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Seasonal and long-term changes in the hydrobiology of the Lam Tsuen River, New Territories, Hong Kong, with special reference to benthic macroinvertebrate distribution and abundance

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With 38 figures and 6 tables in the text

Abstract

An investigation of the macrobenthos, hydrology and sediments of the Lam Tsuen River, New Territories, Hong Kong, was undertaken in November 1976 and at quarterly intervals during 1978–79. Between these two surveys there had been a considerable increase in settlement and agricultural activity in the river valley and this had a significant effect on river ecology. In 1976, there were signs of slight organic enrichment in the middle and lower course of the river but benthic communities were fairly diverse and showed gradual transition from the headwaters to the flood plain. The benthic communities did not fit neatly into the rithron-potamon scheme of river classification and it is doubtful that this classification can be applied at the generic or even familial level in the tropics.

In 1978–79 the river exhibited signs of considerable organic enrichment with all but the headwaters showing high nutrient, B.O.D.$_5$ and seston loading. This deterioration in water quality resulted from wash-off and discharge of farm wastes into the river as was clearly shown by examinations of seston composition at each sampling station. Seasonal changes in water quality were apparent, with "flushing" of the river by spates during the summer wet season leading to a reduction in enrichment; conversely, nutrient, B.O.D.$_5$ and organic seston loads were maximal in the dry season. Such changes affected sediment characteristics, with greatest downstream changes in physical parameters and levels of sedimentary organic matter occurring in the dry season.

Benthic faunal diversity was reduced in 1978–79 although the abundance of certain taxa was greatly enhanced by cultural eutrophication. Only the two upstream stations maintained faunal diversities equivalent to those seen in 1976; elsewhere the distribution of sensitive taxa was restricted and many previously widespread species were confined to the upper course. By contrast, some species tolerant of enrichment were able to increase in range and abundance as a result of the increased availability of food. Seasonal changes in water quality influenced the macrobenthos, with maximum community diversity in the river as a whole being attained at the end of the wet season after the river had been "flushed out" during periods of high discharge. In the dry season, water quality in the middle course of the river deteriorated and

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certain taxa were eliminated from these sites whilst others became more numerous. Evidently, the polluted zone of the river shifted up and downstream according to the incidence of seasonal rainfall in Hong Kong.

These observations were discussed with particular reference to the interactions of rivers and their valleys. It is concluded that changing conditions in the Lam Tsuen River were indicative of the transfer of materials (agricultural and domestic wastes) from the terrestrial to the aquatic components of the environment.

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Introduction

Hong Kong lacks any rivers which could, on a world scale, be considered as large. However the territory boasts a few smaller systems such as the Indus, Shum Chun, Lam Tsuen and Shatin Rivers, all of which are situated in the New Territories. Recent Hong Kong Government policy has involved decentralization of the urban population so that new towns have appeared in previously rural areas. A consequence has been increased rates of environmental deterioration in parts of the New Territories, and many rivers have become grossly polluted. Only one system, the Lam Tsuen River, has escaped the extreme effects of water pollution, but even in 1976 showed signs of enrichment of the lower course as a result of the input of agricultural wastes. Signs of deterioration since then are apparent, reflecting increased use of the river valley for intensive raising of pigs, ducks and chickens.

Studies of the longitudinal distribution of benthic animals in many world rivers indicate a trend towards faunal zonation, with differing communities occupying upland and floodplain reaches. An appreciation of such changes have led a number of workers to impose systems of faunal classification upon river zones, often based on the fish present in different parts of the habitat (Carpenter 1928a; Hawkes 1975). While such schemes may be of value in Europe (where many were formulated) they are of little use in the tropics and subtropics where the fauna, climate and geology are different. The division of rivers into rithron and potamon regions (Illies 1961; Bayly & Williams 1973), based largely on temperature, is of more general use but this classification is still subject to vagaries of local climate and relief (Hynes 1970) and may not apply equally to all rivers in a single country (Towns 1979). Indeed, there is little information in such a classification that could not be imparted by the use of the terms "lowland" or "flood plain" and "upland" or "highland" to describe the parts of a river system.

Various factors affect the longitudinal distribution of lotic macrobenthos. Temperature (e. g. Carpenter 1928b) and its interaction with current velocity (Zahar 1951; Philipson 1954, 1969; Philipson & Moorhouse 1976; Phillipson 1956; Edington 1965, 1968; Hildrew & Edington 1979; Boon 1979), as well as downstream changes in substrate composition (Bagge & Salmela 1978), are particularly important in this respect. Longitudinal zonation of river fauna has been investigated in many parts of the world including Central Africa (Hynes & Williams 1962), Southern Africa (Harrison 1958a, 1958b, 1965; Harrison & Elsworth 1958; Allanson 1961; Chutter 1963; Oliff 1963), Malaysia (Bishop 1973), Japan (Miyata 1976), New Zealand (Towns 1979), West Indies (Hynes 1971), the Antilles (Harrison & Rankin 1976), North America (Richardson 1928; Sprules 1947; Armitage 1961), Lapland (Ulfstrand 1968) and the United Kingdom (Maitland 1966; Wise 1976; Hildrew & Edington 1979).

The natural pattern of longitudinal distribution and community structure of lotic macrobenthos can be profoundly altered by the activities of man; the input of nutrients, sewage, silt, pesticides and industrial wastes can be particularly significant. The effects of sewage and wash-off from agricultural land lead to organic enrichment and do not usually involve the devastation of the aquatic biota associated with aquatic wastes and pesticides. However the extent of community alteration will be related to the degree of enrichment, faunal diversity decreasing with increasing nutrient input (Patrick et al. 1954; Patrick 1961; Cummins 1970; Minshall 1970; Wilhm 1970a, 1975).

The differential effects of pollutant type and concentration on benthic macroinvertebrates has led to the use of the latter as indices of water quality (Hart & Fuller 1974; Wilhm 1975; Bryce et al. 1978). These animals effectively integrate short and long term changes in the habitat and react to critical factors of short duration which would be undetected by a regularly timed sampling programme. In addition they are restricted in their movement from a newly polluted locality by their strict ecological requirements (e. g. Phillipson 1956; Cummins 1964; Cummins & Lauff 1969) and this lack of mobility increases ease of sampling. Many studies have included the use of species occurrence as a pollution index as it has long been thought possible to arrange the components of freshwater communities in a hierarchical fashion on the basis of their tolerance to a particular pollutant (e.g. Bick 1963). The use of indicator species requires a knowledge of short and long term pollution tolerances and ecological requirements of the taxa concerned; the incidence of a particular taxon indicating that pollution has not exceeded critical thresholds in its lifetime. As such detailed information is lacking for Asian species it would be unwise to apply this criterion as a means of pollution assessment without comparable information from ecologically similar habitats in the region. There are no such data for habitats comparable to the Lam Tsuen River in Hong Kong and in this case all that can be inferred from the absence of a particular species is that it does not occur there.

More promising approaches to the use of biological indicators of water quality include using the whole benthic community as the indicating unit (Wilhm & Dorris 1968). Pollution induced community changes are probably best described mathematically by the use of diversity indexes (e.g. Cairns et al. 1972; Cairns 1974; Denis & Patil 1977) which have been employed in a variety of freshwater biological investigations (Pesek & Hergenrader 1976; Bryce et al. 1978; Moore 1979; Slack et al. 1979; Towns 1979).

The present study was undertaken in order to obtain data on three main aspects of the Lam Tsuen River. Firstly, the course of the river was surveyed in 1976 when information on faunal zonation in the relatively unpolluted river was gathered. A second study was undertaken in 1978–79 to investigate seasonal variation in faunal succession in a river showing the visible effects of organic enrichment. Thirdly, it was hoped that data gained from the 1976 and 1978–79 surveys would indicate long term changes in the habitat. Additionally this investigation was intended to provide data comparable with world rivers as well as with other freshwaters in Hong Kong.

Study area

The Lam Tsuen River is about 9 km in length, running from southwest to northeast across central New Territories, Hong Kong, and drains an area of approximately 20 km^2. The mouth is located in the western, inner-most corner of Tolo Harbour on the eastern side of the New Territories, where the town of Tai Po is sited (Fig. 1). The river arises to the southwest of Tai Po, on the slopes of Tai Mo Shan and flows downhill through relatively undisturbed scrub and subsequently agricultural land until, approximately 2 km from its mouth, the course changes from a southwest-northeast to a northeast-southwest direction, the result of an old river capture. The geology of the upper and western sides of the Lam Tsuen Valley is dominated by the presence of pyroclastic rocks and associated lavas (Allen & Stephens 1971). The valley floor is largely alluvium while the lower eastern portion is made up of intrusive igneous rock dating from the Jurassic era referred to as Tai Po grandodorite.

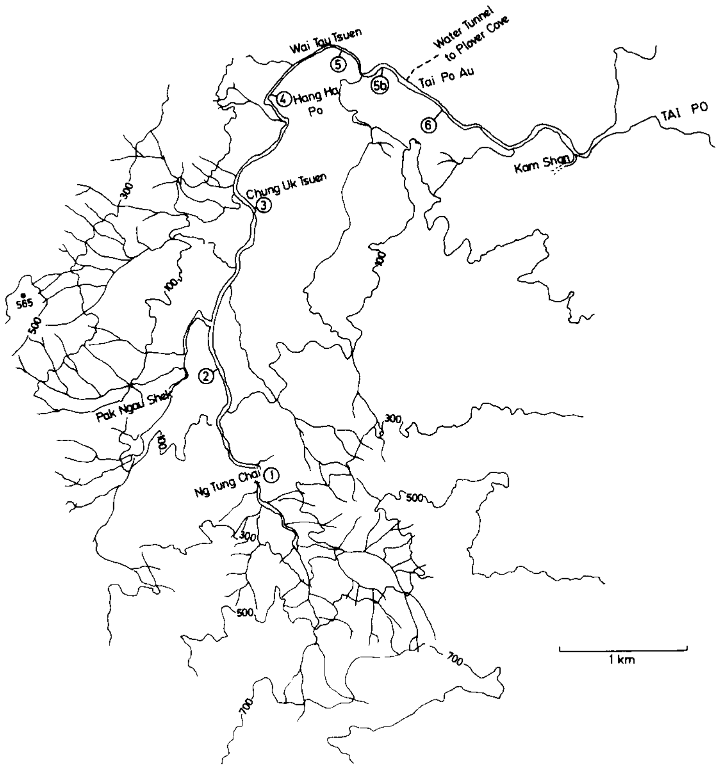


Fig. 1. Map of the Lam Tsuen Valley, New Territories, Hong Kong, showing the main river and its tributaries.

Six stations along the river were selected for study (Fig. 2). Station 1 was situated on the slopes of Tai Mo Shan at about 160 m altitude. The character of the river above this site did not change noticably until point T when it bifurcated into a number of small, intermittently flowing-tributaries. Access to the river beyond

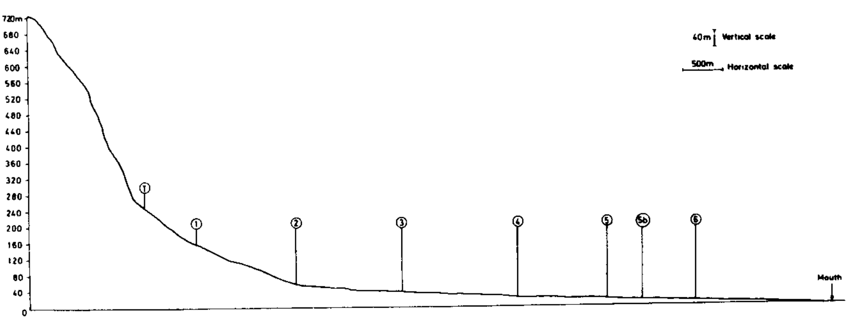


Fig. 2. Profile of the Lam Tsuen River showing the location of sampling stations 1–6. Site T marks the location of the uppermost permanently flowing section of the river.

Station 1 was extremely difficult. At this sampling site, the river bed was narrow (1–2.5 m) and the swiftly flowing water (0.9–1.6 m/sec.) was shallow (5–15 cm). The water was clean and clear and there was no overhanging vegetation. Amounts of allochthonous detritus in the river were very small. The floral composition of the surrounding scrubland was typical of many hillside catchment areas in Hong Kong (e.g. DUDGEON 1983a) where the earths are generally acidic podsols. Station 2, at an altitude of 80 m, was situated further down the valley and, like Station 1, had a bed of stones and boulders between which the frequently turbulent water flowed. The current was swift (>0.5 m/sec.), the water shallow (10–25 cm) and the bed quite narrow (2–4 m). Water is drawn from the river at this point for domestic consumption and irrigation of a few small-holdings. Although the water was clear, domestic rubbish and litter left by picnickers were sometimes present in the river. During the winter and spring, filamentous algae blanketed the stony sediments but there was very little allochthonous detritus present.

Beyond Station 2 intensive agriculture, including market gardening and the intensive raising of pigs, ducks and chickens, is practised in the valley. The habit of spreading animal manure on the fields is widespread although the use of synthetic fertilizers is increasing. A number of villages are situated along the course of the river and in recent years some of the duck farmers in the valley have fenced off portions of the river for use as a swimming area for their birds. The river also provides irrigation water, and serves as a convenient waste disposal unit for the residents of the valley.

At Station 3 the river bed was quite wide (5–10 m) but the water was generally shallow (10–30 cm, with a few pools over 1 m deep) and fast-flowing (0.4–0.8 m/sec.). The sediments comprised rocks and stones (but few boulders) and sand accumulated in areas of slack flow. The surrounding land was, with the exception of a few trees, cleared for agriculture which included market gardening and chicken rearing. A small pig farm was established at this site in 1978. Dead chickens, sweepings from chicken coops, pig faeces and litter were frequently seen in the river during 1978–79. Sewage fungus (*Sphaerotilus:* Chlamydobacteriales) was recorded in March 1979 and large accumulations of algae were always present on the river bed.

Station 4 was similar to Station 3 with a substrate of flat stones covered by filamentous algae. The water here was generally shallow (10–20 cm) and quite fast flowing (0.4–0.7 cm/sec.). River width varied between 7 and 12 m. In 1978 this section of the river was fenced off and used as a swimming space and run for a neighbouring duck farm. The ducks denuded the area of riparian vegetation and the region immediately downstream supported extensive growths of *Sphaerotilus.* During 1978–79 samples were taken about 100 m downstream from the duck enclosure where the water was rather grey and murky. At Station 5 the water was clearer and *Sphaerotilus* only present (in small amounts) in the dry season of 1979. The water was 20–40 cm deep and the current quite rapid (0.4–0.7 m/sec.). The sediments comprised rocks and stones set in a sand bed. Filamentous algae and *Hydrilla verticillatum* (L.) ROYLE (Hydrocharitaceae) were abundant and frequent accumulations of farm and domestic refuse were noted. Duck and pig raising was carried out in the vicinity and the riparian vegetation was reduced to a few trees.

