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Functional assessment of the effects of increased sediment loads resulting from riparian-zone modification of a Hong Kong stream

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Introduction

A general problem arises in assessing anthropogenic impacts on communities: should structural data (population densities, species richness, etc.) or functional parameters (e.g. productivity, energy flow, nutrient cycling) be used to measure impact? Which will be most appropriate, and provide the most sensitive 'early warning' of environmental degradation, depends upon the relationship between community structure and function. This relationship can take three forms. Firstly, community structure and function may be interlinked intimately; change one and the other changes too. Alternatively, there may be functional redundancy among species (periphytic algae, for instance), so that a change in structure may not affect functional parameters (such as primary productivity). A third possibility is that community function is altered (by 'stress') before species are lost, so that function changes before structure alters.

This paper documents the effects of increased suspended sediment loads resulting from riparian-zone clearance along a Hong Kong stream. The impacts on zoobenthos community structure and leaf-litter breakdown by invertebrates – an important functional parameter in stream ecosystems (CUFFNEY et al. 1990) which is relatively easy to measure – were assessed by comparing an impacted and an unimpacted stream reach. The assessment was supplemented by an inter-site transfer experiment designed to show whether conditions at the impacted site caused rapid changes in zoobenthos communities.

Materials and methods

Research was undertaken in a tributary of the Lam Tsuen River near Pak Ngau Shek, New Territories, Hong Kong. DUDGEON (1984, 1991 and references therein) has described the hydrobiology of the river, including a site immediately adjacent to the study area. Two reaches 690 m apart were investigated. The upstream site drained secondary forest; riparian vegetation around the downstream site comprised trees also, but immediately upstream the vegetation was cleared and the banks cut during river channelization associated with road construction. As a result, soil and earth entered the river and suspended-solid (SS) loads increased at the downstream site. Preliminary channelization work began in late January 1991, and extensive vegetation clearance and bank cutting commenced in April 1991. Preimpact data on zoobenthos were available from the downstream site only, but post-impact data (February–July 1991) on zoobenthos, stream sediments and SS loads have been obtained for both sites. Water chemistry at both sites was similar in 1991; conductivity was 76 (range 46–112) micromhos $\cdot$ cm^{-1} at the upstream site and 83 (range 62–118) downstream.

Total SS loads were monitored by filtering known volumes of stream water (4 replicates at each site; 15 site visits) through pre-ashed Whatman GF/F filters. Suspended organic (SOM) load was calculated from weight loss after ignition in a muffle furnace. Interstitial sediments were sampled using 300 ml cores (5 replicates at each site) on 20 May 1991. Samples were oven dried, sieved into three fractions (> 2 mm, 250 μm–2 mm, and < 250 μm), and weighed. The organic-matter content of the < 250 μm fraction was obtained from weight loss after ignition. Zoobenthos composition and abundance were estimated in July 1990 and 1991 using Hester-Dendy multiplate samplers (MPS; surface area 0.13 m^2). Six replicates were taken at each site, and the colonization period was 4 weeks.

On 2 July 1991, 30 *Bauhinia variegata* (Caesalpiniaceae) leaf packs were placed in the stream at each site. Each pack comprised a known dry weight (approximately 5 g) of leaves. Packs were tagged and tethered to steel stakes driven into the stream bed. At each site, 8 packs were retrieved after 7 days, 10 after 11 days, and 8 after 16 days. Litter breakdown was estimated from rates of AFDW loss; invertebrate densities were expressed as numbers per g dry weight of litter, and species richness as taxa per leaf pack.

To determine whether conditions at the impacted site caused rapid changes in zoobenthos densities, 20 MPSs were placed at the upstream site for a 4-week colonization period. On 12 March 1991, each MPS was enclosed in a 220 μm mesh net and removed from the stream. MPSs and associated animals were transported in steam water to the impacted site where 10 were placed on the stream bed. The remaining 10 MPSs (a procedural control) were returned to the upstream site. All 20 MPSs

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Table 1. Comparison of interstitial sediments (percent by weight) at two sites on Lam Tsuen River. ANOVA undertaken on arcsine-transformed data (** $P < 0.01$; *** $P < 0.001$).

	Unimpacted site	Impacted site	ANOVA
>2 mm	93.5±2.1	82.2±1.6	**
250 μm–2 mm	6.2±2.1	16.6±1.7	**
<250 μm	0.3±0.1	1.2±0.3	**
% organic matter	11.4±0.9	6.6±0.6	***

were recovered 24 hours later and the fauna enumerated.

Results

SS loads differed greatly at the two sites following impact, and mean (± SEM) values were almost 20 times greater downstream: 5.3 ± 0.8 versus 102.6 ± 35.9 mg · l^{-1}. SOM loads showed a similar trend (2.8 ± 0.5 versus 16.3 ± 6.2 mg · l^{-1}). These differences influenced interstitial sediment characteristics (Table 1), with more fine inorganic particles, and a lower proportion of organic matter in the < 250 μm fraction, at the impacted site.

