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The impact of agricultural runoff on stream benthos in Hong Kong, China

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Abstract

We investigated three small streams in the New Territories of Hong Kong, China. In each stream, we compared the benthic macroinvertebrate fauna of one site immediately upstream of an area of agricultural land (market gardening) with a second site immediately downstream. Each pair of sites was <300 m apart. Samples were taken at the end of the dry season (March 2000) and again (April 2000) just after heavy rainfall had caused runoff from the fields. The total number of taxa at the downstream sites was the same as that in the upstream sites in March. In April, the total taxon richness was lower at the downstream localities although this difference was statistically significant in only one stream. The acute toxic effect of runoff became clearer when focusing on the group of sensitive benthic fauna. The grouping was done by ranking the relatively physiological tolerance to organotoxins following the relevant literature (Bull. Environ. Contam. Toxicol. 67 (2001) 360). All streams showed a significant downstream decrease in the number of sensitive taxa in April, while in two of three streams the number of relatively tolerant taxa increased. Ordination (by n-MDS) confirmed this pattern. It revealed a marked temporal trend in all streams resulting from a decrease of sensitive taxa downstream that was not apparent at the upstream sites. The size of the observed effects varied among streams, and may have reflected differences in the composition of the agricultural runoff.

Keywords: Stream; Benthic macroinvertebrates; Agricultural runoff; Sensitive taxa; Organotoxins; Hong Kong; China

1. Introduction

Runoff from agricultural fields introduces soil, organic matter, manure, fertiliser and pesticides into small streams, increasing the volume of stream discharge and changing water quality. Cooper [1] has reviewed the acute toxic and sublethal chronic effects of such runoff, and has identified pesticides as one of the major stressors of aquatic communities. The New Territories (or northern, mainland portion) of Hong Kong, China (lat. 22°N), provides an opportunity to study the effect of agriculture runoff on the aquatic fauna of small streams in the monsoonal tropics. Crops are mainly high-value vegetables and flowers and are sprayed with a range of pesticides and fertilisers. Because land is at a premium in Hong Kong, fields are cultivated up to the stream margins where agriculture is practised. However, because of competition with farmers in mainland China, much agricultural land in Hong Kong has been abandoned in recent years [2]. Active and abandoned agricultural land is generally situated in portions of drainage basins that do not receive industrial effluents and where, because of recent controls on livestock rearing (see [3]), animal waste is unlikely to confound attempts to measure the impact of agriculture on the stream community. In this study, we investigated the effects of runoff from agricultural fields by comparing the benthic macroinvertebrate communities of paired

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sites upstream and downstream of farms along three streams. Communities were sampled once at the end of the dry season and again at the start of the wet season when the streams received runoff after heavy rainfall. Our null hypothesis was that the magnitude of the difference between the upstream and downstream pairs of sites would remain unchanged between sampling dates. We anticipated that any difference arising in the data set would manifest during the wet season, when lower densities or species richness of macroinvertebrates might occur downstream of farmland.

2. Materials and methods

2.1. Study area

We sampled three small streams that drain low hills covered with secondary forest and flow through areas of intensive cultivation of vegetables and flowers. Stream A is located near the village Man Uk Pin on the western side of the Sha Tau Kok Road, north-eastern New Territories. It drains into the Ng Tung Ho stream. Stream B flows from the eastern side of the same road and is located near the village of Loi Tung. Stream C is situated close to the village of Tai Wo on the eastern side of the Tai Po Road in the northern-central part of the New Territories.

All sampling sites were unshaded and situated at low altitudes (<60 m asl). They were low gradient (<1%) streams with substrate of mixed sand and cobbles, and a discharge between 0.1 and 0.25 m s^{-1}. Water depths varied between 8 and 20 cm and the width of the wetted channel ranged from 40 to 100 cm. Hong Kong streams are generally slightly acidic with soft water and few dissolved minerals (aside from silicates), reflecting the igneous geology of the territory (for details see [4,2]). Water samples taken at upstream and downstream sites in March and April revealed that all three streams were well oxygenated ($\geqslant$6 mg l^{-1}) and circum-neutral (pH 6.1–7.2) with low conductivity (560–790 μS cm^{-1}), low Nitrate ($\leqslant$0.9 mg l^{-1}) and some phosphate enrichment ($\leqslant$0.3 mg l^{-1}). The range of values is in line with those reported from unpolluted or slightly enriched streams in Hong Kong [4,3] and references therein.