In 1976 an intermediate site, Station 5b, between Stations 5 and 6 was investigated. Samples were taken slightly upstream of the Tai Po Au pumping Station (which is connected by underground pipeline to Plover Cove Reservoir) (Fig. 1). Here the river was slow flowing (0.1–0.3 m/sec.) and wide (15 m), and the shallow water (15–30 cm) was rather turbid. Despite this, extensive growths of *Hydrilla verticillatum* and filamentous algae were present. There was considerable evidence of organic pollution with domestic refuse, dead fowls and *Sphaerotilus* in abundance.

Station 6, the lowest site, was situated immediately upstream of a small weir which prevented any tidal influence from reaching the study area. The water was murky and approximately 30 cm deep (with areas >1 m in depth); flow was generally <20 cm/sec. The substrate of stones and rocks was covered with a layer of silt and clay. Aquatic plants were abundant at this site and on occasions the water surface was almost entirely obscured by growths of *Eichhornia crassipes* (MART.) SOLMS (Pontederiaceae). *Hydrilla verticillatum* and *Lemna minor* L. (Lemnaceae) were also abundant and *Ludwigia adscendens* (L.) HARA. (Onagraceae) grew near to the bank. The surrounding land was given over to market gardening and pig rearing. There were small quantities of refuse in the water.

Materials and methods

Samples were collected from each station on 25 November 1976, and at quarterly intervals over the year 1978–79: 30 June 1978, 20 September 1978, 27 December 1978 and 20 March 1979. Water and air temperatures were taken on each visit and water samples collected for laboratory analysis in 5 l, pre-washed, P.V.C. containers. Dissolved oxygen, pH and conductivity were determined with bench meters immediately upon return to the laboratory and all other analyses carried out within 24 hrs of sample collection. Total reactive phosphates were measured using the stannous chloride method (APHA 1971). Nitrite-nitrogen and nitrate-nitrogen were determined using a modified Griess-Ilosvay method (MACKERETH et al. 1978) with the reduction step achieved by using hydrazine sulphate in the presence of copper sulphate solution. B.O.D.$_5$ was determined by APHA standard methods and the quantities of organic and inorganic seston measured by passing known volumes of river water through Whatman GF/F filters, dry weighing, with ashing at 550°C followed by a second dry weighing. Details of these procedures are given elsewhere (DUDGEON 1981, 1982a). In order to characterize seston components, 10–25 ml of water from each site were passed through 0.8 µm milipore filters. These were dried, mounted and the area of each seston component (detritus, diatoms, inorganic material, etc.) calculated by measuring the size of these particles with the use of a graduated eyepiece at 600x magnification (MECOM & CUMMINS 1964).

Macrobenthos samples were collected in riffle areas at each station using a modified transect method. Details of the transect method are given elsewhere (DUDGEON 1979, 1982b).

A large triangular framed net (mesh size 200 μm) was placed in the river facing upstream with its flat edge buried in the sediments. All of the substratum within an area of 36.5 × 36.5 cm (which was the length of the lower edge of the net frame) was dug out down to bed rock and transferred to strong plastic bags or basins. Additionally, material washed into the net by the current was added to the sample. The procedure was repeated five times across a given reach, including two samples close to the bank, one in the centre, and two in intermediate positions. This method collected numerous macroinvertebrates and subsampling the chironomid component of the sample was frequently necessary. NEEDHAM & USINGER (1956) and CHUTTER & NOBLE (1966) have stated that three square foot samples, or sampling 0.3 m^2, of a stony riffle should be satisfactory for normal purposes. The area sampled at each site in the present investigation exceeded their recommendations and samples were considered to be representative of the benthic fauna. The use of a fine meshed net and the sampling of the hyporheal zone probably improved sampling accuracy.

After collection all samples from each station were pooled and preserved in 5% neutral formalin. Organic material was separated from inorganic sediments by elutriation and those taxa which did not float (large gastropods) were picked out by hand. Samples were sorted and macroinvertebrates counted at 15x magnification. In order to investigate variations in benthic macroinvertebrate community composition, the Shannon-Weiner diversity index was employed. This index measures the average rarity of the test community thus circumventing the need for ecologists to invoke "information theory" as a conceptual basis for the Shannon formula (DENNIS & PATIL 1977). WILHM & DORRIS (1968) and WILHM (1970a) have examined the performance of the index in various situations using the following relationship (which was that employed in the present study) to derive $\bar{d}$:

$$\bar{d} = -\sum_{1}^{s} (n_i/n) \log_2 (n_i/n)$$

where n_i equals the number of individuals in each taxon, n equals the total number of individuals and s is the total number of taxa. Except when low numbers of individuals are present, $\bar{d}$ is independent of sample size (WILHM 1970a). Moreover, a comparable range of diversity values are obtained for unpolluted streams in different localities, even when parity of sampling methodologies is not attained. "Clean" streams have a $\bar{d}$ value of between 3 and 4 but this is reduced if pollutants are present in the environment; in conditions of extreme pollution $\bar{d}$ may be less than 1 (WILHM 1970a, 1970b). $\bar{d}$ was calculated in this study using a modification of the computer program employed by CAIRNS & DICKSON (1971).

Sediment samples were collected using cores with 80 mm internal diameter. Approximately 1.5 kg of sediments were collected from each site on the subjective basis of taking samples which appeared to be representative of the habitat. Substrate analysis followed the procedure described by DUDGEON (1981, 1982c). All samples were oven dried, passed through a graded series of Wentworth sieves, and each fraction was weighed and ashed separately. Calculation of sediment statistics was undertaken according to the formulae of FOLK & WARD (1957) and FOLK (1966).

Results

A. Hydrology

Hydrological data for the Lam Tsuen River collected by the author in November 1976 are shown in Table 1. Table 2 shows additional hydrological data gathered from a variety of sources. Figures for Station 6 were kindly provided by Waterworks Office, Hong Kong Government, from their monitoring facility at the

Table 1. Water temperature, dissolved oxygen (mg/l) and pH at seven stations along the Lam Tsuen River on 25th November 1976.

station	water temperature	dissolved oxygen	pH
1	24.0	8.40	6.95
2	24.5	8.20	6.95
3	24.5	7.95	6.90
4	24.0	7.90	6.90
5	24.0	7.60	6.85
5b	24.5	7.50	6.80
6	24.5	5.10	6.80

Tai Po Au Pumping Station and are for the year ending March 1975. Data for Stations 2, 3 and 5b are from an unpublished M. Phil. thesis (1973) undertaken by H. Kan of the Botany Department, the University of Hong Kong. No data were available on nutrient loads at Stations 1 and 2 in 1976 but, as land use around these sites did not change between 1976 and 1978, it was assumed that the water quality remained fairly constant over the study period. The figures presented in Table 2 should be interpreted with caution as they do not represent the actual conditions in the river in 1976, but indicate what the water quality might have been like. They show a tendency towards increasing nutrient concentrations with greater distance from the river source. Dissolved oxygen showed a tendency to decrease downstream (Tables 1 and 2) and this is reflected to a lesser degree by pH. There was no obvious variation in water temperatures between upper and lower course sites (Table 1).

Table 2. Projected values for pH, dissolved oxygen, B.O.D.$_5$, nitrates, phosphates and silicates in water from a number of sites in the Lam Tsuen River during 1976.

site		pH	oxygen (mg/l)	B.O.D.$_5$ (mg/l)	NO_3 (mg/l)	PO_4 (mg/l)	silicates (mg/l)
LT 1	max.	7.00	10.00	1.19	0.21	0.23	–
	mean	6.93	8.90	0.80	0.95	0.14	–
	min.	6.90	8.25	0.40	0.04	0.04	–
LT 2	max.	7.65	11.00	8.00	4.00	0.10	8.20
	mean	7.12	9.20	4.07	1.00	0.05	7.00
	min.	6.55	8.00	1.65	0.02	0.03	4.00
LT 3	max.	7.40	11.00	21.50	10.50	0.93	8.80
	mean	6.94	8.80	8.39	5.10	0.50	7.20
	min.	6.40	6.80	5.50	3.00	0.20	4.80
LT 5b	max.	7.80	11.00	43.50	11.00	1.90	8.20
	mean	6.85	7.00	21.40	6.20	0.85	7.30
	min.	6.40	4.90	15.50	3.50	0.15	5.00
LT 6	max.	7.00	7.70	14.30	1.14	8.51	24.40
	mean	6.80	4.90	3.50	3.28	1.83	17.90
	min.	6.70	1.20	0.50	0.36	0.65	9.50

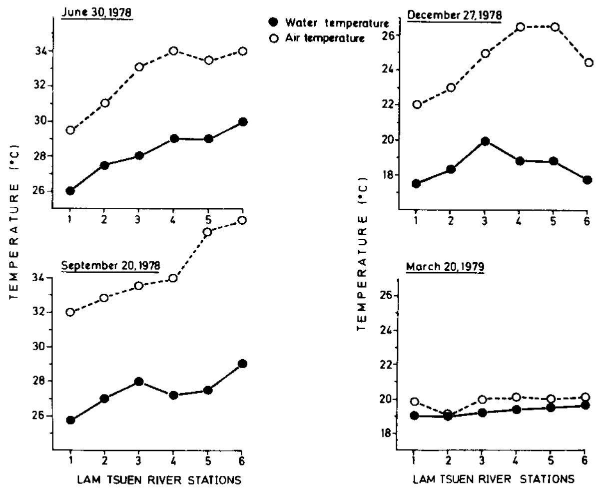


Fig. 3. Air and water temperatures at six sites along the Lam Tsuen River during 1978–79.

Knowledge of hydrological conditions prevailing in the Lam Tsuen River in 1978–79 is more substantial. In general, water temperature (Fig. 3) followed air temperature and increased downstream in June and September 1978. However, in December 1978 temperature peaked at Station 3, and in March 1979 water temperatures at all stations were almost equal. The maximum range from the headwaters to Station 6 was 3.5 °C. pH was always slightly acid to neutral and decreased downstream (Fig. 4) although the magnitude of the change never exceeded 0.25 pH units. Conductivity was generally lower in upstream sites and tended to increase with decreasing pH. The general pattern of downstream changes in pH and conductivity was unaffected by season.

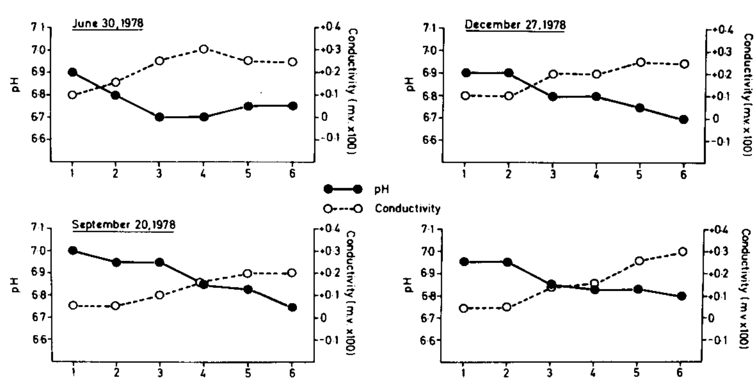


Fig. 4. pH and conductivity at six sites along the Lam Tsuen River during 1978–79.

Dissolved oxygen concentrations decreased in the lower course of the river, particularly between Stations 5 and 6. This general pattern showed no seasonal change although the magnitude of the downstream fall in concentration varied between 2.25 and 6.75 mg/l in June and December 1978 respectively (Fig. 5).

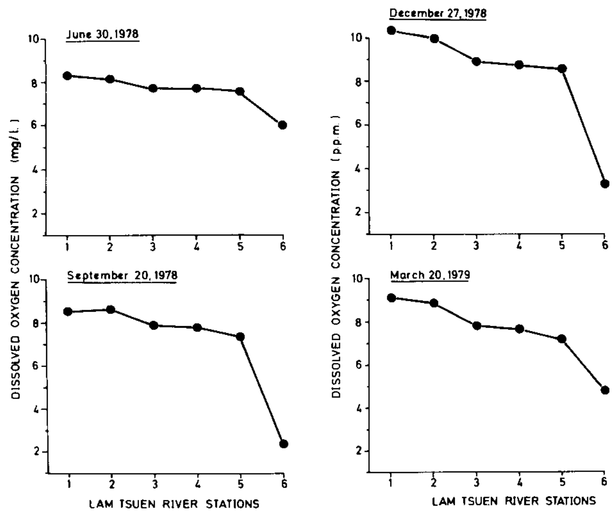


Fig. 5. Dissolved oxygen concentrations at six stations along the Lam Tsuen River during 1978–79.

Significant downstream changes in phosphates were also noted, concentrations in the lower course exceeding those in the headwaters by between 1.55 and 4.68 mg/l. On two occasions phosphate concentrations at Station 5 were lower than those recorded at Stations 4, but those at Station 6 were always highest. Of particular interest was the large concentration increase between Stations 2 and 3 in December 1978 and March 1979 (Fig. 6).

Both nitrate-nitrogen and nitrite-nitrogen concentrations increased in the middle and lower course of the river (Fig. 7). This was not a simple downstream increase and nitrate concentrations at Station 5 always exceeded those at Station 6; in March 1979 the highest levels were recorded at Station 4. A similar trend was apparent for nitrites excepting June 1978. The maximum and minimum downstream changes in nitrate concentrations (0.76 and 1.96 mg/l) were recorded in September and December 1978 respectively, and in nitrite concentrations (1.00 and 1.25 mg/l) in December and June 1978 respectively. In June and December 1978 the concentration of nitrates in river water was generally greater than that of nitrites; in September 1978 and March 1979 this trend was partially reversed although nitrates were always in excess of nitrites at the two upstream stations.

