0	0	1	0	0
Aphrophila neozelandica	4.3	3	0	0	0	0	0.7	0
Indet. larvae	0	0	0	0	0	0	0	0.3
Indet. pupae	0	2	0	0	0	0	0	0
TRICHOPTERA								
Rakiura	0	2	0	0	0	0	0	0
Aoteapsyche spp.	186.7	314	0.7	33.3	0.7	5.7	8.7	1.3
Polyplectropus puerilis	0	0	0.3	0	0	0	0	0
Hydrobiosella stenocerca	0	0	0	2	0.3	0	0.3	2.3
Hydrobiosid	12.7	1	0	0	0	0	0	0
Hydrobiosis spp.	0	114	7.3	12.7	2	4	7.7	4.7
Hydribosidae pupae	2.7	0	0.7	0	0	0	0.3	0
Psilochorema spp.	1.3	1	0	0	0	0	1.7	0
Oxyethira sp.	0.7	7	0.3	0	0.7	5.3	0	0
Pycnocentrodes sp.	6.7	1	0	0	0	0	0	0
Pycnocentrodes pupae	4.3	0	8.3	0	0	0	0	0
Pycnocentria funerea	0	4	0.7	6	0	0	0	0
Olinga feredayi	3	5	1.7	15.3	3.7	0	0	0
Conuxia gunni	83.3	40	0	0	0	0.3	0	0
Conuxia gunni pupae	1	1	0	0	0	0	0	0
Helicopsyche spp.	0.7	11	0	2	0	0	10	7.3
Helicopsyche pupae	0.3	0	0	0	0	0	0	0
Triplectides spp.	0.7	11	0	2	-	-	10	7.3
Zelolessica cheira	0	0	0	0	0.3	0.3	3.7	0
Philorheithrus sp.	1.7	0	0	0.3	0	0	0	0
Triplectides sp.	0	0	0	0.3	0	0	0	0
Philopotamidae	0	0	0	0.3	0	0	0	0
Canoesucidae	0	0	0	2	0	0	0	0
Ecnomid	0	16	0	0	0	0	0.3	0
Trichoptera indet pupae	1	0	0	1	0	0	0	0
ACARI	0.7	3	1.7	5.7	1.3	0	11	5.3
TOTAL	1072.1	3851	838.6	1311.9	749.8	499.5	696.7	393.6
Dry weight (mg)	251.1	215.9	142.6	156.1	325.7	42.4	266.2	95.4

TABLE AIII.2. Percentage composition of benthic fauna at sampling sites in the Duffers Creek catchment, February 1990.

	Site							
Taxa	1	2	3	4	5	6	7	8
PLATYHELMINTHES								
Trichadida	0.9	<0.1	0	1.0	1.3	<0.1	1.6	0.2
ANNELIDA								
Lumbricidae indet.	0	0	0	<0.1	0	0	0	0
Oligochaeta indet.	13.1	10.1	8.8	40.9	7.1	8.7	32.2	33.7
GASTROPODA								
Potamopyrgus antipodarum	2.5	<0.1	<0.1	0	0	0	0.6	0.2
COPEPODA indet.								
Harpacticoid	0	<0.1	0	<0.1	0	0.1	0	0
EPHEMEROPOTERA								
Zephlebia versicolor	0	0	0	0	0	0	0	0.5
Coloburiscus humeralis	0.7	1.8	3.8	11.8	2.1	0.3	2.9	5.1
Nesameletus ornatus	0	<0.1	0	0.1	0	0	1.1	0.6
Ameletopsis perscitus	0	0	0	0	0	0	0	0.2
Deleatidium spp.	8.6	5.8	22.0	11.1	8.2	1.7	18.4	26.2
Atalophlebioides	0	0	0	0.2	0	0	0	0
Ichthybotus	0	0	0	0.3	0	0	0	0
PLECOPTERA								
Stenoperla prasina	<0.1	0	<0.1	0.5	0.8	0	1	1.5
Austoperla cyrene	0.1	0.1	0.2	0.7	1.3	0	0.7	0.8
Zelandoperla agnetis	<0.1	0	0	0	0.1	0	1	0.7
Zelandobius sp.	0	2.6	0.8	0.4	0.4	<0.1	2.9	7.8
Spaniocerca zelandica	0	0	0	0	0	0	0.1	0.4
Spaniocercoides sp.	0	0	0	0	<0.1	<0.1	0.1	0
Megaleptoperla	0	0	0	0.2	0	0	0.1	0
Acroperla spiniger	0	0	0	<0.1	0	0	0	0
Cristaperla fimbria	0	0	0	<0.1	0	0	0	0
Hegaleptoperla diminuta	0	0	0	0	0	0	0.1	<0
MEGALOPTERA								
Archichauliodes diversus	0.2	0.3	0.4	1.4	1.2	0.3	0.9	0
COLEOPTERA								
Hydraenidae indet.	0.1	0.3	0	0	0.4	0	0	0
Hydraenidae adults	0	0	0.8	4.6	0	0	3.8	0.8
Elmidae indet.	27.4	2.0	6.0	1.4	8.8	1.3	16.2	6.6
Elmidae adults	0.5	0	0.8	0	0	<0.1	0.3	<0.1
Scirtidae indet.	<0.1	<0.1	0.2	0	0	0	<0.1	0
Indet larvae	0	0	0	0	<0.1	0	0	<0.1
DIPTERA								