In each stream an upstream site surrounded by abandoned fields was compared to a downstream section where there was active agriculture (Fig. 1). Apart from this difference, sites were selected to be similar in physical aspect, riparian features and substrate. To minimise the confounding effects of longitudinal variation, the upstream and the downstream sample point were not more than 300 m apart. No point-sources of pollution were evident within the study reaches. We sampled both sampling sites in all three streams twice: on March 14th 2000 and April 8th 2000. Hong Kong receives an annual rainfall of 2214 mm. However, the first sample date corresponded to the end of the dry season when rain was infrequent. Indeed, total rainfall from February 1st to March 31st was only 70 mm (Fig. 2). The second sample was taken a few days after heavy rainfall (169 mm within 48 h: Fig. 2) and consequent surface runoff.

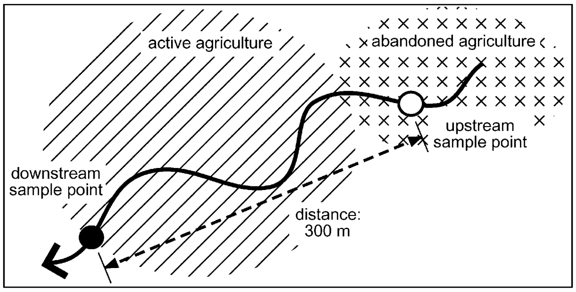

Fig. 1. Schematic diagram of the sampling strategy in all three streams.

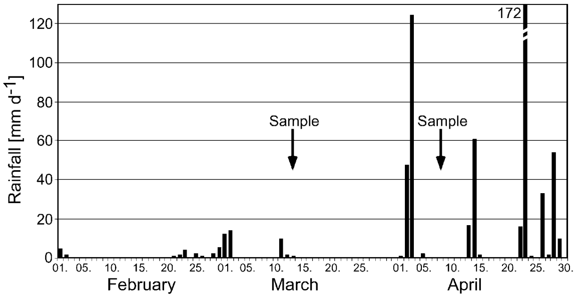

Fig. 2. Daily rainfall recorded at the Hong Kong Observatory between February and April 2000 (http://www. info.gov.hk/hko/). The sampling dates are indicated.

2.2. Sampling and data analysis

Three replicate benthic samples were taken at each site on each date. Samples were equal effort (1 min) kick, samples were taken with a 500 μm, D-frame net and preserved in 70% ethanol. Samples were sorted to species or morphospecies and counted.

Independent *t*-tests for equality of means (SPSS 10.0) were used to analyse differences in taxon richness and abundance of individual taxa between upstream and downstream sites on each sample date. The normal distribution of the data was confirmed by performing Kolmogorov–Smirnov tests. The equality of variances was checked by Levene's test and, where necessary, we performed *t*-tests appropriate for unequal variances. Analyses were carried out on taxon richness per sample, and numbers per sample of the abundant taxa *Baetis* spp. (Baetidae: Ephemeroptera) and *Brotia hainanensis* (Thiaridae: Gastropoda).

To obtain an overall picture of the community change in response to agricultural runoff we performed an ordination on the data set. Rare taxa, which are liable to random and uninterpretable variations in abundance, may distort or obscure underlying patterns in the data. Accordingly, we eliminated those taxa that were collected at 3 or fewer of the 12 sampling sites (i.e. 6 stream sites times two sampling occasions). Two-dimensional ordination by nonmetric Multidimensional Scaling (n-MDS; strictly, Kruskal's nonmetric procedure) was carried out on the data set using the *z*-score transformed abundance data and the Euclidean distance dissimilarity coefficient (SPSS 10.0). The optimal n-MDS solution minimises the metric space and is measured by the so-called "stress" [5]. Kenkel and Orloci [6] advocate n-MDS as the best strategy for ecological ordination, and Shepard [7] recommends the use of only two, or at most three dimensions in n-MDS. Accordingly, we restricted our analysis to two dimensions.