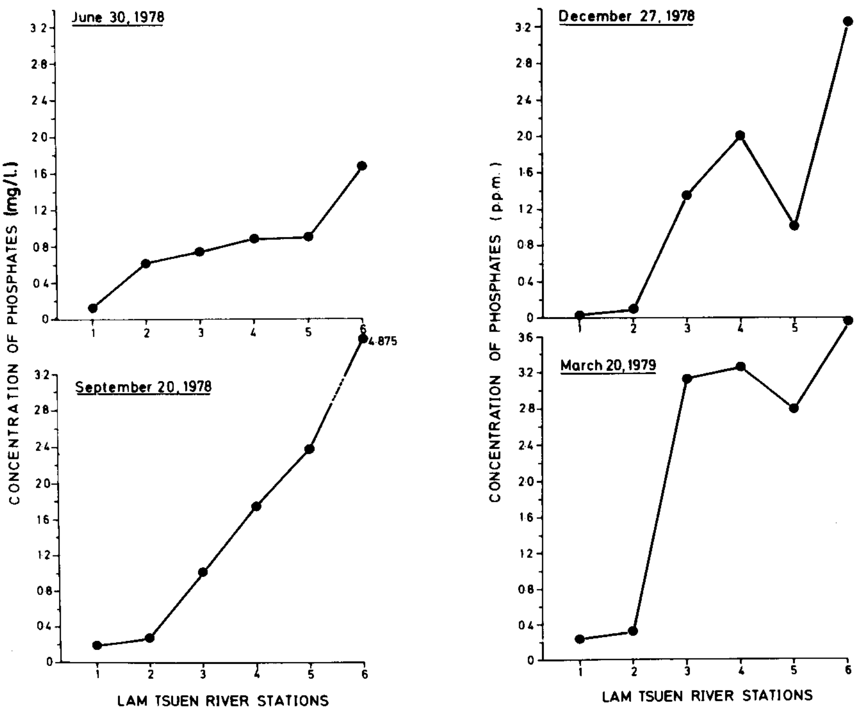


Fig. 6. Phosphate concentrations at six stations along the Lam Tsuen River during 1978–79.

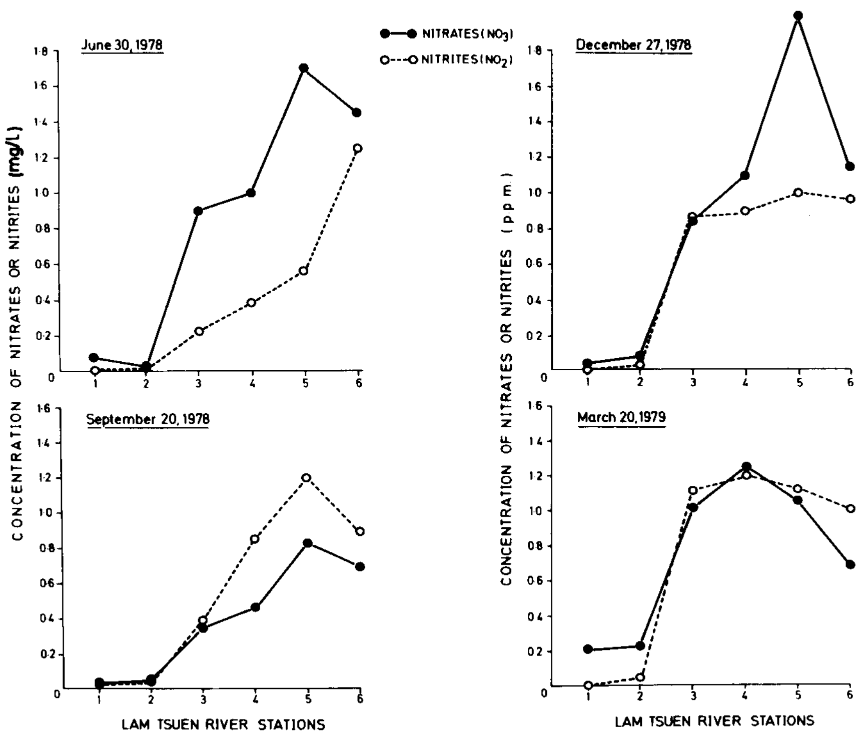


Fig. 7. Nitrate and nitrite concentrations at six stations along the Lam Tsuen River during 1978–79.

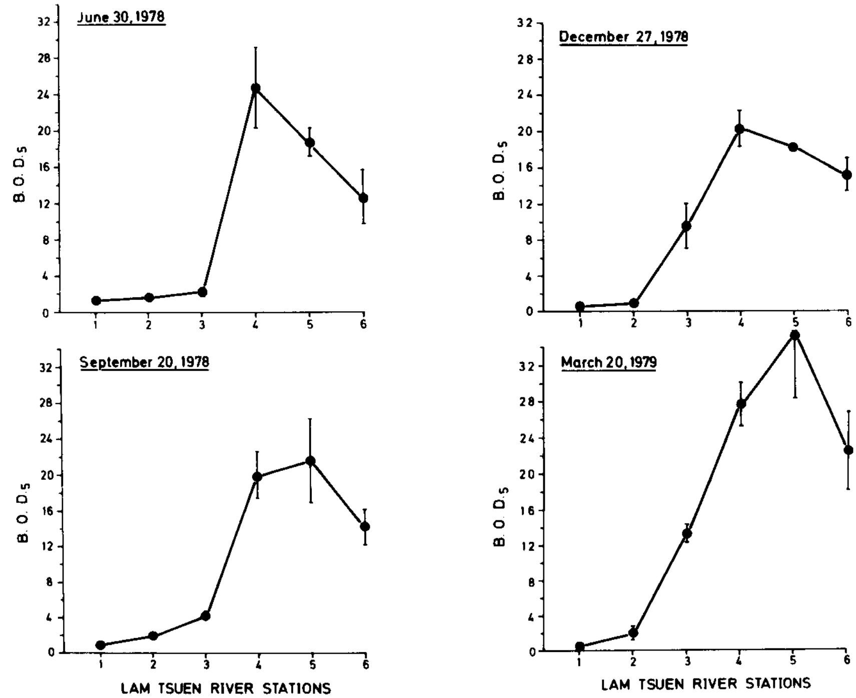


Fig. 8. 5-day B.O.D. ($\bar{x}$ and range of values) at six stations along the Lam Tsuen River during 1978–79.

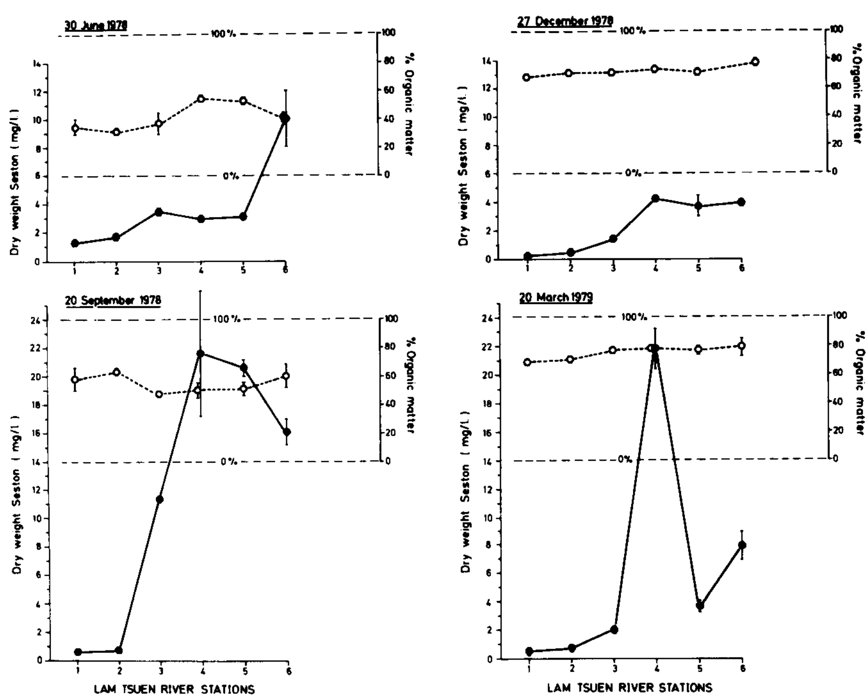


Fig. 9. The dry weight and % organic matter of seston at six sites along the Lam Tsuen River in 1978–79.

5-day B.O.D. values were generally low at Stations 1 and 2 and increased downstream (Fig. 8). Values were maximal at Station 4 in June and December 1978, and at Station 5 in September 1978 and March 1979. The highest downstream increase (35.02 mg/l) was recorded in March 1979, and the lowest (19.69 mg/l) in December 1978. $B.O.D._5$ values were generally higher in March 1979 than at any other time during the study.

Amounts of suspended material (seston) generally increased downstream but tended to show mid-course peaks in loading (Fig. 9). The maximum recorded load was 21.80 mg/l, 17.03 mg/l of which was organic matter. Seston levels were relatively low in June and December 1978, and higher in September 1978 and March 1979. The mean percentage of organic matter was, however, lower in June and September 1978 (41.75 ± 9.69 and $55.08 \pm 6.27\%$ respectively). Highest inorganic loads were recorded in September 1978 (mean for all stations = 5.65 mg/l) and the lowest in December 1978 ($\bar{x} = 0.65$ mg/l). Highest organic loads were recorded in September 1978 ($\bar{x} = 6.19$ mg/l) and the lowest in June ($\bar{x} = 1.64$ mg/l).

Seasonal changes in the hydrology of the six stations along the Lam Tsuen River are summarized in Table 3. They indicate a general tendency towards a greater range of values for most parameters with increasing distance from the head-waters. There are slight trends towards increased mean values for seston organic matter and conductivity, as well as a downstream decrease in pH.

In order to supplement information on seston organic content, the proportions of those components comprising the suspended load were measured and represented by frequency histograms (Figs. 10 and 11). Nine categories of material were enumerated: filamentous Chlorophyta, Bacillariophyceae, Cyanophyta, other algal unicells, terrestrial macrophyte detritus, aquatic macrophyte detritus, animal derived detritus (faeces, feathers, etc.), unidentifiable detritus (probably largely faeces and farmyard wastes), and inorganic material. In September 1978 and March 1979 samples were examined from all six stations but in June and December 1978 only samples from Stations 1 and 6 received detailed study. In general, significant quantities of inorganic material were only found at Station 1, although never amounting to more than 10% of the area of the total load. Also important at this site were diatoms and terrestrial macrophyte detritus (mainly riparian grasses) each comprising 20–35% of the seston. The remainder was largely unidentifiable detritus and this was generally the major category at Station 1.

Seston composition at Station 2 was very similar to that of the upstream site except in March 1979 when 40% of the load was filamentous Chlorophyta which was abundant on the sediments at this site during the spring. Similarly, filamentous chlorophytes were dominant at Station 3 in March 1979, but, in contrast to the upstream sites, diatoms and allochthonous macrophyte detritus were relatively unimportant and animal derived detritus was present. However, unidentified detritus was again the major seston component and here probably comprised farmyard refuse and washings. Similar material dominated the seston at Station 4

Table 3. Seasonal variations (1978–79) in the hydrology of six stations along the Lam Tsuen River.

stations		water temperature (°C)	dissolved oxygen (mg/l)	pH	conductivity (mV × 100)	phosphates (mg/l)	nitrites (mg/l)	nitrates (mg/l)	B.O.D. 5-day	seston (mg/l)	% seston organic matter
1	min.	17.50	8.25	6.90	0.05	0.040	0.000	0.040	0.40	0.15	28.57
	mean	22.06	8.96	6.94	0.08	0.149	0.018	0.095	0.80	0.65	57.57
	max.	26.00	10.05	7.00	0.10	0.230	0.035	0.212	1.45	1.40	70.45
2	min.	18.30	8.10	6.80	0.05	0.100	0.023	0.030	0.83	0.40	29.44
	mean	22.95	8.88	6.90	0.09	0.329	0.033	0.098	1.46	0.89	58.30
	max.	27.50	10.00	6.95	0.15	0.615	0.045	0.225	2.88	1.80	72.43
3	min.	19.20	7.70	6.70	0.10	0.740	0.225	0.345	2.70	1.60	29.73
	mean	23.80	8.08	6.83	0.18	1.559	0.649	0.776	7.84	4.73	58.12
	max.	28.00	8.90	6.95	0.25	3.125	1.120	1.020	14.35	11.60	78.44
4	min.	18.80	7.65	6.70	0.15	0.885	0.390	0.460	17.33	2.80	44.62
	mean	23.61	7.98	6.79	0.20	1.971	0.835	0.953	23.16	12.63	63.94
	max.	28.80	8.80	6.85	0.30	3.250	1.200	1.250	30.20	26.00	79.10
5	min.	18.80	7.20	6.75	0.20	0.900	0.565	0.825	17.00	2.93	50.17
	mean	23.70	7.68	6.79	0.24	1.769	0.973	1.294	23.53	7.76	63.08
	max.	29.90	8.60	6.83	0.25	2.800	1.200	2.000	42.60	21.20	80.00
6	min.	17.75	2.35	6.70	0.20	1.675	0.890	0.680	9.80	3.80	38.33
	mean	24.09	4.11	6.75	0.25	3.394	1.014	0.993	16.18	9.46	63.34
	max.	30.00	6.00	6.80	0.30	4.875	1.250	1.450	26.90	17.00	85.29

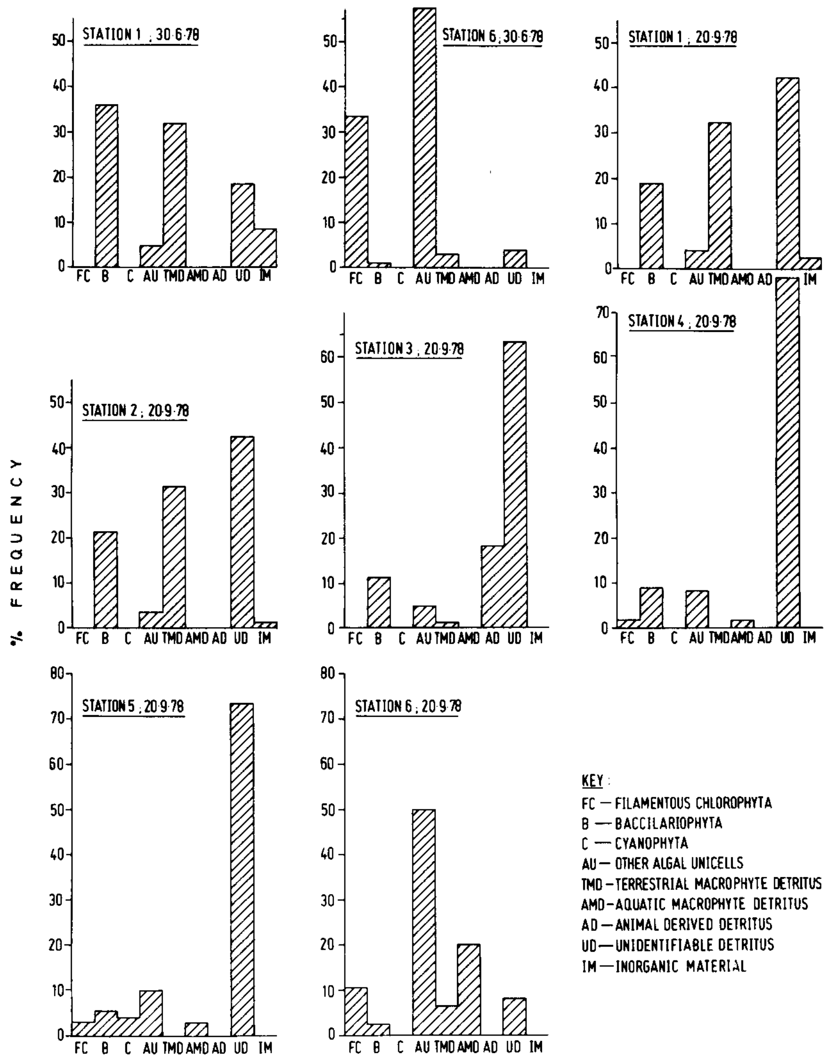


Fig. 10. Frequency histograms showing seston composition in the Lam Tsuen River on 30 June 1978 and 20 September 1978.

and in September 1978 the remaining suspended solids at this site were algae and small amounts of aquatic macrophyte detritus (probably *Hydrilla verticillatum*). In March 1979 this component was largely replaced by animal derived detritus although the unidentified detritus was still dominant.

