Response of the benthic fauna of an urban stream during six years of restoration

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Abstract

Okeover Stream flows through the University of Canterbury campus and has been subject to restoration since 1998. While initially spring-fed, its main source of flow is now aquifer water, which has been used for cooling university buildings. Water quality is generally good, but the low-gradient streambed includes substantial amounts of fine inorganic sediment and organic matter including deciduous tree leaves. Restoration activities include riparian plantings, channel shaping, substratum manipulations and additions, the construction of sediment traps and macrophyte management. Thirty aquatic invertebrate taxa (13-19 per year) have been recorded in annual surveys since 2000. *Paracalliope fluviatilis* (Amphipoda), Copepoda and Oligochaeta were most abundant in all years, whereas Mollusca and Trichoptera always made up <4% and <2% of individuals, respectively. Furthermore, cased caddisflies were found only in the two (of four) downstream reaches, whereas Copepoda were predominantly in the upper two reaches where flow was generally slower. Low annual MCI (69-84) and SQMCI (3.5-4.8) values indicated the fauna comprised mainly species that are tolerant of poor water quality or degraded habitat conditions. Our data indicate that the invertebrate fauna has yet to respond positively to the changes in physical habitat and riparian conditions made along Okeover Stream. The introduction of pulses of poor quality water during heavy rainfalls, high levels of siltation, heavy metals in bed sediments, large accumulations of slowly decomposing leaves and an inadequate source of potential colonists may all contribute to the weak response of the invertebrate fauna to restoration activities.

Keywords: Urban stream - restoration - invertebrates - Amphipoda - Trichoptera - water quality - habitat degradation.

Introduction

Urban development has a substantial effect on streams and their biological communities. Waterways have been modified in various ways to act as conduits for stormwater and urban waste, to reduce the effects of floods and for recreational purposes. Urbanisation often results in altered hydrology, increases in runoff and increased siltation, and the banks of urban streams are likely to be cleared of their natural vegetation, have reinforced banks and in many instances courses that have been channelised or piped to increase their drainage function (Suren 2000).

Three tributaries of the Avon River flow through the grounds of the University of Canterbury in the west of Christchurch city. Initially, they arose from springs and drained the low-lying wetlands on which much of the city was built. With the continuing development of the western suburbs the water table has been lowered, springs have been lost and their sources have migrated downstream. For example, Robb (1980) showed the Okeover Stream rising about 2.5 km west of its present source near Ilam Road, and the adjacent Ilam Stream now has its source about 800 m downstream of the spring source described by Marshall (1974). Reductions in base-flow have led to siltation and periodic stagnation, especially in upper reaches, as well as reductions in the diversity and abundance of benthic invertebrate and fish populations (Robb 1992; O'Brien 1998).

The Okeover (formerly Clarkson's Drain) is the smallest of the three campus streams and was identified by O'Brien (1998) as a candidate for restoration in order to increase aquatic invertebrate abundance and diversity, increase native fish diversity, and maintain it as a trout-free stream. To achieve these objectives, in-stream and riparian habitat diversity is being increased, flow patterns are being manipulated, and the aeration capacity of the stream enhanced. To these ends native trees and shrubs have been planted on the banks of the stream along much of its course through the campus, and gravel, large stones and logs have been added to the channel in places. In addition, several sediment traps have been created. Most ambitious has been the reconstruction of the headwaters reach above Engineering Road (Figure 1) to create a series of shallow riffles linking deep pools containing artificial habitat structures suitable for colonization by Canterbury mudfish (*Neochanna burrowsius*).