Taxa	Site 1	2	3	4	5	6	7	8
Chironomidae indet.	11.3	59.7	27.2	16.6	25.6	68.1	7.6	7.5
Chironomidae indet. pupae	1.2	1.4	3.4	0.5	1.1	8.9	0.4	0.2
Ceratopogonidae indet.	<0.1	0.2	0.1	1.2	0.5	0.6	1.0	0.3
Simuliidae	3.8	0.6	21.1	0.6	36.6	4.8	0.1	0.3
Simuliidae pupae	0.2	0	0.7	0	1.7	0.7	0	0
Empididae	0.3	1.2	0.3	0.2	0.3	0.4	0.4	0.2
Eriopterini	0.1	<0.1	0.6	<0.1	0.3	0.4	0	0.5
Hexatomini	0	0	0	0	0	0	0	0
Tabanidae	<0.1	0	<0.1	0	0.8	0	<0.1	0
Tanyderidae	<0.1	0	0	0	0	0	0	0
Limnophera	0	<0.1	0	0	0	0.2	0	0
Aphrophila neozelandica	0.4	<0.1	0	0	0	0	0.1	0
Indet. larvae	0	0	0	0	0	0	0	<0.1
Indet. pupae	0	<0.1	0	0	0	0	0	0
TRICHOPTERA								
Rakiura	0	<0.1	0	0	0	0	0	0
Aoteapsyche spp.	17.4	8.2	0.1	2.5	0.1	1.1	1.2	0.3
Polyplectropus puerilis	0	0	<0.1	0	0	0	0	0
Hydrobiosella stenocerca	0	0	0	0.2	<0.1	0	<0.1	0.6
Hydrobiosid	1.2	<0.1	0	0	0	0	0	0
Hydrobiosis spp.	0	3.0	0.9	1.0	0.3	0.8	1.1	1.2
Hydribosidae pupae	0.3	0	0.1	0	0	0	<0.1	0
Psilochorema spp.	0.1	<0.1	0	0	0	0	0.2	0
Oxyethira sp.	<0.1	0.2	<0.1	0	0.1	1.1	0	0
Pycnocentrodes sp.	0.6	<0.1	0	0	0	0	0	0
Pycnocentrodes pupae	0.4	0	1.0	0	0	0	0	0
Pycnocentria funerea	0	0.1	0.1	0.5	0	0	0	0
Olinga feredayi	0.3	0.1	0.2	1.2	0.5	0	0	0
Conuxia gunni	7.8	1.0	0	0	0	<0.1	0	0
Conuxia gunni pupae	0.1	<0.1	0	0	0	0	0	0
Helicopsyche spp.	<0.1	0.3	0	0.2	0	0	1.4	1.9
Helicopsyche pupae	<0.1	0	0	0	0	0	0	0
Triplectides spp.	0	0	0	<0.1	0	0	0	0
Zelolessica cheira	0	0	0	0	<0.1	<0.1	0.5	0
Philorheithrus sp.	0.2	0	0	<0.1	0	0	0	0
Triplectides sp.	0	0	0	<0.1	0	0	0	0
Canoesucidae	0	0	0	0.2	0	0	0	<0.1
Ecnomid	0	0.4	0	0	0	0	<0.1	0
Trichoptera indet pupae	0.1	0	0	0.1	0	0	0	0
ACARI	<0.1	<0.1	0.2	0.4	0.2	0	1.6	1.3

TABLE AIII.3. Actual numbers of fish and crayfish, and number of fish species caught at eight sites, Duffers Creek catchment, February 1990.