Further downstream at Station 5 the quantities of filamentous algae in the seston increased, making up approximately 25% of the load in September 1978 and

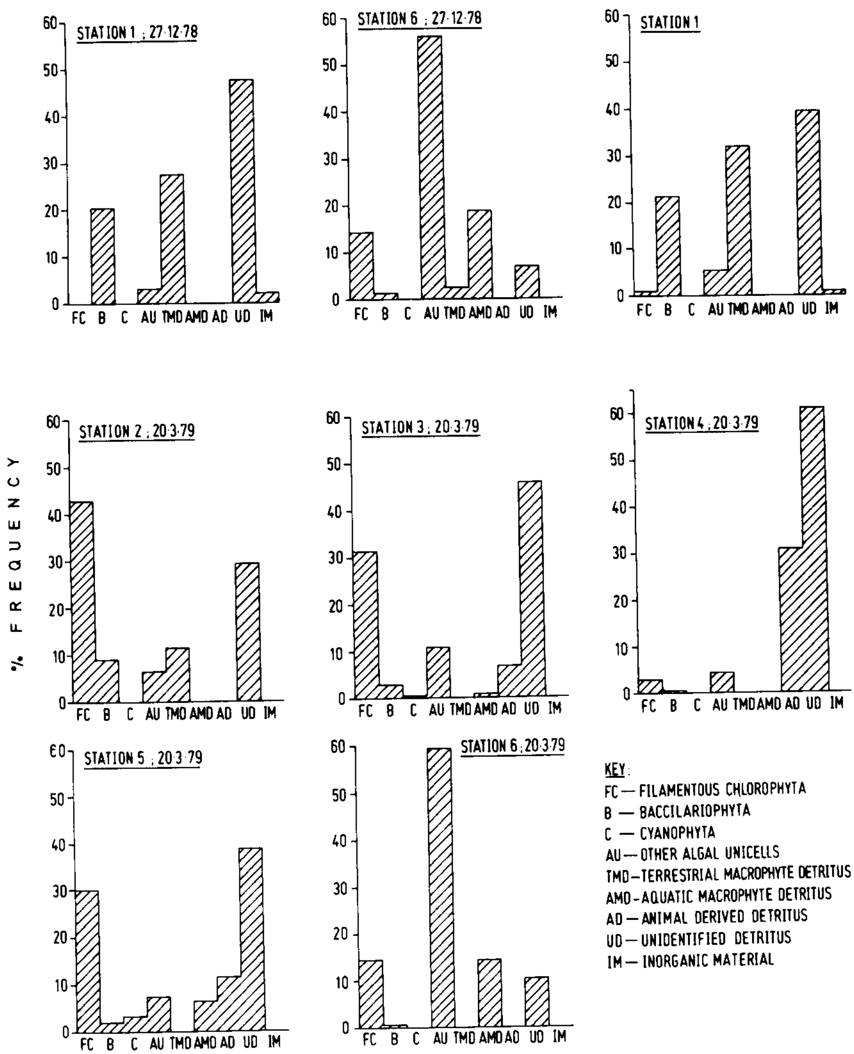


Fig. 11. Frequency histograms showing seston composition in the Lam Tsuen River on 27 December 1978 and 20 March 1979.

40% in March 1979. *Hydrilla verticillatum* also contributed suspended material, and animal derived detritus comprised >10% of the load in March 1979. Algal unicells (mainly Chlorophyta) were pre-eminent in the seston at Station 6 where unidentifiable detritus was a relatively small component. Filamentous chlorophytes comprised 10–30% of the seston load and quantities of aquatic macrophyte detritus (10–20%) derived from aquatic plants at this site (*Hydrilla verticillatum*, *Ludwigia* *adscendens* and *Eichhornia crassipes*) were recorded on all dates except June 1978 when a recent spate had denuded macrophyte standing stock. Trailing riparian grasses contributed small amounts of material between June and December 1978.

Clearly, there are marked seasonal variations in seston composition in the Lam Tsuen River, with the importance of certain components, such as filamentous algae, depending upon their temporal abundance. Additionally, seston composition changes along the course of the river. This parallels observed trends in nutrient loads and might be expected to influence the distribution of the river fauna.

B. (I) Total macrobenthos

The benthic macroinvertebrates of the Lam Tsuen River are listed in Table 4. Due to a lack of taxonomic information on Asian macrobenthos, many animals were assigned only to the lowest taxon within which they could be placed with certainty. Where more than one form or morph occurred within a particular taxonomic category, identification was carried to the generic or family level with numbers and letters used to distinguish different species. Most taxa were recorded in both 1976 and 1978–79. Some of those recorded in only one of these surveys were represented by isolated individuals which may have been absent from other samples by chance. Exceptions to this are the absence of *Psephenoides* sp. (Coleoptera: Psephenidae) in 1978–79, and the incidence of *Physella acuta, Hippeutis cantonensis,* the exotic *Biomphalaria straminea* (Gastropoda: Pulmonata), Oligochaeta spp. L_1 & L_2 (Naididae), and Cypridae L_2 (Crustacea: Ostracoda) in the later study. Additionally, conspicuous changes in species abundance and distribution occurred between the two surveys.

Fig. 12 shows the abundance of invertebrates and numbers of taxa found at each station in the Lam Tsuen River in 1976, as well as values for diversity ($\bar{d}$) and redundancy ($\bar{r}$). The number of taxa at each station decreased downstream from 47 at Station 1 to 12 at Station 6. Associated with this, diversity dropped from 3.84 to 1.41 and redundancy increased toward unity (0.34 to 0.61). Changes in macrofaunal abundance did not follow a clear pattern but tended to increase downstream.

Seasonal changes in the numbers of taxa encountered at each station in 1978–79 (Fig. 13) mirrored the general trend seen in 1976 with the fewest taxa recorded at Station 6. On some occasions, more taxa were recorded from Station 5 than Station 4 thereby disrupting the smooth downstream decrease. When compared with findings from the November 1976 survey, there were fewer taxa present in the lower course of the river in 1978–79, particularly in March 1979. Numbers of taxa at Stations 5 and 6 were reduced by about 20% while those at Stations 3 and 4 fell by 42–47%. Stations 1 and 2 did not show any significant variation between surveys in this respect (Table 5). Between 1976 and 1978–79 the mean number of taxa in the river as a whole decreased by 21%.

Table 4. Benthic macroinvertebrate taxa collected from the Lam Tsuen River in 1976 and 1978–79.

Hydroidea
- *Hydra* sp.

Oligochaeta
- Oligochaete sp. indet. L_1
- Oligochaete sp. indet. L_2

Hirudinea
- *Barbonia weberi* (Blanchard 1897)

Bivalvia
- *Corbicula fluminea* (Müller 1774)

Gastropoda
- *Brotia hainanensis* (Brot 1872)
- *Melanoides tuberculata* (Müller 1774)
- *Sinotaia quadrata* (Benson 1842)
- *Physella acuta* (Draparnaud 1805)
- *Hippeutis cantonensis* Yen 1939
- *Biomphalaria straminea* (Dunker 1848)
- *Ferrissia baconi* (Bourguignat 1853)

Cladocera
- *Simocephalus* L_1
- *Simocephalus* L_2

Ostracoda
- Cypridae sp. indet. L_1
- Cypridae sp. indet. L_2

Decapoda
- *Caridina lanceifrons* Yu 1936
- *Neocaridina serrata* (Stimpson)
- *Macrobrachium hainanense* (Parisi)
- *Potamon* sp.

Ephemeroptera
- *Baetis* $T_1, T_2, T_3, T_4, T_5, L_5, L_6, L_7, L_8$ and cf. T_3
- *Centroptilium* L_1
- *Pseudocloeon* T_1, T_2, L_3
- *Ecdyonurus* T_1, T_2
- *Epeorus* T_1, T_2
- *Iron* sp.
- *Thalerosphyrus* T_1
- *Choroterpes* T_1
- *Choroterpes (Euthraulus)* L_1
- *Isca* sp.
- *Ephemerella* T_1, T_2, L_3
- *Ephemera* sp.
- *Caenis* T_1, T_2, L_2, L_3

Odonata
- *Protosticta* sp.
- *Euphea decorata* (Selys)
- *Anax guttatus* (Burmeister)
- *Ictinogomphus pertinax* (Selys)
- *Heliogomphus sinicus* Chao
- *Heliogomphus* T_2
- *Onychogomphus* T_1
- *Zygonyx iris* (Kirby)

Plecoptera
- *Amphinemura* sp.
- Perlidae spp. indet.

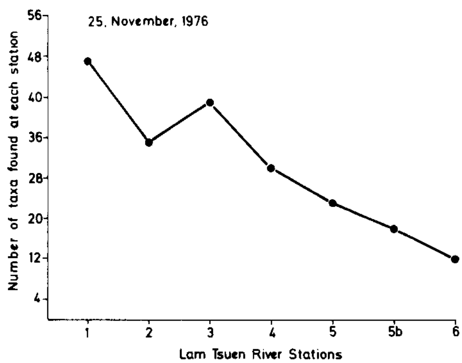
Heteroptera
- *Apheilochirus* T_1
- *Sphaerodema rusticum* (Fabricius)

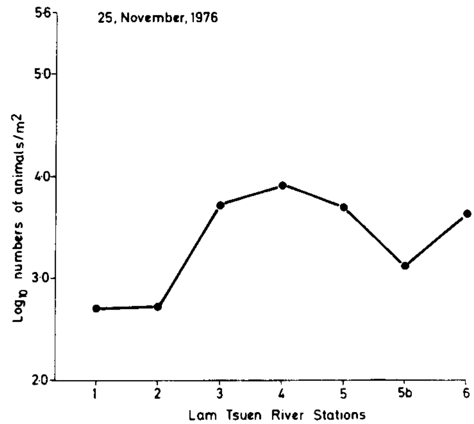
Megaloptera
- *Neochauloides boweringi* (McLachlan)

Trichoptera
- *Rhyacophila* T_1
- *Himalopsyche* L_1
- *Agapetus* T_1
- *Chimarra* T_1, L_4
- *Hydropsyche* $T_s, T_v, T_y, L_w, L_x, L_y, L_z$ and sp. indet.
- *Cheumatopsyche* L_x, L_y, L_z and sp. indet.
- Hydropsychidae genus indet. Ch
- *Psychomyia* T_1
- *Pseudoneureclipsis* TA_1, TA_2, TA_3
- *Psilotreta* T_1
- *Hydroptila* sp.

Coleoptera
- *Enochrus* sp.
- Hydrophilidae genus indet. T_2
- *Helodes* T_1
- *Stenocolus* sp.
- *Eubrianax* sp.
- *Psephenus* sp.
- *Psephenoides* sp.
- Elmidae genus indet. T_1
- Elmidae genus indet. T_2
- cf. *Zaitzevia* sp.
- cf. *Limnius* sp.
- *Stenelmis* T_1
- Elmidae spp. indet.

Diptera
- Chironomidae spp. indet.
- *Chironomus* cf. *plumosus* (L.)
- *Polypedium (Polypedium)* sp.
- *Dicrotendipes* sp.
- *Microspectra* sp.
- Tanypodinae spp. indet.
- cf. *Thienemannimyia* sp.
- *Simulium* $T_1, T_{2(D)}, L_3, L_4$ and S_6
- cf. *Pedicia* sp.





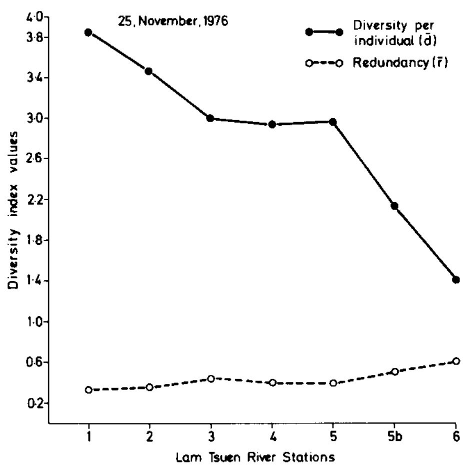


Fig. 12. The number of taxa, abundance, diversity and redundancy of macroinvertebrates at seven stations along the Lam Tsuen River in November 1976.

Table 5. Number of macroinvertebrate taxa at six stations along the Lam Tsuen River, and a comparison of the number of taxa present in 1976 and 1978–79.

station	25.11.76	30.6.78	20.9.78	27.12.78	20.3.79	mean (1978–79)	magnitude of change
1	47	41	43	50	39	43.3	0.92
2	35	34	36	39	40	37.3	1.07
3	39	22	31	19	18	22.5	0.58
4	30	16	20	15	12	15.8	0.53
5	23	18	23	28	8	19.3	0.84
6	12	12	7	12	8	9.8	0.82

$\bar{x}$: 0.79

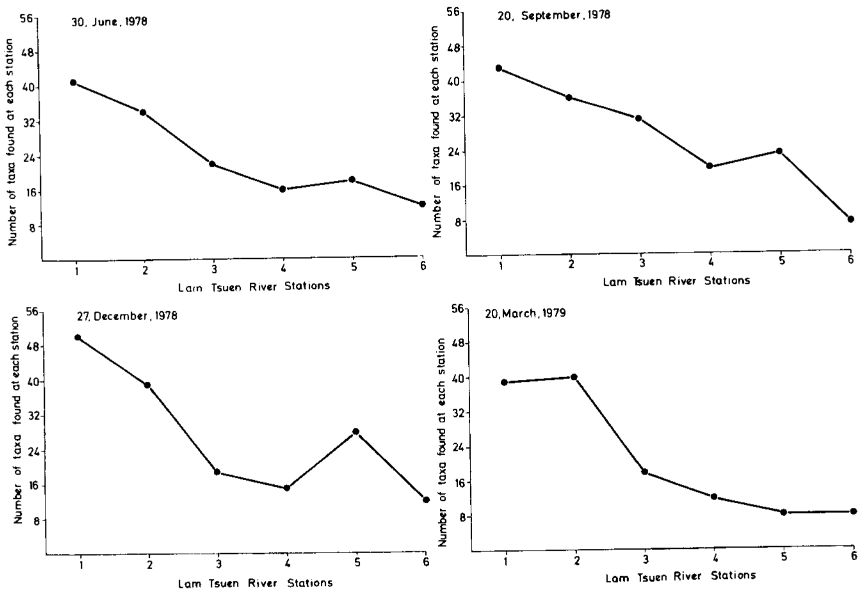


Fig. 13. The number of macroinvertebrate taxa found at six stations along the Lam Tsuen River during 1978–79.