The purpose of this paper is to summarise results of annual invertebrate surveys of Okeover Stream, initiated in

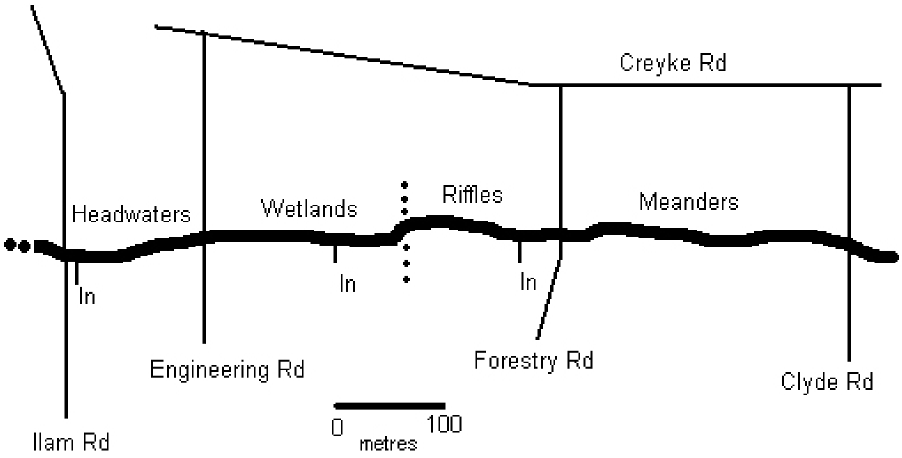

Figure 1. Sketch map of the Okeover Stream showing the four sampling reaches and sites of the main inputs of water (In).

2000, and to evaluate whether on-going restoration is resulting in changes to the invertebrate fauna.

Okeover Stream

The stream originally had its origin in springs west of the University of Canterbury campus but increasing urban development in its headwaters has resulted in a lowering of the water table and downstream displacement of the stream source. Clean water pumped from local, subterranean aquifers and used in the air-conditioning plants of campus buildings, is discharged into Okeover Stream at three main points (Figure 1) and now provides the major source of flow. It is supplemented by several minor inputs to and west of the campus, as well as by periodic inputs of storm-water. Above the uppermost discharge point near Ilam Road the stream has a wooden-sided channel, which is replaced by an underground pipe further upstream. Much of the time these upper sections of stream are either dry or contain stagnant water, but they can carry a large volume of storm-water following heavy rainfall. Water quality in the 820 m long section of stream on the campus appears to be generally good. Alkalinity is about 41 g m^{-3} $CaCO_3$, pH 6-7 and dissolved oxygen (DO) concentration is generally high (Blakely & Harding 2005). Thus, late-morning DO values obtained from points throughout the campus on eight occasions in November 2002-January 2003 ranged from 8.3-10.1 mg l^{-1} (82-98 % saturation) (Blakely 2003). The results of heavy metal analyses undertaken on a limited number of sediment samples from the Okeover Stream showed moderately high concentrations of cadmium, copper, lead and zinc, with some of the values for the latter three metals exceeding the ANZECC trigger values (ISQG-low) (Blakely & Harding 2005). These findings are a cause for concern as the ISQG-low values indicate a 10% probability of ecological damage (ANZECC 2000).

Okeover Stream has a very low gradient (about 0.1%), a width of 1-4 m, and a bed composed mainly of gravel, mud, silt and small patches of bedrock. Some large cobbles have been added in places as part of the restoration process. The stream flows through three culverts within the campus and leaves the university through another beneath Clyde Road. Stream banks are a combination of lawns, gardens, shrubberies, tree roots, and both stone and wooden walls. In many places the channel is overhung by deciduous and evergreen trees. Gravel substrata support extensive growths of moss (mainly *Leptodictium riparium*) and filamentous algae. Aquatic macrophytes including watercress (*Rorippa microphylla*), starwort (*Callitriche stagnalis*) and the grass *Glyceria maxima* are patchily distributed (Carroll & Robb 1986; Robb *et al.* 1994). Heavy growths of watercress have been evident in the very low gradient wetlands reach (Figure 1) and have been managed since 2001 to create a narrower, faster flowing channel than before. Eels (*Anguilla* spp.), upland bullies (*Gobiomorphus breviceps*) and possibly trout (*Salmo trutta*) inhabit the stream in small numbers and both Mallard (*Anas platyrhynchos*) and Grey ducks (*Anas superciliosa*) are present most of the time.