2.3. Relative physiological tolerances

Table 1 shows the relative physiological tolerance (T_{rel}) for each taxon and their relative abundance and frequency in benthic samples. The tolerances were derived according to the methods of Wogram and Liess [8], based on information from 2187 acute toxicity tests for 179 different organic substances derived from a total of 283 publications. The effect concentration was compared to that reported for *Daphnia magna* for the same toxicity test. The raw data were obtained from the database "aquire" of the Environmental Protection Agency (United States EPA, 2001). Wogram and Liess [8] calculated T_{rel} at the level of order only. To increase taxonomic penetration we calculated an independent T_{rel} for family. This was only done if there were more than 5 test results available within a family. For T_{rel} of order we used all available tests including those already used for family calculation. The number of available tests varied from 1 for Megaloptera to 726 for Diptera. Note that, based on the arithmetic mean score for all toxicity test, a positive T_{rel} means that the taxon is relatively more tolerant to organic substances than *Daphnia magna* (and vice versa).

For further data analysis in this paper we divided all taxa into two groups. Those with T_{rel} smaller 0.41 were grouped as "sensitive" taxa and those with $T_{\mathrm{rel}} > 0.40$ were treated as "tolerant" taxa. This boundary is, in some respects, rather arbitrary and a lack of data may lead to some taxa being misclassified as "tolerant" or "sensitive". For instance, although we had a T_{rel} value at the ordinal level for Coleoptera it was not possible to calculate one for individual families in this order. As a result, Elmidae and Hydrophilidae were grouped both as "tolerant" even though some elmids are sensitive to pollution [9], while Hydrophilids tend to be more tolerant and often occur in lentic habitats. Classification of other families matched our general ecological experience of their distribution in Hong Kong streams: for example, the Libellulidae was treated as "tolerant" whereas other Odonates were labelled "sensitive".

3. Results

The aquatic macroinvertebrate community at the study sites was quite diverse, supporting the impression gained from water-quality measurements that these streams were generally unpolluted by organic wastes. Diptera, Ephemeroptera, Odonata and Coleoptera larvae were dominant, while Plecoptera were absent as is typical of lowland streams in Hong Kong and much of tropical Asia [4,10].

There were only minor differences in the number of macroinvertebrate taxa collected in upstream Versus downstream sites in March (Fig. 3), although the number of taxa present in Stream C was over 50% higher than in streams A and B (which were rather similar in this respect). In April, the pattern in streams A

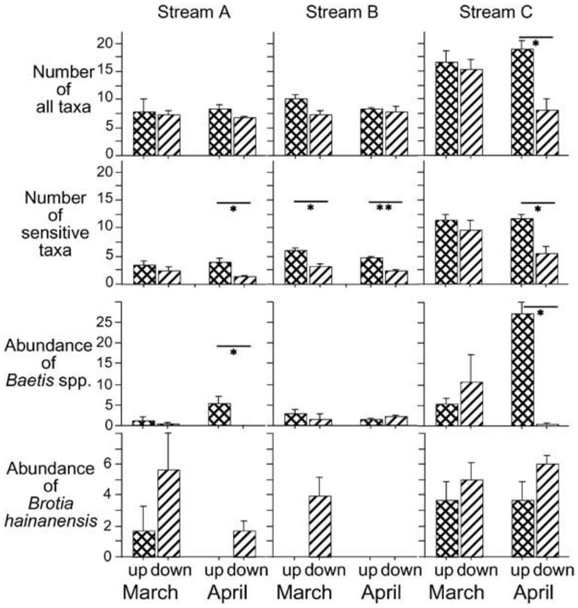

Fig. 3. Mean number ($n = 3$; $\pm$SE) of taxa in the upstream and the downstream sampling points on each of Streams A, B and C in March and April 2000. Abundance data for *Baetis* spp. and *Brotia hainanensis* are shown, as examples of (respectively) "sensitive" and "tolerant" species. Differences between upstream and downstream sites (independent *t*-tests) are indicated: $^*P<0.05$; $^{**}P<0.01$.