Diversity and redundancy showed marked seasonal variations in 1978–79 (Fig. 14). Stations 1 and 2 generally exhibited the greatest faunal diversity but were exceeded by Station 3 in September 1978. With this exception, Station 3 showed $\bar{d}$ values of <1.1 and the fall in diversity between Stations 2 and 3 was the greatest recorded between any two sites along the river. Station 4 generally had the least diverse benthic community. Redundancy ($\bar{r}$) mirrored diversity and tended toward unity as $\bar{d}$ fell; Station 4 had the highest redundancy values. Differences in redundancy at all sites were insignificant in September 1978. This appeared to result from a general increase in diversity and $\bar{d}$ values at the 6 stations were more similar at this time than on any other sampling occasion. Additionally, the downstream decrease in diversity was relatively small. When compared with 1976, macrofaunal diversity was generally lower in the river as a whole during 1978–79.

Macroinvertebrate abundance at all sites along the river in 1978–79 exceeded that recorded in 1976 (Table 6). This increase was seen at Stations 1 and 2 and was particularly significant at Stations 3, 4 and 5 where the magnitude of increase varied between 14.1 and 32.1 fold; by contrast, that observed at Station 6 was relatively small. The mean increase in macrobenthos abundance over the whole river was 15.2 fold (Table 6). Downstream trends in abundance were marked by a great increase between Stations 2 and 3 with a peak with Station 4 or 5 (Fig. 15).

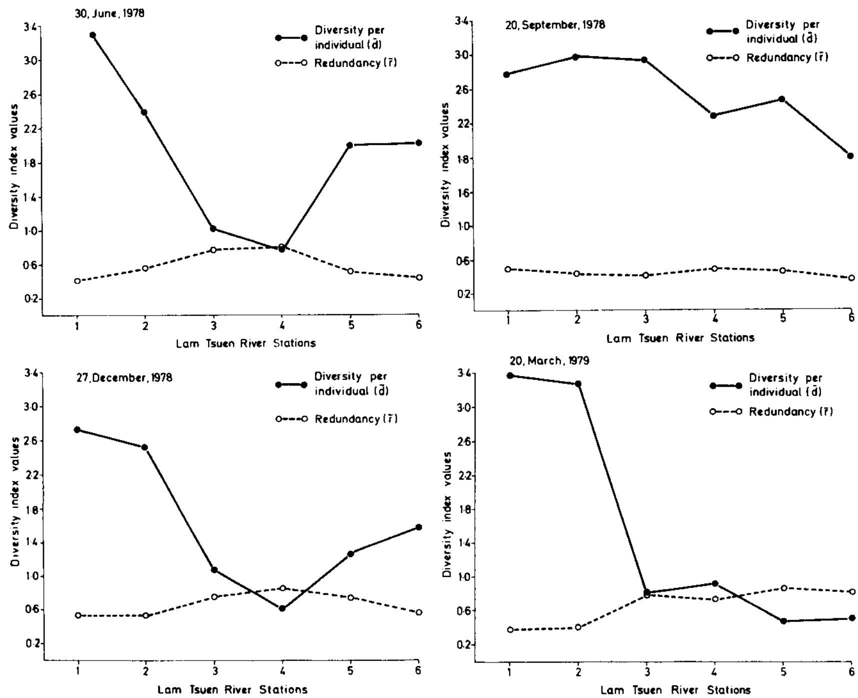


Fig. 14. Diversity and redundancy values for macrobenthos samples from six stations along the Lam Tsuen River during 1978–79.

Table 6. Macroinvertebrate abundance (numbers/m^2) at six stations along the Lam Tsuen River, and a comparison of population densities in 1976 and 1978–79.

station	25.11.76	30.6.78	20.9.78	27.12.78	20.3.79	mean (1978–79)	magnitude of increase
1	505	2071	4367	4931	2964	3583	7.10
2	534	2940	5720	7937	4510	5277	9.88
3	5387	149517	41721	131218	164668	121781	22.61
4	8314	65638	248293	74544	80297	117193	14.10
5	5227	72762	34488	173671	389308	167557	32.06
6	4548	29869	8183	17042	40612	23927	5.26

$\bar{x}$: 15.17

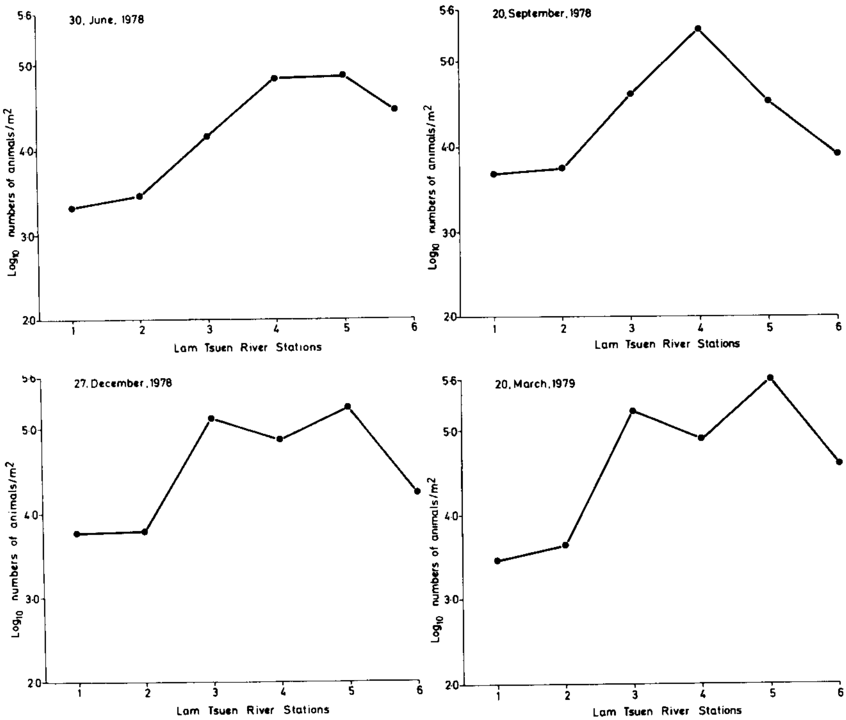


Fig. 15. The abundance of benthic macroinvertebrates at six stations along the Lam Tsuen River during 1978–79.

(II) Non-insectan Invertebrata

Two species of cyprids (Crustacea: Ostracoda) were recorded from the study area. Cypridae L_1 was widespread and in 1976 showed a discontinuous distribution, occurring in both upper and lower reaches (Fig. 16). In 1978 these animals were recorded from Stations 2–6 in September and December only. By contrast, Cypridae L_2 was restricted to Station 6 and not found in 1976. Cyprid abundance in November 1976 was considerably less than that in December 1978 (the nearest comparable date in the 1978–79 survey), reflecting greater numbers of sites colonized in the later study and high population densities at Stations 3–6.

Oligochaetes showed a simple pattern of longitudinal zonation (Fig. 16). In June and September 1978, Oligochaete L_1 was found at Stations 5 and 6, extending its range to include Station 4 in December 1978 and March 1979. Oligochaete L_2 was less numerous, occurring at Station 6 on only two sampling dates. Neither taxon was encountered in 1976.

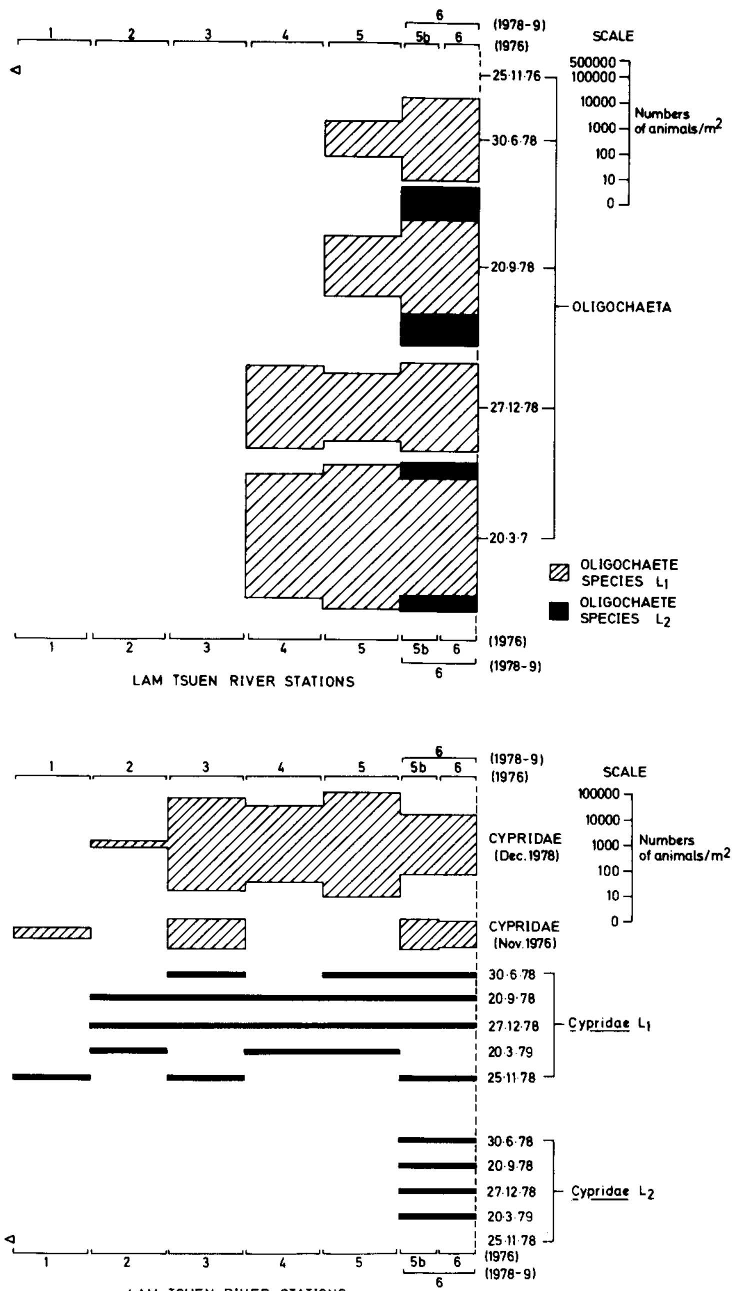
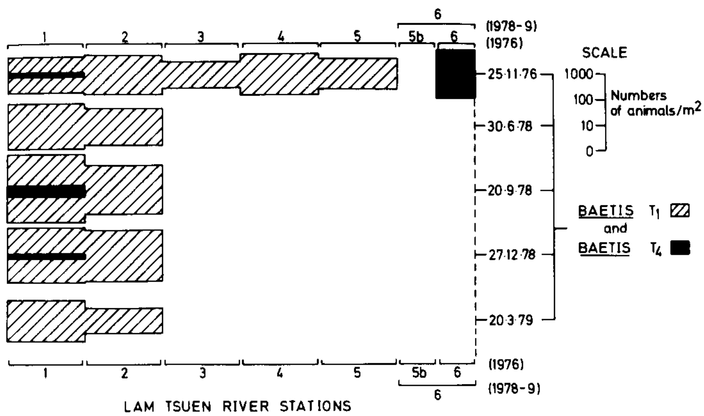


Fig. 16. The distribution and abundance of Cypridae (Crustacea: Ostracoda) and Oligochaeta in the Lam Tsuen River during 1976 and 1978–79.

The Mollusca were represented by the bivalve *Corbicula fluminea* (MÜLLER 1974) (Corbiculacea: Corbiculidae) and seven gastropod species. The distribution and abundance of the latter greatly increased in 1978–79 and has been discussed in detail elsewhere (DUDGEON 1983b).

(III) Ephemeroptera

Numerically dominant among the Ephemeroptera were baetid nymphs; their distribution and abundance is shown in Figs. 17–22. *Baetis* T_1, T_2 and T_4 were



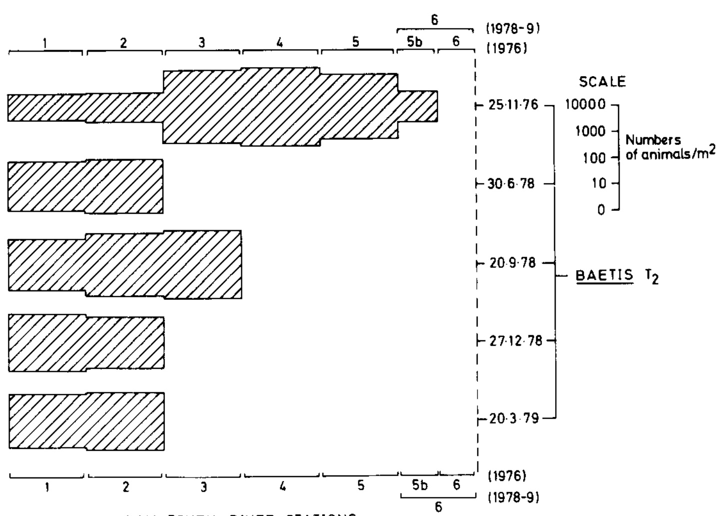


Fig. 17. The distribution and abundance of *Baetis* T_1, *Baetis* T_2 and *Baetis* T_4 (Ephemeroptera: Baetidae) in the Lam Tsuen River in 1976 and 1978–79.

more widely distributed in 1976 than during the later survey (Fig. 17). Throughout 1978–79 *Baetis* T_1 was confined to Stations 1 and 2 although present at Stations 1–5 in 1976. Similarly, the distribution of *Baetis* T_2 was restricted to Stations 1–3 in the later survey. *Baetis* T_4 was found at Station 1 in September and December