Fifty-two zoobenthic taxa colonized MPSs at the downstream site in July 1990 (before impact) compared with only 24 taxa after impact in July 1991; at that time, however, 51 taxa were recorded from MPSs at the upstream (unimpacted) site where community structure resembled that downstream in 1990. Of the total of 65 taxa colonizing MPSs (all samples and dates combined), 16 were Ephemeroptera. ANOVA revealed significant differences between sites with respect to the abundance of mayfly families, total taxa, and total numbers of colonizers (Table 2). In all but one instance, densities were lowest at the impacted site (i.e. downstream, July 1991). The exception was Caenidae which are morphologically-adapted to inhabit fine sediments and were most numerous at the polluted site.

Litter weight loss increased the longer the leaves remained in the stream (2-way ANOVA on arcsine-transformed data, $P < 0.001$) regardless of site (Table 3), but breakdown was significantly slower downstream ($P < 0.001$); the ANOVA interaction term (site x time) was insignificant. More macroinvertebrate individuals and taxa colonized leaf packs at the unimpacted site where shredders – mainly the atyid shrimp *Neocaridina serrata* and the thiarid snail *Brotia hainanensis* – were relatively abundant (Table 4). The importance of invertebrates in litter breakdown is underscored by significant regressions of log densities/g litter against % AFDW lost (arcsine-transformed) for total individuals ($r = 0.42$, $P < 0.05$), *Brotia hainanensis* ($r = 0.55$, $P < 0.05$), *Neocaridina serrata* ($r = 0.61$, $P < 0.01$), and total shredders ($r = 0.41$, $P < 0.05$). However, such regressions were significant at the unimpacted site only.

MPSs transferred to the impacted site yielded fewer taxa (mean ± SEM = 9.9 ± 0.5 versus 17.5

Table 2. Inter-site differences in zoobenthos colonization of multiplate samplers: upstream unimpacted (U); downstream pre-impact (B); downstream post-impact (L). ANOVA undertaken on log-transformed data ($n/0.13\,m^2$); site contrasts based on SNK tests where $P < 0.05$ (*** $P < 0.001$).

	ANOVA	Site contrasts
Total individuals	***	U = B > L
Total taxa	***	U > B > L
Baetidae	***	B > U > L
Heptageniidae	***	U = B > L
Ephemerellidae	***	U > B > L
Leptophlebiidae	***	B > U > L
Caenidae	***	L > B > U

Table 3. Inter-site comparison of *Bauhinia variegata* litter breakdown: AFDW lost (mean ± SEM).

	7 days	11 days	16 days
Upstream	69.9±5.9	92.2±5.6	96.7±1.7
Downstream	56.0±9.0	78.1±5.2	95.0±1.9

Table 4. Inter-site comparison of invertebrates colonizing leaf packs (U, unimpacted site; L, impacted site). Two-way ANOVA undertaken on log-transformed data (* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$).

	Site	Time	S × T	Site contrasts
Total taxa (per leaf pack)	***	***	***	U > L
Total individuals (per g litter)	***	n.s.	n.s.	U > L
Brotia hainanensis	***	*	n.s.	U > L
Neocaridina serrata	**	*	n.s.	U > L
Total shredders	***	*	n.s.	U > L

± 1.4/0.13 m^2) and fewer individuals (49.5 ± 4.2 versus 108.0 ± 10.6/0.13 m^2) than MPSs in the procedural control group upstream ($P < 0.001$; ANOVA on log-transformed data).

Discussion

Before-and-after comparisons at the impacted site, and post-impact comparisons of impacted and unimpacted sites, showed that reductions in zoobenthos densities and diversity were related to changes in stream sediments and increased SS loads. This is in general agreement with the results of similar studies elsewhere (e.g. LLOYD et al. 1987, CAMPBELL & DOEG 1989, RYAN 1991). Rapid reductions in density and diversity occurred when macroinvertebrates were transferred to the impacted site, providing strong support for the detrimental effects of high SS loads. Immediate reductions in density of this type have been attributed to catastrophic drift caused by saltating sediments (CULP et al. 1986).

Functional changes were coupled with alterations in community structure, because litter breakdown rates were correlated with macroinvertebrate abundance – especially shredders – and were slower at the impacted site where zoobenthos densities were low. STOUT & COLBURN (1989) recorded similar findings in a Tennessee stream affected by highway construction. Apparently there is a close link between structural and functional attributes of stream communities.

Litter breakdown rates can be measured conveniently and, in the present study, results were obtained after less than 3 weeks. HORTON & BROWN (1991) report comparable breakdown rates in a North American stream. Leaf-pack samples take less laboratory and field time to process than conventional zoobenthos samples, and thus provide a cost-effective means of monitoring environmental change (BRUNS et al. 1992). Indeed, MERRITT et al. (1979) and WEBSTER & BENFIELD (1986) have suggested that litter breakdown can be used as a bioassay of human impacts on streams. Functional data of this type complement and may even replace community structural data as a means of assessing enthropogenic impacts, because measurement of structure is an instantaneous 'snapshot' assessment upon every visit to the stream, whereas function is cumulative over the same period and therefore permits continuous monitoring of ecosystem parameters (DUDGEON 1991). The cumulative nature of functional measures make them especially valuable for environmental impact assessment.

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