Site No.	Brown trout	Longfinned eel	Shortfinned eel	Upland bully	Redfinned bully	Dwarf galaxias	Lamprey ammocoetes	Torrent-fish	Total all fish	Crayfish	No. of fish species
1	3	62	3	21	20	0	28	1	138	1	7
2	29	24	0	0	24	8	6	0	91	4	5
3	24	30	1	1	0	14	0	0	70	2	5
4	14	13	0	0	0	82	4	0	113	17	4
5	25	13	1	35	0	31	0	0	105	1	5
6	34	8	2	0	0	21	3	0	68	6	5
7	0	1	0	0	0	0	0	0	1	14	7
8	1	2	0	0	0	0	0	0	3	23	2

TABLE AIII.4. Estimated fish density for eight sites in the Duffers Creek catchment, February 1990. Data are presented for 100 linear metres of channel (100 m^1) and 100 m^2 wetted area.

Site No.	Brown trout		Longfinned eel		Shortfinned eel		Upland bully		Redfinned bully		Dwarf galaxias		Lamprey ammocoetes		Torrentfish		Total all fish	
	100 m^1	100 m^2	100 m^1	100 m^2	100 m^1	100 m^2	100 m^1	100 m^2	100 m^1	100 m^2	100 m^1	100 m^2	100 m^1	100 m^2	100 m^1	100 m^2	100 m^1	100 m^2
1	3.8	0.5	82.5	11.1	3.8	0.5	28.8	3.9	25.0	3.4	0	0	35.0	4.7	1.3	0.2	180.2	24.3
2	44.6	15.9	40.0	14.2	0	0	0	0	56.9	20.3	12.3	4.4	10.8	3.8	0	0	164.6	58.6
3	24.7	7.1	46.4	13.2	1.0	0.3	1.0	0.3	0	0	20.6	5.9	0	0	0	0	93.7	26.8
4	16.1	12.4	14.9	11.5	0	0	0	0	0	0	128.7	99.1	#4.6	3.5	0	0	164.3	126.5
5	31.6	9.3	15.2	4.5	1.2	0.3	56.2	16.6	0	0	46.8	13.8	0	0	0	0	151.0	44.5
6	28.3	12.3	6.7	2.9	1.7	0.7	0	0	0	0	*17.5	7.6	2.5	1.1	0	0	56.7	24.6
7+	0	0	2.2	2.5	0	0	0	0	0	0	0	0	0	0	0	0	2.2	2.5
8+	2.2	1.3	4.4	2.5	0	0	0	0	0	0	0	0	0	0	0	0	6.6	3.8

+ = single sweep only.
* = actual catch in the sequence.
# = actual catch in the sequence 0 fish, 4 fish.

TABLE AIII.5. Estimated fish biomass (g) for eight sites in the Duffers Creek catchment, February 1990. Data are presented for 100 linear metres of channel (100 m[1]) and 100 m² wetted area.

Site No.	Brown trout		Longfinned eel		Shortfinned eel		Upland bully		Redfinned bully		Dwarf galaxias		Lamprey ammocoetes		Torrentfish		Total all fish	
	100 m¹	100 m²	100 m¹	100 m²	100 m¹	100 m²	100 m¹	100 m²	100 m¹	100 m²	100 m¹	100 m²	100 m¹	100 m²	100 m¹	100 m²	100 m¹	100 m²
1	307.8	41.6	144448.0	1952.4	165.8	22.4	42.7	5.8	139.9	18.9	0	0	46.4	6.3	27.5	3.7	15178.1	2051.1
2	439.1	156.8	4160.8	1486.0	0	0	0	0	338.0	120.7	7.1	2.5	9.5	3.4	0	0	4954.5	1769.4
3	562.5	160.5	6195.9	1767.7	3.6	1.0	1.0	0.3	0	0	6.2	1.8	0	0	0	0	6769.2	1931.3
4	100.0	77.0	2189.5	1685.8	0	0	0	0	0	0	69.3	53.3	#3.2	2.5	0	0	2362.0	1818.6
5	234.5	69.0	4933.1	1452.7	8.4	2.5	61.0	18.0	0	0	23.4	6.9	0	0	0	0	5260.4	1549.1
6	135.6	58.9	883.9	384.3	3.9	1.7	0	0	0	0	*8	3.5	1.1	0.5	0	0	1032.5	448.9
7+	0	0	41.6	46.2	0	0	0	0	0	0	0	0	0	0	0	0	41.6	46.2
8+	176.7	100.6	343.1	195.4	0	0	0	0	0	0	0	0	0	0	0	0	519.8	296.0

+ = single sweep only.
* = actual catch in the sequence 9 fish, 12 fish.
# = actual catch in the sequence 0 fish, 4 fish.