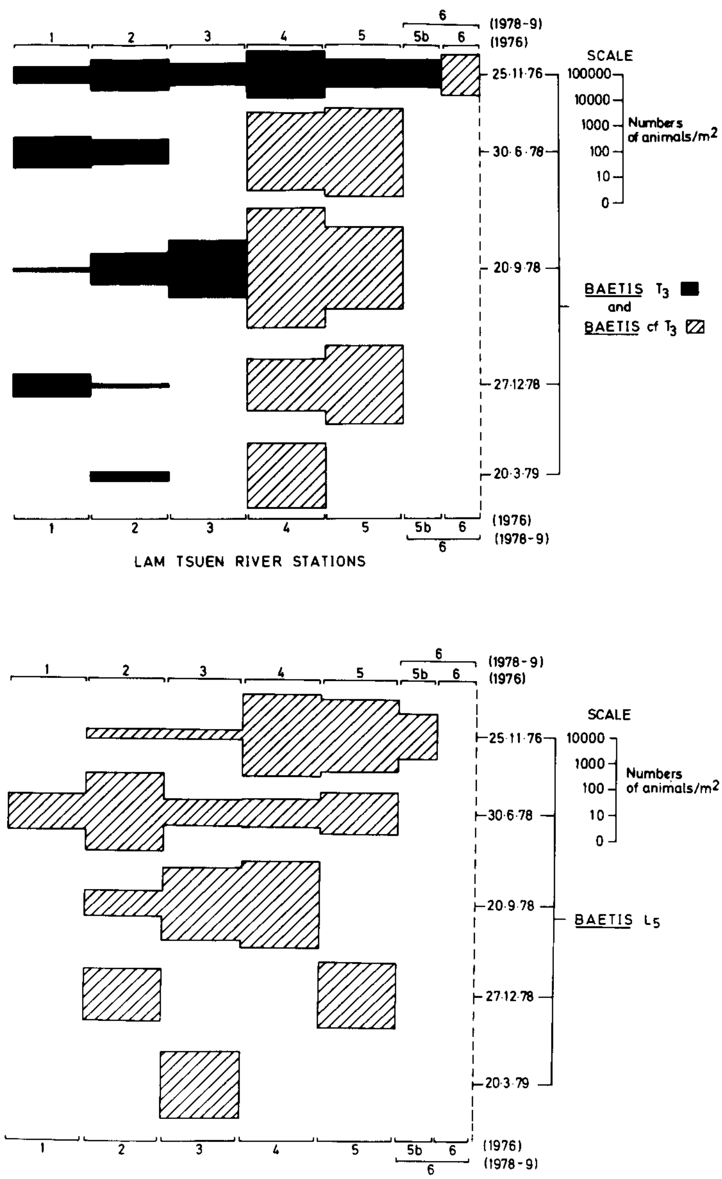
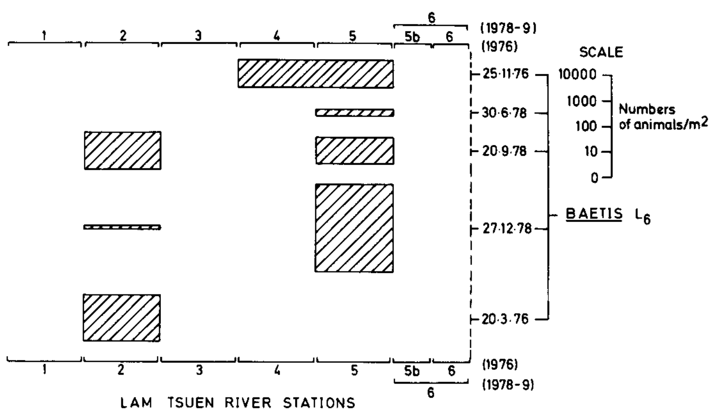


Fig. 18. The distribution and abundance of *Baetis* L_5, *Baetis* T_3 and *Baetis* cf. T_3 (Ephemeroptera: Baetidae) in the Lam Tsuen River in 1976 and 1978–79.

1978 and in November 1976 when it was also common at Station 6. The distribution pattern of this taxon was unusual, but on the basis of nymphal morphology, populations at both sites comprised but a single species. The abundance of *Baetis* T_1 and T_2 at sites where they occurred in 1976 and 1978–79 had not changed significantly, although their numbers in the river as a whole fell substantially as a result of their restricted distribution in the later study.

The zonation of *Baetis* T_3 and L_5 is shown in Fig. 18. Two sub-groups of the former taxon, *Baetis* T_3 and *Baetis* cf. T_3 were distinguished on the basis of slight morphological differences (principally dorsal abdominal patterns). It was unclear whether these were phenotypic variations reflecting microhabitat characteristics. *Baetis* T_3 was found at Stations 1–5b in 1976 but only at Stations 1–3 in 1978–79. In June 1978 *Baetis* T_3 was confined to Station 2 and *Baetis* cf. T_3 restricted to



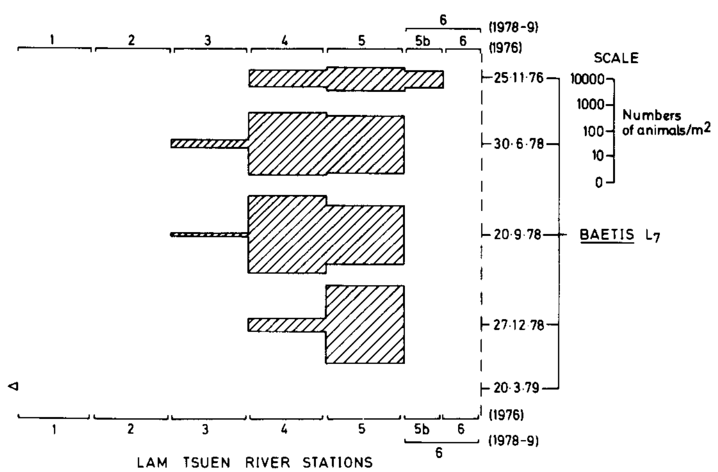
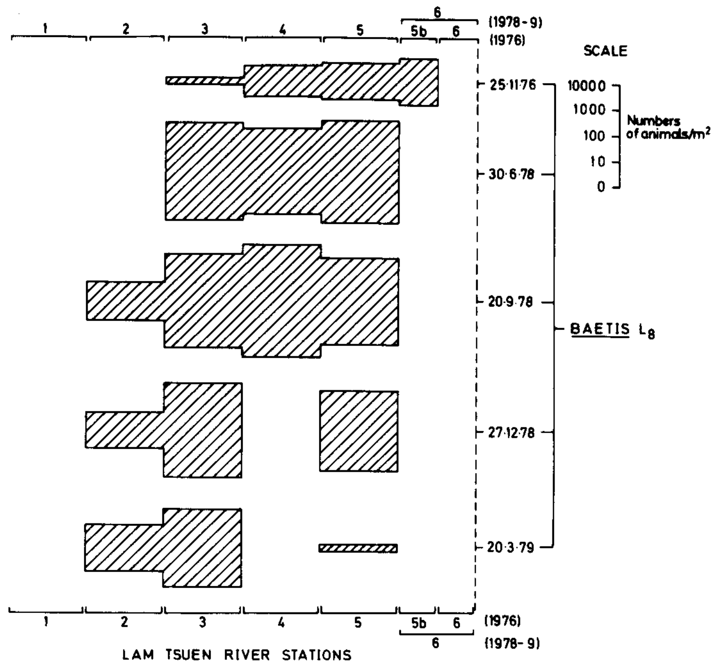


Fig. 19. The distribution and abundance of *Baetis* L_6 and *Baetis* L_7 (Ephemeroptera: Baetidae) in the Lam Tsuen River in 1976 and 1978–79.



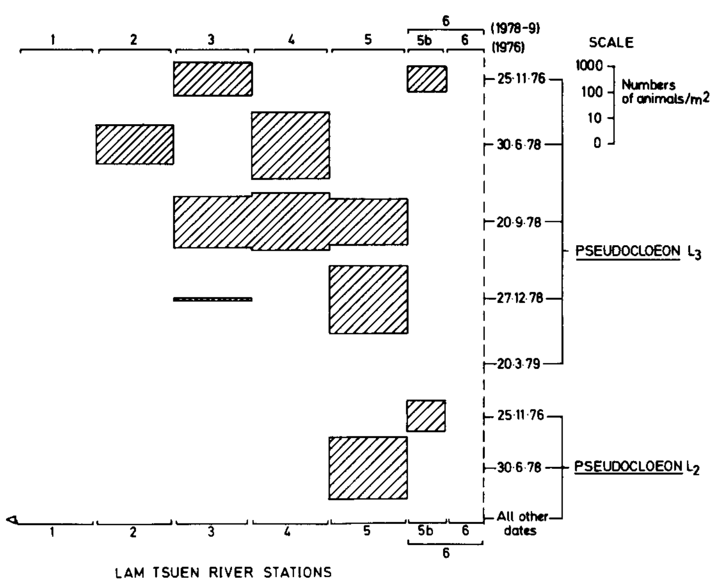


Fig. 20. The distribution and abundance of *Baetis* L_8, *Pseudocloeon* L_2 and *Pseudocloeon* L_3 (Ephemeroptera: Baetidae) in the Lam Tsuen River in 1976 and 1978–79.

Station 4. At other times in 1978–79 *Baetis* cf. T_3 was recorded from Stations 4 and 5 but in 1976 occurred only at Station 6. Numbers of *Baetis* cf. T_3 increased in 1978–79 reflecting a wider distribution and higher population densities at colonized sites. By contrast, the overall abundance of *Baetis* T_3 was reduced.

Baetis L_5 was widespread in 1976, but more numerous in the lower course of the river (Fig. 18). During 1978–79 its distribution was discontinuous, including Stations 1–5 in June 1978 with reduction to Station 3 only in March 1979.

Baetis L_6 and L_7 showed contrasting distribution patterns (Fig. 19). In 1976 *Baetis* L_6 L_7 were found at Stations 4 and 5 but in 1978–79 the distribution of *Baetis* L_6 was discontinuous, individuals occurring only at Stations 2 and 5, being restricted to the former in March 1979 and the latter in June 1978. *Baetis* L_6 did

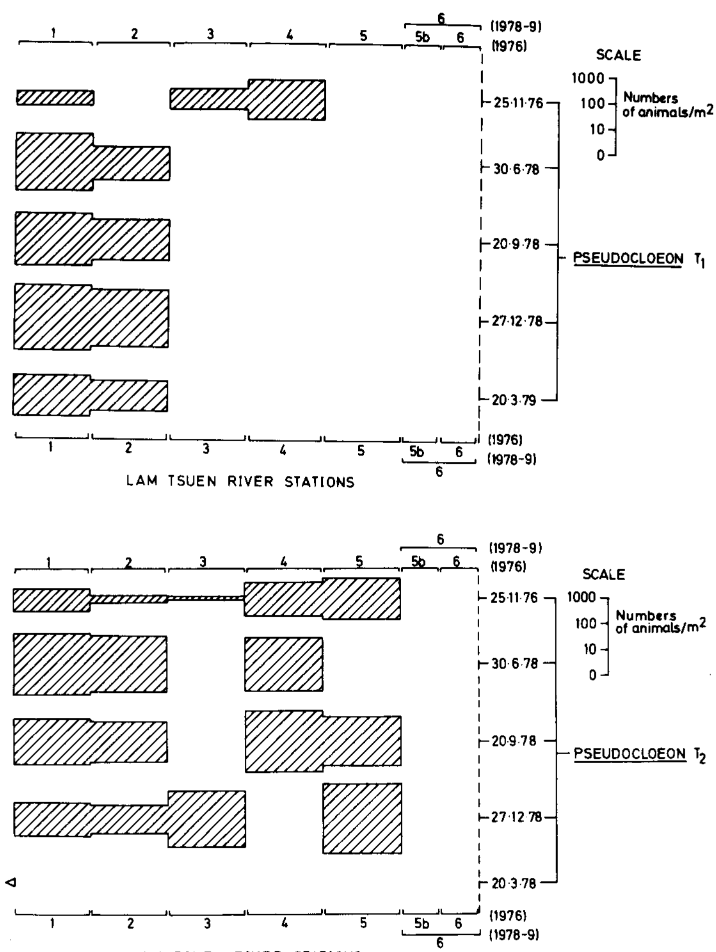


Fig. 21. The distribution and abundance of *Pseudocloeon* T_1 and *Pseudocloeon* T_2 in the Lam Tsuen River in 1976 and 1978–79.

not show significant changes in abundance between 1976 and 1978–79. By contrast, *Baetis* L_7 was considerably more abundant in the later survey when it was recorded from Stations 3 to 5. However it was not found in the river in March 1979.

Baetis L_8 was a relatively widely distributed species and was found at Stations 3–5b in 1976 as well as Station 2 in 1978–79 (Fig. 20). In December 1978 and March 1979 the distribution of *Baetis* L_8 was discontinuous and these animals were not recorded from Station 4. Overall, however, *Baetis* L_8 was more numerous in 1978–79 than in 1976.

Baetid nymphs of the genus *Pseudocloeon* were common in the Lam Tsuen River. *Pseudocloeon* L_3 occurred at Stations 3 and 5b in 1976 and its distribution was similarly discontinuous in 1978–79 (Fig. 20); no individuals were found in March 1979. *Pseudocloeon* L_2 was only recorded from Station 5b in 1976 and Station 5 in June 1978. The abundance of *Pseudocloeon* L_2 and L_3 in 1978–79 was greater than that recorded in the earlier survey although the magnitude of the increase was less than that noted for *Baetis* L_8, L_7 and cf. T_3. By contrast, *Pseudocloeon* T_1 and T_2 showed little change in abundance between 1976 and 1978–79 (Fig.21). In 1976 *Pseudocloeon* T_1 was found at Stations 1, 3 and 4 but throughout 1978–79 was restricted to Stations 1 and 2. *Pseudocloeon* T_2 was more widely distributed occurring continuously between Stations 1 and 5 in 1976 but discontinuously in 1978. In common with *Baetis* L_7 and *Pseudocloeon* L_2 and L_3, *Pseudocloeon* T_2 was not recorded from the Lam Tsuen River in March 1979.

It is clear that a change of the distribution and abundance of various species of Baetidae in the Lam Tsuen River took place between 1976 and 1978. Upon comparing the distribution and abundance of the family as a whole in November 1976 and December 1978 (Fig.22) a general picture of increased abundance at all sites except Stations 4 and 6 can be seen. No baetid nymphs were found at Station 6 in the later survey.

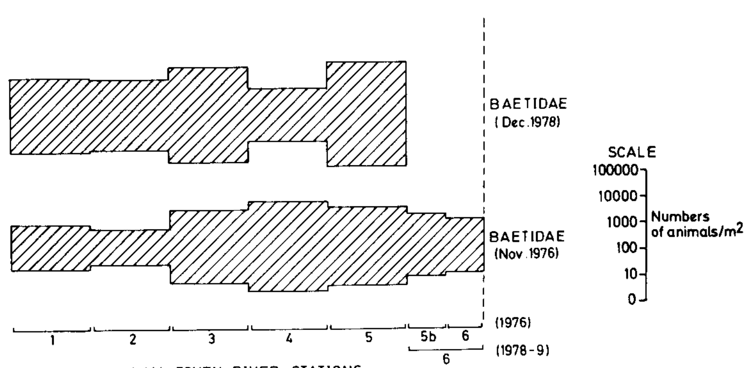


Fig. 22. The distribution and abundance of baetid nymphs in the Lam Tsuen River in November 1976 and December 1978.