The stream restoration programme outlined earlier in this paper commenced in 1998 and is being implemented by the university in partnership with the Christchurch City Council. Significant milestones in the restoration process to

Table 1. Restoration initiatives and activities on Okeover Stream, 1998-2005.

Year	Initiatives and activities
1998	Waterway restoration partnership plan developed; streamside plantings initiated
1999	Planting of natives in riparian zone
2000	More streamside plantings; rocks and logs added to about 10% of the riffles reach to increase habitat diversity and modify flow patterns
2001	Substantial restoration work in about 20% of the wetlands reach including plantings, channel modification and construction of a sediment trap; management of aquatic plants initiated
2003	Large-scale reconstruction (almost 100%) of the headwater reach to create habitat suitable for Canterbury mudfish
2005	Construction of in-stream habitat and a sediment trap in about 40% of the meanders reach
2005	Introduction of Canterbury mudfish and freshwater crayfish to headwaters reach

date are summarized in Table 1.

Methods

Surveys were carried out in September each year except in 2000 and 2003 when fieldwork was done in November. On each occasion samples were taken from 4 stream-reaches: headwaters, wetlands, riffles and meanders (Figure 1). From each reach three Surber samples (0.1 m^2, 0.5 mm mesh) were taken from stony riffles and a general non-quantitative collection was made by kick-sampling and sweeping a net through macrophytes and streamside plants hanging in the water. Samples were sorted live in white trays in the laboratory immediately following completion of fieldwork. Invertebrates were identified to levels required to calculate MCI indices (Boothroyd & Stark 2000), and the abundances of all taxa in Surber samples were assessed on the 5-point scale used to derive the SQMCI (Table 2). Metrics calculated from the data were taxon richness, MCI (based on all samples: Surber, kick and sweep) and SQMCI (based on Surber samples only).

Table 2. Coded abundances used to calculate the SQMCI following Stark (1998).

Descriptor	Abundance	Coded abundance
Rare	1-5	1
Common	6-20	5
Abundant	21-100	20
Very abundant	101-500	100
V. very abundant	>500	500

Because the abundance of most taxa was low, frequency of occurrence of the more common taxa in Surber samples was also calculated. Community composition across years was compared using the Sorensen distance measure:

$$2c / a+b$$

where "a" and "b" are the numbers of taxa present in the years being compared, and "c" is the number of taxa held in common.

Measurements of pH, conductivity (at 25 °C), dissolved oxygen and water temperature were made in the field at the time of invertebrate sampling (afternoon) using appropriate meters.

Results

Physicochemical factors

Values for physicochemical variables (Table 3) are indicative of generally good

Table 3. Mean (±1SD) values for physicochemical factors measured in 4 reaches of Okeover Stream in 6 years, 2000-2005. - = no measurement made. * a single stream measurement made.

	2000	2001	2002	2003	2004	2005
Temp (^{o}C)	-	15.8±0.8	14±0.4	14.4±0.7	13.6±0.3	14.3±0.2
pH	7.0*	6.5	6.6±0.1	6.8	7.0±0.1	7.2 ±0.1
Cond (μS cm^{-1})	140*	172±26	-	159±2	168±1	167±1
DO (g m^{-2})	9.8*	-	9.9±0.6	8.2±0.8	7.0±0.3	8.7±0.2

water quality and showed limited variation along the stream and between years. Mean percentage saturation of dissolved oxygen in the four years 2002-2005 ranged from 67-95 %, some of the variation likely reflecting differences in photosynthesis and respiration of aquatic plants and micro-organisms. The variation in conductivity among sites in 2001 (Table 3) was largely a consequence of a high value (211 μS cm^{-1}) recorded in the headwater reach where water was effectively stagnant and confined to pools.