Table 1
List of all taxa with their relative abundance and the frequency of occurrence at sampling sites. The physiological tolerance (T_{rel}) of each taxon to organic substances, relative to *Daphnia magna* is given (for details see Wogram and Liess, 2001). Taxa with T_{rel} smaller than 0.41 were treated as "sensitive" taxa (S); the rest were classified as "tolerant" taxa (T)

Order taxon	Family	T_{rel} of order	T_{rel} of family	Sensitive or tolerant	Relative abundance in all samples combined (%)	Frequency of occurrence (n/12)
Turbellaria						
Dugesia sp.	Dugesiidae	(0.56)	**0.48**	*T*	5.7	5
Oligochaeta						
Naididae spp.	Naididae	**0.75**	n.a.	*T*	18.0	10
Hirudinea						
Helobdella sp.	Glossiphoniidae	**0.74**	n.a.	*T*	0.2	1
Eulamellibranchia						
Corbicula fluminea	Corbiculidae	(0.87)	**0.25**	*S*	1.2	2
Basommatophora						
Radix plicatulus	Lymnaeidae	(0.72)	**0.6**	*T*	0.7	4
Biomphalaria straminea	Planorbidae	(0.72)	**1.18**	*T*	3.3	9
Prosobranchia						
Pomacea lineata	Ampullariidae	**1**	n.a.	*T*	2.7	5
Brotia hainanensis	Thiaridae	**1**	n.a.	*T*	5.8	8
Decapoda						
Caridina cantonensis	Atyidae	**0**	n.a.	*T*	0.1	1
Coleoptera						
Elmidae sp.	Elmidae	**0.93**	n.a.	*T*	0.3	3
Eulichas sp.	Eulichadidae	**0.93**	n.a.	*T*	0.1	1
Hydrophilidae sp.	Hydrophilidae	**0.93**	n.a.	*T*	0.1	2
Lampyridae sp.	Lampyridae	**0.93**	n.a.	*T*	0.1	1
Eubrinax sp.	Psephenidae	**0.93**	n.a.	*T*	0.1	1
Diptera						
Chironomidae	Chironomidae	(0.33)	**0.23**	*S*	17.7	11
Simulium sp.	Simuliidae	(0.33)	**0.64**	*T*	1.1	5
Tipulidae sp.	Tipulidae	**0.33**	n.a.	*S*	0.7	7
Odonata						
Pyrrhosoma sp.	Coenagrionidae	(0.22)	**0.11**	*S*	0.54	3
Euphaea decorata	Euphaeidae	**0.22**	n.a.	*S*	0.5	4
Platycnemis sp.	Platycnemididae	**0.22**	n.a.	*S*	2.02	8
Sinictogomphus sp.	Gomphidae	**0.22**	n.a.	*S*	0.1	1
Brachythemis sp.	Libellulidae	(0.22)	**0.89**	*T*	1.8	9
Orthetrum sp.	Libellulidae	(0.22)	**0.89**	*T*	1.5	5
Zygonyx iris	Libellulidae	(0.22)	**0.89**	*T*	0.1	1
Ephemeroptera						
Alainites sp.	Baetidae	(−0.08)	**−0.23**	*S*	0.4	2
Baetis spp.	Baetidae	(−0.08)	**−0.23**	*S*	6.8	11
Liebebiella sp.	Baetidae	(−0.08)	**−0.23**	*S*	0.3	1
Caenis spp.	Caenidae	**−0.08**	n.a.	*S*	3.9	5
Serratella sp.	Ephemerellidae	**−0.08**	n.a.	*S*	2.0	3
Ephemera sp.	Ephemeridae	**−0.08**	n.a.	*S*	1.2	3
Cinygmina sp.	Heptageniidae	**−0.08**	n.a.	*S*	10.5	4
Choroterpes spp.	Leptophlebiidae	**−0.08**	n.a.	*S*	6.3	4
Isca purpurea	Leptophlebiidae	**−0.08**	n.a.	*S*	0.9	2
Paraleptophlebia sp.	Leptophlebiidae	**−0.08**	n.a.	*S*	0.4	1
Heteroptera						
Trephotomas sp.	Helotrephidae	**0.58**	n.a.	*T*	0.2	3
Megaloptera						
Neochauliodes sp.	Corydalidae	**0.93**	n.a.	*T*	0.2	4