Numbers of heptageniid mayflies in the Lam Tsuen River were generally greater in 1978–79 although there was a reduction in species range in the later survey (Fig. 23). *Epeorus* spp. were restricted to Stations 1 and 2 in 1978–79 but also occurred at station 3 in 1976. Similar reductions in the incidence of *Ecdyonurus* T_1 and T_2 were noted. Leptophlebiids were more widespread in the river than heptageniids but their range and abundance was reduced in 1978–79 when they were only recorded at Stations 1–3 (Fig. 24). By contrast, leptophlebiid nymphs were present throughout the river system in 1976. During both surveys *Isca* sp. and *Choroterpes* T_1 occurred at Station 1 with some records from Station 3. *Choroterpes (Euthraulus)* L_1 was found at Station 3 on all occasions in 1978 but in 1976 was widely distributed throughout the middle and lower course of the river. In common with some Baetidae, *Choroterpes (Euthraulus)* L_1 was not recorded in March 1979.

In 1976 ephemerellid nymphs were found at Stations 1–5 (Fig.25). The species concerned were *Ephemerella* T_2 at Stations 1–4, and *Ephemerella* L_3 which occurred at Stations 3, 4 and 5. In 1978–79, however, the range and abundance of these animals was restricted. *Ephemerella* L_3 was recorded only from Station 3 in September 1978 whilst *Ephemerella* T_2 was confined to Stations 1 and 2. A third species, *Ephemerella* T_1, was recorded in small numbers at Station 1 and had not been collected in 1976. This animals was rather rare and its absence from the earlier survey may have been a chance occurrence.

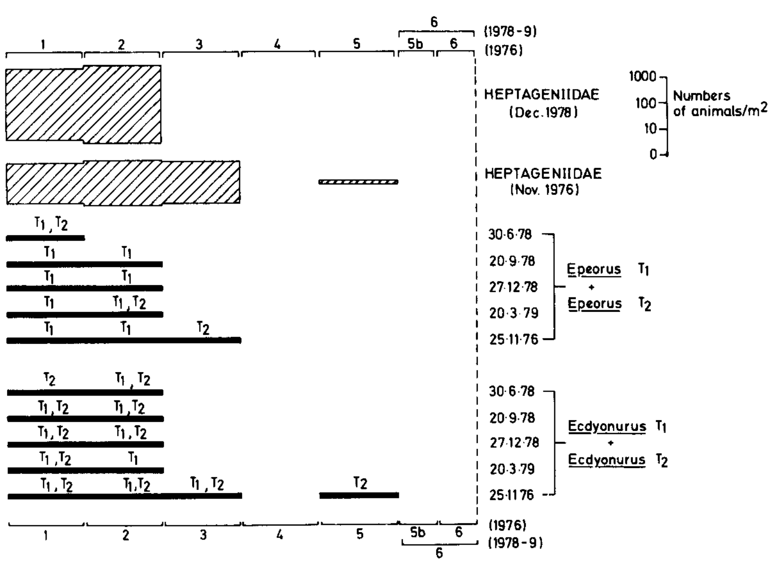


Fig. 23. The distribution and abundance of nymphal Heptageniidae (Ephemeroptera) in the Lam Tsuen River in November 1976 and December 1978. Also shown is the distribution of *Epeorus* T_1, *Epeorus* T_2, *Ecdyonurus* T_1 and *Ecdyonurus* T_2 in 1976 and 1978–79.

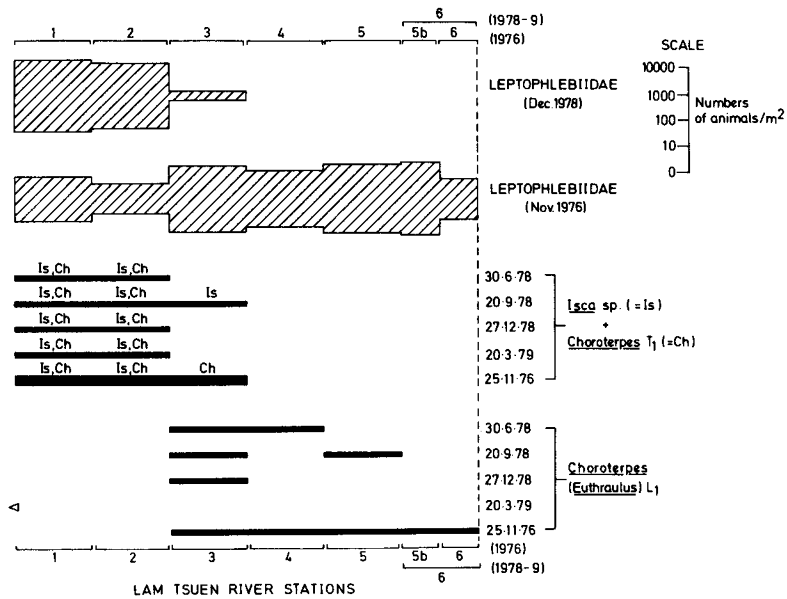


Fig. 24. The distribution and abundance of nymphal Leptophlebiidae (Ephemeroptera) in the Lam Tsuen River in November 1976 and December 1978. Also shown is the distribution of *Choroterpes* T_1, *Choroterpes (Euthraulus)* L_1 and *Isca* sp. in 1976 and 1978–79.

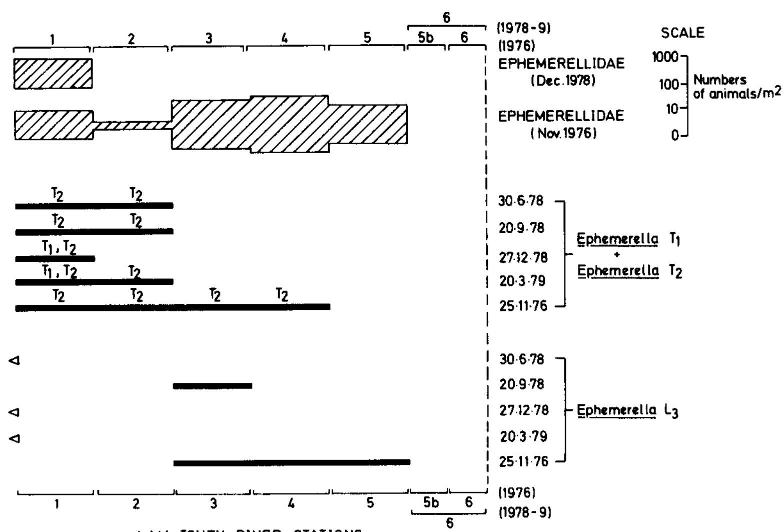


Fig. 25. The distribution and abundance of nymphal Ephemerellidae (Ephemeroptera) in the Lam Tsuen River in November 1976 and December 1978. Also shown is the distribution of *Ephemerella* T_1, *Ephemerella* T_2 and *Ephemerella* L_3 in 1976 and 1978–79.

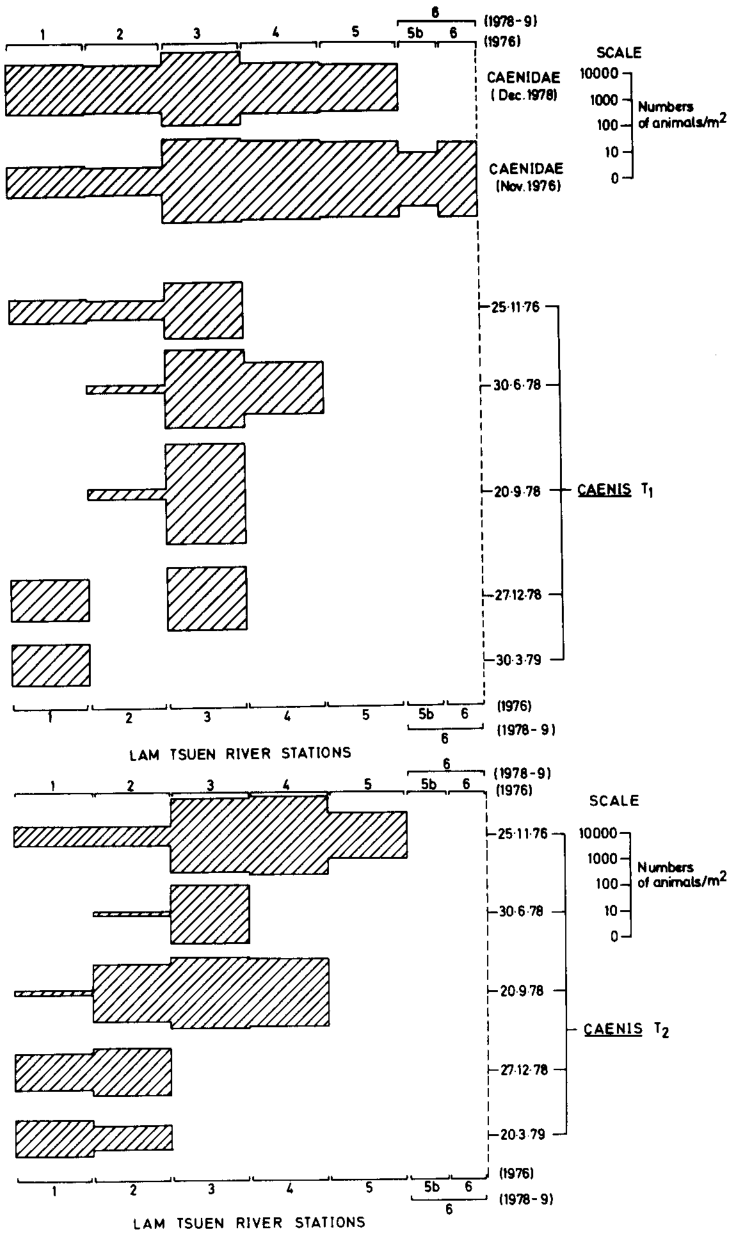


Fig. 26. The distribution and abundance of all nymphal Caenidae (Ephemeroptera) as well as *Caenis* T_1 and *Caenis* T_2 in the Lam Tsuen River in 1976 and 1978–79.

The Caenidae were numerous in the Lam Tsuen River and in combination with the Baetidae comprised the majority of the ephemeropteran populations investigated during this study. Caenids occurred throughout the river in 1976 and at Stations 1–5 in December 1978 (Fig. 26). *Caenis* T_1 showed a general range restriction in 1978–79 occurring at Stations 2, 3 and 4 in June 1978 but only at Station 1 in March 1979. However, there were no marked changes in overall range and abundance of *Caenis* T_1 between the two surveys. By contrast, the numbers of *Caenis* T_2

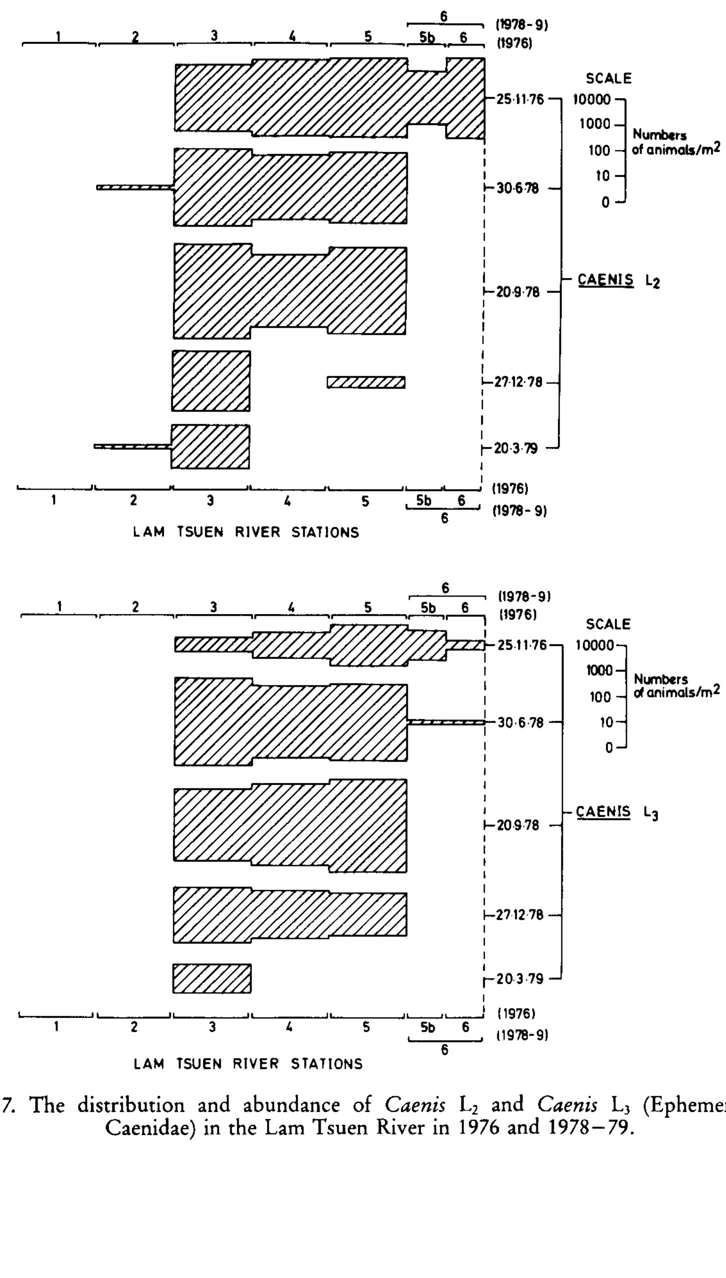


Fig. 27. The distribution and abundance of *Caenis* L_2 and *Caenis* L_3 (Ephemeroptera: Caenidae) in the Lam Tsuen River in 1976 and 1978–79.

decreased in 1978–79, reflecting a restriction in species distribution. *Caenis* T_2 occurred at Stations 1–5 in 1976 but in 1978–79 was generally restricted to the upper course. Only in September 1978 was this species recorded more widely when it had colonized Stations 1–4.

Caenis L_2 was recorded from Stations 3–6 in 1976 but was absent from the lowest site in 1978–79 (Fig. 27). In addition, this species was eliminated from Stations 4 and 5 in March 1979, occurring only at Stations 3 and 5 in December 1978. In summer 1978, *Caenis* L_2 abundance was comparable to that in 1976 although subsequent range restrictions resulted in a fall in overall numbers. *Caenis* L_3 showed a similar distribution pattern to *Caenis* L_2 and was restricted to Station 3 in March 1979. At other times in 1978–79, *Caenis* L_3 was more numerous than in 1976, despite elimination from Station 6.