Invertebrate fauna

In the 6 years 2000-2005, 30 taxa were recorded at the level of resolution required to calculate the MCI (Appendix I). Oligochaeta included *Lumbriculus variegatus*, Tubificidae and the lumbricid *Eiseniella tetraedra*; Ostracoda included *Herpetocypris pascheri* and an unidentified, white species. Two species of calanoid copepod were identified: *Eucyclops serrulatus* and *Mesocyclops leukarti*, both of which are common in a range of habitats but are primarily littoral and benthic species (Chapman & Lewis 1976). Larval Orthocladiinae and Tanypodinae (Chironomidae) were not identified further. The record of the mayfly *Deleatidium* is based on a single nymph found in the riffles reach in 2002. We believe it may have been a specimen tipped into the stream following a laboratory class.

Numbers of taxa found per year ranged from 13 to 19. In all years the amphipod *Paracalliope fluviatilis* was most abundant (relative abundance 37-80% calculated from the sum of coded abundance values), except in 2005 when its relative abundance (24%) was exceeded by Copepoda (56%). Copepoda, Oligochaeta, and Orthocladiinae (Chironomidae) were the next most abundant taxa in most years. Mollusca and Trichoptera always made up less than 4% and 2% of the fauna, respectively.

The high degree of similarity in species composition of the stream fauna among years is shown by the high Sorensen scores (Table 4), which averaged 0.77 for all pair-wise comparisons. Their very low coefficient of variation (8.4%) emphasizes the strong similarity in species composition of the stream fauna in all years. The frequency of occurrence of individual taxa in Surber samples provides

Table 4. Faunal similarity among years expressed as Sorensen scores calculated from presence: absence data, all sites combined each year.

	2000	2001	2002	2003	2004
2001	0.74	-	-	-	-
2002	0.72	0.85	-	-	-
2003	0.74	0.86	0.78	-	-
2004	0.76	0.88	0.80	0.76	-
2005	0.63	0.83	0.80	0.75	0.71

another comparative indicator of their commonness and distribution. *Paracalliope fluviatilis* was present in all samples collected in the 6 years; Oligochaeta, *Cura pinguis* and Orthocladiinae were found in over half of them (Figure 2).

Mean taxon richness in the four reaches ranged from 7.6 to 12.8 and was significantly greater in the lowermost (meanders) reach than in the headwaters (ANOVA, $P < 0.05$; Table 5). Richness varied little within reaches between years (coefficients of variation (cv) 17-24%), except in the headwaters (cv = 56%). Pronounced longitudinal distribution patterns were shown by the caddisflies *Pycnocentria evecta* and *Pycnocentrodes aureola*, which were most common in the lowermost reach, occasionally found in the riffles reach but seen nowhere else (Figure 3). The opposite pattern was displayed by copepods, which were taken most frequently in the headwaters and wetlands reaches where flow tended to be lower and slower (Figure 3).

MCI (mean 78, range 69-84) and SQMCI (mean 4.2, range 3.5-4.8) scores for the stream fauna showed only a small amount of variation among years and the MCI scores were similar to those calculated from survey data for 1980 and 1990 (Table 5). Neither index showed a systematic increase or decrease over time. Furthermore, mean MCI scores did not