Table 1 (*continued*)

Order taxon	Family	T_{rel} of order	T_{rel} of family	Sensitive or tolerant	Relative abundance in all samples combined (%)	Frequency of occurrence (n/12)
Trichoptera						
Cheumatopsyche spp.	Hydropsychidae	(0.15)	**0.35**	*S*	1.2	3
Goerodes doligung	Lepidostomatidae	**0.15**	n.a.	*S*	1.2	6
Psilotreta kwangtungensis	Odontoceridae	**0.15**	n.a.	*S*	0.1	1

and B was unchanged, but the number of taxa in the downstream site in Stream C fell to less than half that recorded upstream and at both sites in this during March. If we refine the analysis to take account only of the number of "sensitive" taxa, all three streams show a significant reduction in the number of taxa at the downstream site in April (Fig. 3). A similar reduction at the downstream site was seen in March along Stream B, but not along streams A or C. Analysis of the abundance of a sensitive taxon (*Baetis* spp.) revealed significant downstream declines in abundance in streams A and C in April but not in March (Fig. 3). There was no significant trend in abundance in Stream B. Comparing these data with the results for a "tolerant" species (*Brotia hainanensis*) is likely to be informative as they may indicate whether the reduced densities of *Baetis* spp. at the downstream sites are a result of agricultural runoff in April. As Fig. 3 shows, there was no significant downstream trend in abundance of *B. hainanensis* in either March or April.

To further assess the effect of agricultural runoff, we calculated the difference between the mean number of "sensitive" and "tolerant' taxa at the downstream and upstream sites on each stream on both sampling dates. Calculation of the percentage difference for each stream allowed comparison of the effect size among streams, notwithstanding any difference in taxonomic richness and benthic community structure. The number of "sensitive" taxa was always lower at the downstream sample point (Fig. 4) and was significantly greater during April in Stream A and Stream C (where the effect was particularly strong). By contrast, and with the exception of Stream C in April, the number of "tolerant" taxa was always higher at the downstream point. In streams A and B (especially the latter) the relative abundance of "tolerant" taxa increased in April.

The n-MDS analysis included the 19 most frequent taxa representing 79.4% of the total abundance of all macroinvertebrates. They comprised 9 "sensitive" and 10 "tolerant" taxa (see Table 1). The two-dimensional solution had a stress value of 0.126-i.e. it represented a good, useable summary of the sample relationships.

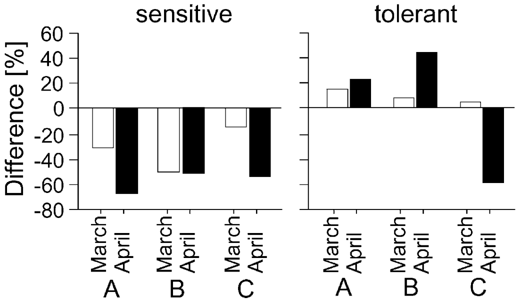

Fig. 4. Percentage difference between the mean number of taxa at upstream and downstream sampling points on each of Stream A, B and C. The data are presented separately for "sensitive" and "tolerant" taxa (see Table 2).

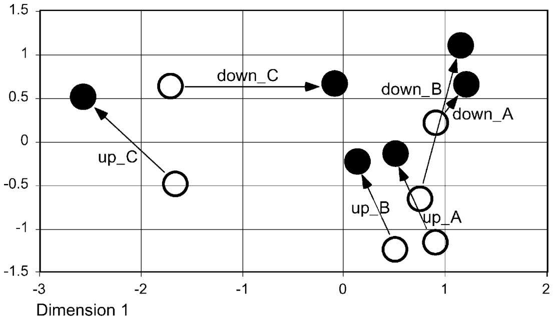

Fig. 5. N–MDS biplot of community composition at streams A, B and C in March and April (stress = 0.126). The open circles represent the March samples and the closed circles the April samples. Upstream and downstream sampling points on each of Stream A, B and C are indicated also.

Dimension 1 of the ordination plot (Fig. 5) appeared to represent the effect of agricultural runoff as upstream and downstream sample points on each stream were separated along this axis. Dimension 2 may have

Table 2
Taxa correlated with one of the two dimensions of the *n*-MDS ordination (Fig. 5). Only those taxa that satisfied the Kolmogorov-Smirnov test for normal distribution are given here. *S* or *T* indicates if a taxon was classified as "sensitive" or "tolerant"

		Dimension 1			Dimension 2		
Taxa		*R*	R^2	*p*	*R*	R^2	*p*
Oligochaeta							
Naididae spp.	*T*				−0.666	0.44	0.018
Basommatophora							
Log *Radix plicatulus*	*T*	−0.813	0.66	0.001			
Diptera							
Chironomidae	*S*				−0.798	0.64	0.002
Odonata							
Log *Euphaea decorata*	*S*	−0.820	0.67	0.001			
Log *Platycnemis* sp.	*S*	−0.623	0.39	0.030			
Log *Orthetrum* sp.	*T*				−0.596	0.35	0.041
Ephemeroptera							
Baetis spp.	*S*	−0.695	0.48	0.012			
Log *Caenis* spp.	*S*	−0.926	0.86	0.000			
Choroterpes spp.	*S*	−0.684	0.47	0.014			
Megaloptera							
Log *Neochauliodes* sp.	*T*	−0.764	0.58	0.004			

represented the difference between samples taken in March and April. All sample points (with the exception of the downstream site in Stream C) increased along Dimension 2 between March and April. This axis was negatively correlated with the abundance of Chironomidae, Naididae and *Orthetrum* sp. (Table 2) and thus the shift on the ordination plot was correlated with a decrease in these taxa.

Dimension 1 is the axis of particular interest here. All upstream sites shifted to the left of the plot between March and April, whereas all downstream sites moved to the right. Significantly, most of the macroinvertebrates correlated with Dimension 1 (Table 2) were "sensitive" taxa–especially among the Ephemeroptera and Odonata. Moreover, the three mayfly taxa listed in Table 2 constituted 17% of the total number of invertebrates collected during this study (see Table 1). A shift to the left of the ordination plot reflects an increase in these taxa. Note that the distance moved by the downstream sites is greatest for Stream C, which had the largest effect size (Fig. 4).

4. Discussion

Our investigation shows that agricultural runoff had a significant effect on the benthic community of three Hong Kong streams. This effect was evident from a comparison of upstream and downstream sites in the stream before and after heavy rainfall and consequent runoff from agricultural land, that impacted the downstream sites. Note that the comparison here was relative, not absolute, size of the effect. The size of the effect varied among the three streams but mainly influenced those taxa, particularly mayflies, that were relatively more sensitive to organic substances. This is evident from the large effect size noted in Stream C, which supported a relatively high proportion of sensitive species in March.

We were able to eliminate longitudinal variation in the streams as a confounding factor in this study, because the sample points were chosen close together. Furthermore, sites were matched with respect to features such as stream size, discharge, substrate characteristics and riparian vegetation. If there had been significant animal drift in the stream, it would have increased taxonomic richness and abundance at the downstream sites and could not, therefore, account for the decline in these parameters at the downstream sites affected by runoff. Insect emergence is also unlikely to have been a confounding factor as the two sites on each stream were in close proximity, and many of the taxa included present in the benthos were small, polyvoltine species with short life cycles year-round emergence in Hong Kong [4,2].

Runoff from agricultural fields in temperate latitudes is known to cause short-term changes in abiotic conditions in streams; in particular, increases in hydraulic stress [11] and suspended sediment loads [12]. Although these factors may cause reductions in benthic fauna, especially as a result of substrate displacement (e.g. [13,14]), it is unlikely that the magnitude of this effect would have varied systematically between the upstream and the downstream sites in the three study streams. Nor is it likely to have selectively targeted those taxa grouped as "sensitive" to organotoxins. Acid rainwater has little effect on the pH of Hong Kong streams during storm events [15] and seems unlikely to have significantly impacted the benthic fauna in this study.