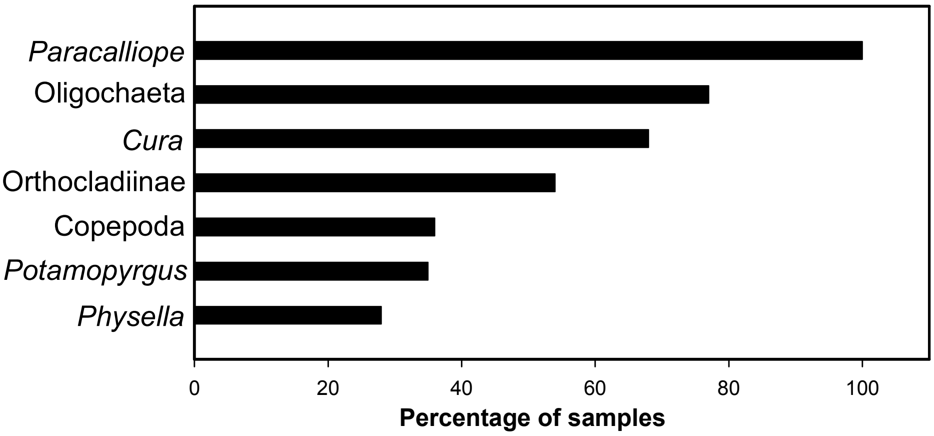

Figure 2. The percentage of Surber samples taken from the four reaches (2000-2005) containing Copepoda and two cased caddis, *Pycnocentria evecta* and *Pycnocentrodes aureola*.

Table 5. MCI and SQMCI scores and total numbers of invertebrate taxa found in Okeover Stream in 6 years (2000-2005) based on samples taken from four reaches within the University of Canterbury campus. Also shown are MCI scores and numbers of taxa (at the same level of identification) for surveys made in 1980 and 1990 (Robb 1980; 1992). As sampling was non-quantitative in the latter surveys, SQMCI could not be calculated.

	2000	2001	2002	2003	2004	2005	1980	1990
MCI	76	74	84	84	80	69	81	78
SQMCI	3.5	4.6	4.4	4.2	4.8	3.8	-	-
Taxa	19	16	17	19	18	13	15	21

Table 6. Mean (± 1SD) taxon richness and MCI scores for the four reaches of Okeover Stream calculated from data for the 6 years, 2000-2005. Different superscript letters indicate significant differences among sites (Tukey HSD tests).

	Headwaters	**Wetlands**	**Riffles**	**Meanders**
Taxon richness				
Mean	7.6^{a}	9.7^{ab}	9.7^{ab}	12.8^{b}
SD	4.2	1.6	1.8	3.1
MCI				
Mean	79^{a}	70^{a}	73^{a}	77^{a}
SD	7	4	7	6

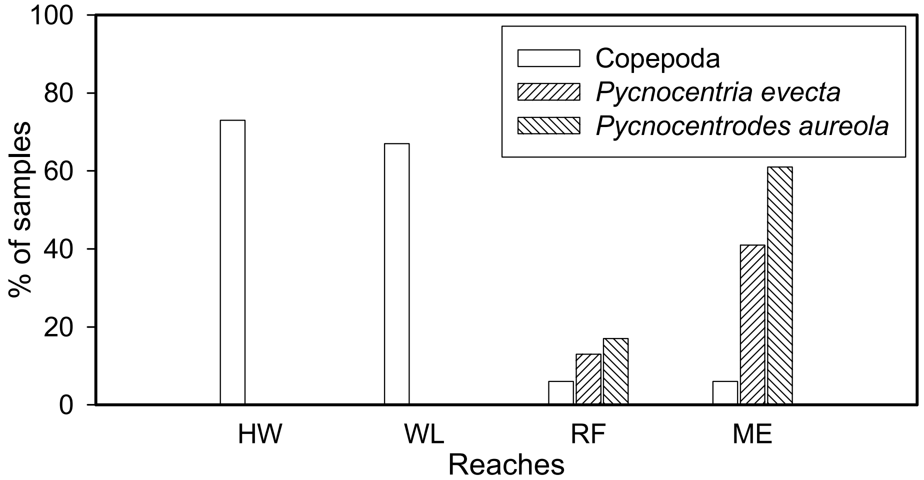

Figure 3. The percentage of samples taken from Okeover Stream (2000-2005) containing the seven most common taxa. HW = headwaters, WL = wetlands, RF = riffles, ME = meanders.

differ significantly among reaches over the 6 years of the study (ANOVA, $P > 0.05$; Table 6). The macroinvertebrate community indices indicated the fauna comprised mainly species tolerant of either poor water quality or degraded habitat conditions.

Discussion

The invertebrate fauna of Okeover Stream has limited diversity and is dominated numerically by Crustacea, Diptera and Oligochaeta. It is not unlike the fauna described by Marshall (1973) from the upper 60 m of the adjacent, spring-fed Ilam Stream, although the latter supported a much larger population of snails (mainly *Potamopyrgus antipodarum*). Cottam (1999) also found that *Paracalliope fluviatilis* was numerically dominant (~ 65%) in the lower campus reach of Okeover Stream in 1999 (before tussocks had been planted along its true right bank) and that sub-dominant taxa were Orthocladiinae, *Pycnocentrodes aureola* and Oligochaeta. However, he found the Okeover site was unusual in being the only one of eight studied on urban Christchurch streams to be dominated by this amphipod. In fact, *Paracalliope fluviatilis* was rare at all other sites, which had large populations of snails (mainly *Potamopyrgus antipodarum*) and oligochaetes. Reasons for these differences in faunal dominance are unknown and were not addressed by Cottam (1999) who commented that because *Paracalliope* and *Pycnocentrodes* have higher MCI scores (5) than *Potamopyrgus* (4) and Oligochaeta (1) their dominance in the Okeover suggested "it could be considered the most "healthy" of the stream sites".

Apart from a single record of the mayfly *Deleatidium* (of debatable origin), the only EPT taxa (mayflies, stoneflies, caddisflies) found in the Okeover were larval caddisflies, none of which was abundant, and only two of which were recorded in most years. These two species, *Pycnocentrodes aureola* and *Pycnocentria evecta* were confined to the lower campus reaches where discharge and current velocity were greatest. Interestingly, they were not found there in 2005 despite no obvious changes in habitat being apparent in that part of the stream. No significant change in the taxonomic composition of the invertebrate community was found over the 6 years encompassed by our surveys, although (coded) abundances and relative abundances of some species varied among years. The amphipod *Paracalliope fluviatilis* was always most abundant, except in 2005 when copepods were most abundant in the headwaters, which had undergone substantial modification to increase the number and depth of pools.

Although 30 taxa were recorded from Okeover Stream between 2000 and 2005, most were rare, and 10 were found only once. Average annual taxon richness (17) was similar to the 15 and 21 taxa found in the 1980 and 1990 Christchurch City Council surveys (Robb 1980; 1992), but because so many taxa were rare in all three surveys their collection or non-collection may have been influenced strongly by chance. The MCI and SQMCI showed no systematic increases or decreases between 2000 and 2005 and the MCI values were very similar to scores calculated from non-quantitative survey data collected in 1980 and 1990. Although not designed specifically for use on urban streams, they nevertheless are indicative of degraded stream conditions.

Up to 2005 the channel restoration activities and riparian plantings undertaken along Okeover Stream have resulted in no enhancement of the invertebrate community.

Reasons for the lack of a faunal response are probably several. First, the physical condition of the stream is unlikely to be conducive to colonization by some taxa, including many EPT species, because of the pervasiveness and high abundance of silt on and within much of the streambed (Ryder 1989; Ryan 1991). Furthermore, extensive accumulations of leaves and other organic matter, especially in the upper reaches, smother stony substrata and may bring about localized conditions of low oxygen concentration. Cottam (1999) found that stony substrata, wood and leaf packs all supported very similar faunas, both quantitatively and qualitatively, in the eight Christchurch streams he studied and recommended the addition of wood to streams to improve retention of leaves. However, our observations on the Okeover indicate there is a fine balance between too little and too much leaf litter, especially where flows are low as in the headwaters and wetlands reaches. Extensive growths of moss and more recently, filamentous algae, throughout the stream may also reduce the quality and amount of habitat available to invertebrates, and deserves attention. Overall, the low gradient and low discharge of the stream limit the opportunity for flushing and removal of excessive organic material and fine sediment, and consequently the interstices between and beneath stones where many larger insects and snails live, remain blocked. A lack of flushing flows and a consequently heavy build up of leaf litter was particularly evident in 2005 when the fauna was more impoverished than in any of the previous five years.