Agricultural field runoff includes nutrients [16] and pesticides [17,18]. Both may degrade the water quality dramatically, but are present for only a few hours after heavy rainfall. To our knowledge, no instance in which nutrients cause short-term toxic effects has been reported in the literature. However, short-term contamination by pesticides has well-documented toxic effects on aquatic communities [1,19,20]. Schulz and Liess [21] provide an overview of field studies undertaken in temperate latitudes that establish a relationship between insecticide contamination and consequent effects on aquatic fauna. In this study, we were able to illustrate a similar effect in tropical streams by focusing on taxa that were "sensitive" to organic substances. Because the study streams did not receive industrial or urban discharges, the only organic substances that would have been introduced to the stream by rainfall were pesticides from the agricultural fields. Accordingly, we conclude that it was these substances that caused changes in the community composition at downstream sites following heavy rain. Differences in the concentration and type of pesticides used in different farms could be invoked to the variation in effect size among streams.

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References

[1] Cooper CM. Biological effects of agriculturally derived surface-water pollutants on aquatic systems—a review. J Environ Qual 1993;22:402–8.
[2] Dudgeon D, Corlett RT. Hills and streams: an ecology of Hong Kong. Hong Kong: Hong Kong University Press, 1994.
[3] Dudgeon D. Anthropogenic influences on Hong Kong streams. Geol J 1996;40:53–61.
[4] Dudgeon D. Pattern and processes in stream ecology: a synoptic review of Hong Kong running waters. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 1992.
[5] Kruskal JB. Multidimensional scaling by optimizing goodness of fit to a nonmetric hypothesis. Psychometrika 1964;29:1–27.
[6] Kenkel NC, Orloci L. Applying metric and nonmetric multidimensional scaling to ecological studies: some new results. Ecology 1986;67:919–28.
[7] Shepard RN. Representation of structure in similarity data: problems and prospects. Psychometrika 1974;39: 373–421.
[8] Wogram J, Liess M. Rank ordering of the sensitivity of macroinvertebrate species to toxic compounds, by comparison with that of *Daphnia magna*. Bull Environ Contam Toxicol 2001;67:360–7.
[9] Brown HP. Biology of riffle beetles. Ann Rev Entomol 1987;32:253–73.
[10] Dudgeon D. Tropical asian streams: zoobenthos, ecology and conservation. Hong Kong: Hong Kong University Press, 1999.
[11] Higler LWG, Repko FF. The effects of pollution in the drainage area of a Dutch lowland stream on fish and macroinvertebrates. Verh Inernat Verein Limnol 1981;21:1077–82.
[12] Kuhnle RA. Bed load transport during rising and falling stages on two small streams. Earth Surface Processes and Landforms 1992;17:191–7.
[13] Cobb DG, Flannagan JF. Trichoptera and substrate stability in the Ochre River, Manitoba. Hydrobiologia 1990;206:29–38.
[14] Statzner B. The relation between hydraulic stress and microdistribution of benthic macroinvertebrates in a lowland running water system, the Schierenseebrooks (North Germany). Arch Hydrobiol 1981;91:192–218.
[15] Peart MR. Acid rain, storm period chemistry and their potential impact on stream communities in Hong Kong. Chemosphere 2000;41:25–31.
[16] Cooper CM, Lipe WM. Water quality and agriculture: Mississipi experiences. J Soil Water Conserv 1992;47: 220–3.
[17] Schulz R, Hauschild M, Ebeling M, Nanko-Drees J, Wogram J, Liess M. A qualitative field method for monitoring pesticides in the edge-of-field runoff. Chemosphere 1998;36:3071–82.
[18] Wauchope RD. The pesticide content of surface water draining from agricultural fields—a review. J Environ Qual 1978;7:459–72.
[19] Heckman CW. Pesticide effects on aquatic habitats. Environ Sci Technol 1982;16:48A–57A.
[20] Liess M, Schulz R. Linking insecticide contamination and population response in an agricultural stream. Environ Toxicol Chem 1999;18:1948–55.
[21] Schulz R, Liess M. A field study of the effects of agriculturally derived insecticide input on stream macroinvertebrate dynamics. Aquat Toxicol 1999;46:155–76.