Lastly, the effective establishment of aquatic insects requires a source of colonists, suitable oviposition sites and appropriate habitat for all life history stages. The Avon River system in general provides a potential source of colonists, although its fauna includes few "desirable" species such as caddisflies and mayflies (Robb 1992; Blakely 2003; McMurtrie & Taylor 2003). Also, recent research indicates that roads and culverts may act as barriers to upstream movement and colonization of headwater tributaries like the Okeover by the aerial adults of aquatic insects. Thus, Blakely *et al.* (2006) found that the number of caddisflies trapped upstream of culverts on the Avon River and Okeover Stream was substantially lower than the number trapped downstream and that catches declined beyond each successive road in an upstream direction. Barriers to flight cannot explain the low abundance in the Okeover of non-insect taxa such as snails and worms, however. The snail *Potamopyrgus antipodarum* in particular, is regarded as a strong colonist of slightly enriched and degraded streams (Schreiber *et al.* 2003), and both fine sediments and high concentrations of organic matter provide ideal habitat for most aquatic oligochaetes (Marshall 1974). Therefore, despite water quality being generally good in the Okeover, pulses of deleterious chemicals in stormwater inputs, and/or the occurrence of heavy metals in bed sediments (Blakely & Harding 2005) may be preventing the establishment of snail and worm populations. Indeed, Walsh *et al.* (2005) concluded that stormwater runoff was the primary factor having a major impact on urban stream ecosystems.

There is now general agreement that the re-establishment of natural flow regimes demands particular attention if restoration of biological communities is to have a chance of success (Boon *et al.* 2002; Booth 2005). Thus, habitat restoration on its own is not enough to ensure that organisms will recolonise, especially if factors that undermine ecological condition remain active in the stream's catchment (Bond & Lake 2003). A realistic expectation for the Okeover might be to achieve an increase in size of the populations of species already there, rather than an increase in species richness, or a change in species composition, given the limited pool of potential colonists available.

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Appendix I. The invertebrate fauna of Okeover Stream, 2000-2005, and their MCI scores. Median coded abundances (see Table 2) across all sites are shown for all taxa. R = rare, C = common, A = abundant, VA = very abundant, VVA = very very abundant.

Taxa	MCI	2000	2001	2002	2003	2004	2005
Odonata							
Xanthocnemis zealandica	5	R			R		
Ephemeroptera							
Deleatidium sp.	8			R			
Trichoptera							
Hydrobiosis parumbripennis	5			R	R		R
Polyplectropus puerilis	8				R		
Oxyethira albiceps	2		R			R	
Pycnocentria evecta	7	R	R	R	R	R	
Pycnocentrodes aureola	5	R	R	R	R	R	
Hudsonema amabile	6					R	
Triplectides obsoletus	5			R			
Coleoptera							
Liodessus plicatus	5	R	R	R	R	R	
Antiporus sp.	6	R					
Diptera							
Tanypodinae	5	R				R	
Orthocladiinae	2	R	R	R	C	R	C
Chironomus zealandicus	1	R					
Paradixa sp.	4				R		
Mischoderus sp.	4		R		R		R
Paralimnophila sp.	6					R	
Austrosimulium sp.	3	R	R	R	R	R	R
Culex pervigilans	3	R					
Empididae	3	R					
Collembola	6				R		
Acarina	5	C	R	R	R	R	R
Crustacea							
Ostracoda	3	R	R	R	R	R	R
Copepoda	5	C	R	R	R	R	R
Paracalliope fluviatilis	5	VA	VA	VA	VVA	VA	VA
Mollusca							
Musculium novaezelandiae	3	R	R	R	R	R	R
Potamopyrgus antipodarum	4		C	R	R	R	R
Physella acuta	3	R	R	R	R	R	R
Oligochaeta	1	A	R	C	A	R	A
Tricladida							
Cura pinguis	2	R	R	C	R	R	R
Total MCI taxa		19	16	17	20	18	13