(IV) Odonata

The libelluid *Zygonyx iris* (KIRBY) was widespread in the Lam Tsuen River and was recorded from Stations 1–5 in 1976 (Fig.28). This species was slightly more abundant in 1978–79 despite being less widely distributed in the lower course of the river. All other benthic odonates were gomphids and occurred throughout much of the river system. The most numerous of these, *Onchogomphus* T_1, was recorded at Stations 1–5 although only occurring simultaneously at all sites in September 1978. *Heliogomphus sinicus* CHAO and *Ictinogomphus pertinax* (SELYS) were restricted to the upper and lower sections of the river respectively.

(V) Plecoptera

Plecopterans are an important group in lotic habitats as a result of the predatory behaviour of many nymphal Perlidae (PENNAK 1978). Most plecopterans found in the Lam Tsuen River were perlids, and these animals were restricted to the upper reaches in 1976 and 1978–79 (Fig. 29). In common with Heptageniidae, plecopteran abundance at these sites was greater during the later survey.

(VI) Trichoptera

Rather few species of Trichoptera were found in the Lam Tsuen River in spite of the diversity of niches adopted by nearctic members of this order (WIGGINS & MACKAY 1979). Filter-feeding taxa were most abundant and, of these, the Hydropsychidae were numerically dominant. The numbers of hydropsychid larvae in the river showed a dramatic increase between 1976 and 1978–79 with population densities increasing at all sites except Station 4. The distribution of these animals did not change significantly, extending downstream to Station 5b in 1976 and Station 5 in the later survey (Fig. 30). Most *Hydropsyche* spp. were restricted to

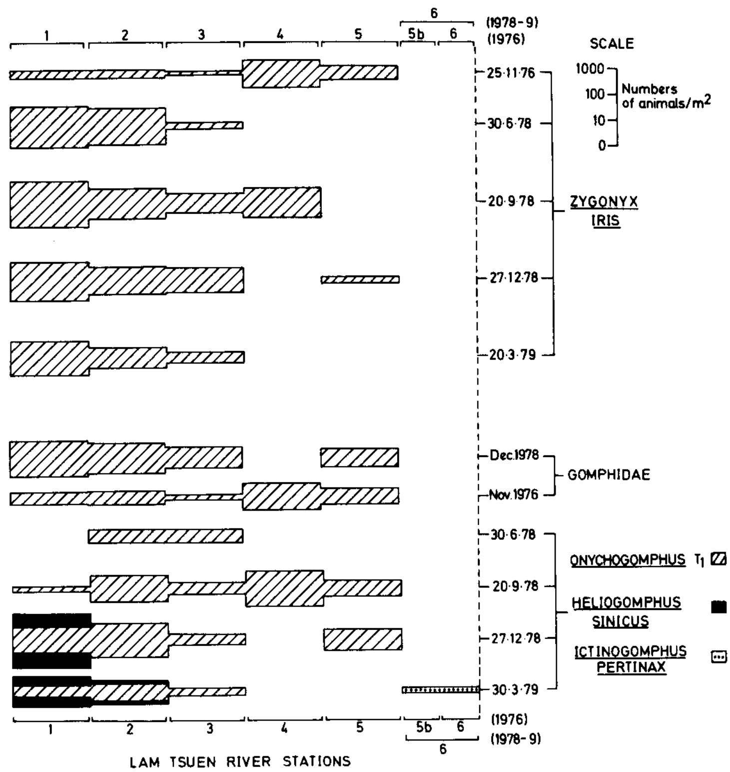


Fig. 28. The distribution and abundance of *Zygonyx iris* (Odonata: Libellulidae) in the Lam Tsuen River in 1976 and 1978–79. Also shown is the distribution and abundance of all nymphal Gomphidae (Odonata) in November 1976 and December 1978, as well as that of *Onychogomphus* T_1, *Heliogomphus sinicus* and *Ictinogomphus pertinax* (Gomphidae) during 1978–79.

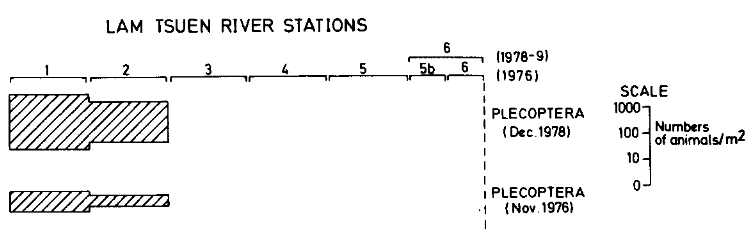


Fig. 29. The distribution and abundance of nymphal Plecoptera in the Lam Tsuen River in November 1976 and December 1978.

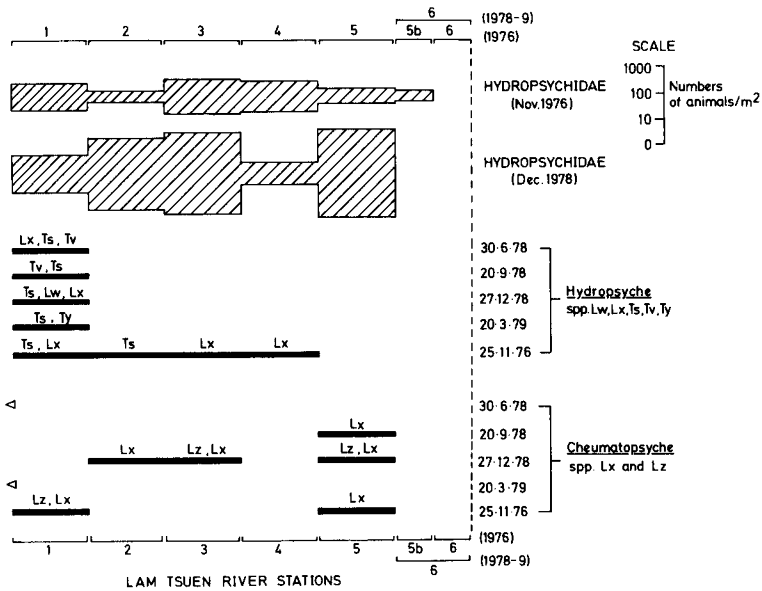


Fig. 30. The distribution and abundance of larval Hydropsychidae (Trichoptera) in the Lam Tsuen River in November 1976 and December 1978. Also shown is the distribution of *Hydropsyche* T_s, *Hydropsyche* T_v, *Hydropsyche* T_y, *Hydropsyche* L_w, *Hydropsyche* L_x, *Cheumatopsyche* L_x, and *Cheumatopsyche* L_z (Hydropsychidae) in 1976 and 1978–79.

the upper course of the river in 1978 (*Hydropsyche* T_v, T_y and L_w) although *Hydropsyche* L_x was recorded at Stations 3 and 4 and *Hydropsyche* L_y occurred at Stations 1, 3, 4 and 5 (Fig. 31). *Hydropsyche* L_y was generally more abundant in the river in 1978–79 but *Hydropsyche* L_z was more numerous in 1976. The latter species was not collected in June 1978 or March 1979 and its distribution was discontinous, including Stations 1, 3 and 4 in 1978 as well as Station 5b in 1976.

Species of the genus *Cheumatopsyche* were generally found further downstream than *Hydropsyche* larvae. For example *Cheumatopsyche* L_x and L_z occurred at Stations 1, 2, 3 and 5 and 1, 3 and 5 (respectively) in 1978 and at Station 5 in 1976 (Fig.30). This is in contrast to the dominance of upstream sites by *Hydropsyche* spp. in the later study. However, as was the case for *Hydropsyche* L_z, both *Cheumatopsyche* L_x and L_z were not collected in June 1978 and March 1979.

Cheumatopsyche L_y was found in the river on all visits and tended to inhabit the middle and lower course (Fig. 31), although it was restricted to Station 2 in March 1979. Overall, this species was more abundant in 1978 than in 1976 and, in combination with *Hydropsyche* L_y, *Cheumatopsyche* L_y was responsible for the observed increase in hydropsychids in the Lam Tsuen River during the later survey (Fig. 30).

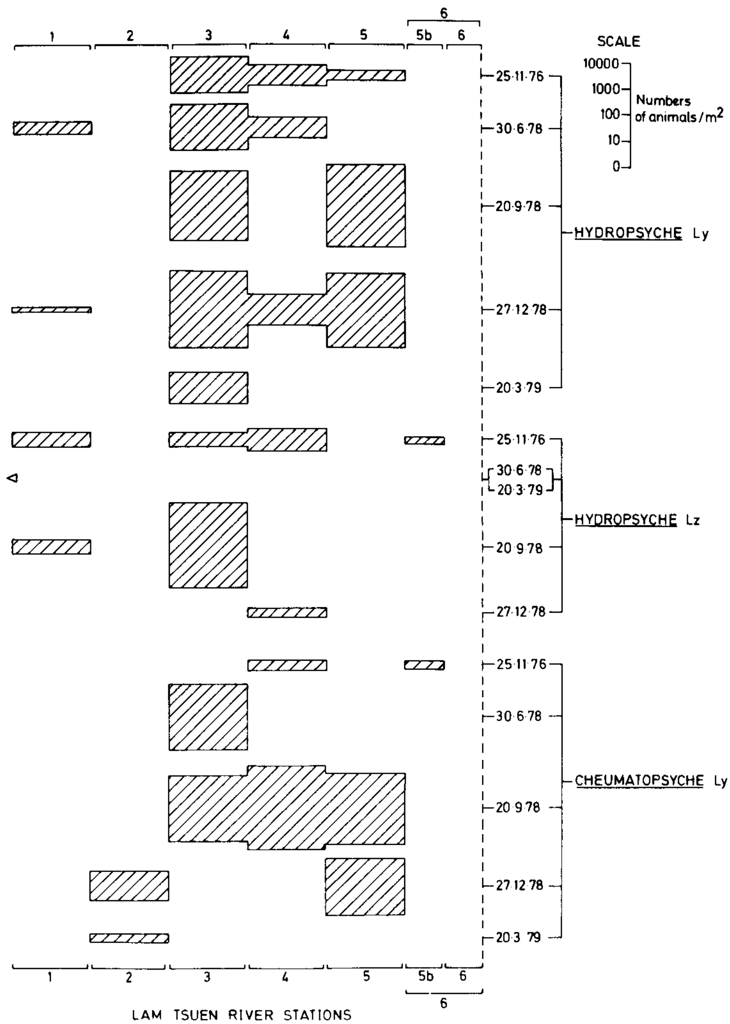


Fig. 31. The distribution and abundance of *Hydropsyche* L_y, *Hydropsyche* L_z and *Cheumatopsyche* L_y (Trichoptera: Hydropsychidae) in the Lam Tsuen River in 1976 and 1978–79.

(VII) Diptera

Dipteran larvae were abundant in the study area, and filter-feeding Simuliidae were especially widespread occurring at all sites except Station 6 in 1976 and 1978–79 (Fig.32). The numbers of these larvae in the river increased considerably between the two surveys, especially at Stations 3 and 5. *Simulium* T_2 (D) and *Simulium* T_1 were found largely in the upper course of the river. *Simulium* T_1 was less common and restricted to Station 1; neither species was recorded in September 1978 or March

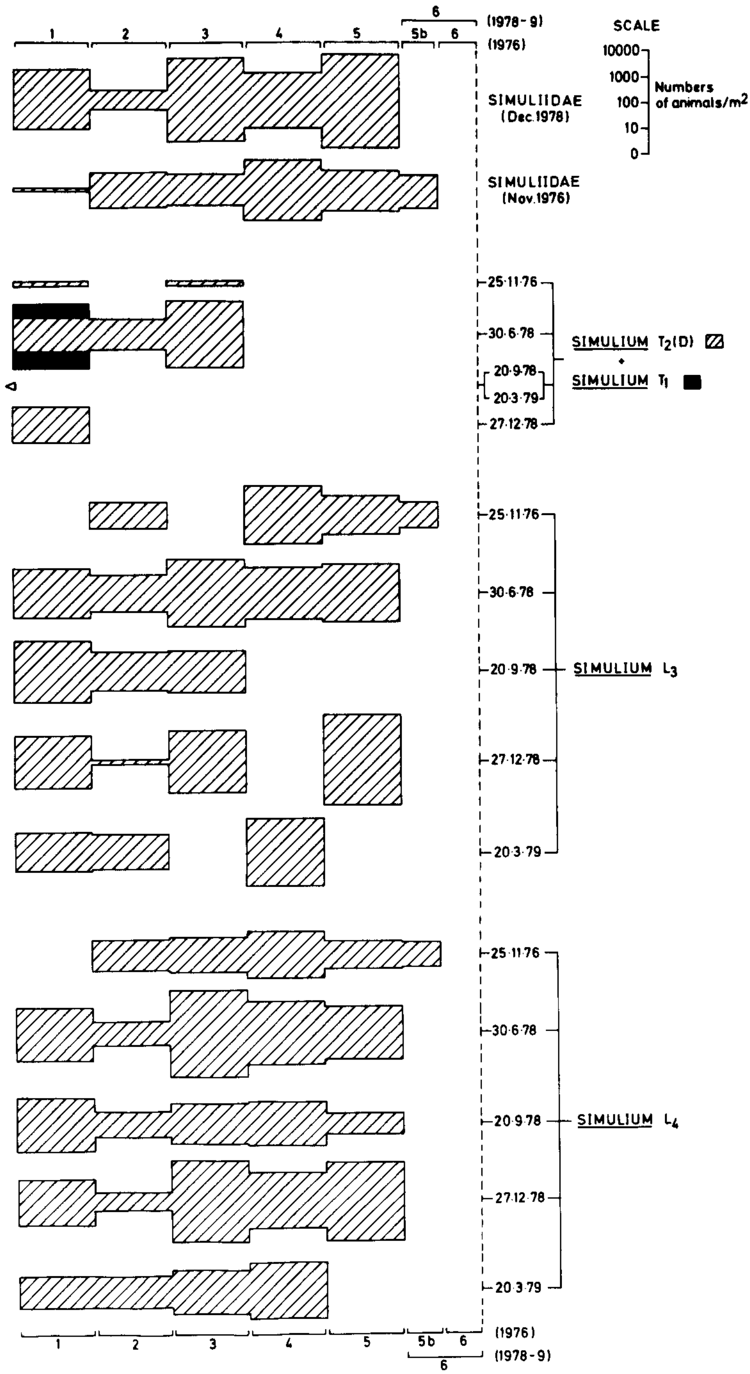


Fig. 32. The distribution and abundance of larval Simuliidae (Diptera) in the Lam Tsuen River in November 1976 and December 1978. Also shown is the distribution and abundance of *Simulium* T_1, *Simulium* T_2(D), *Simulium* L_3 and *Simulium* L_4 in 1976 and 1978–79.

1979. *Simulium* L_3 extended its range from Stations 2, 4, 5 and 5b in 1976 to Stations 1–5 in 1978–79, *Simulium* L_4 was found at Stations 1–5 in the later survey although it was not collected from Station 1 in 1976. Both of these species increased in abundance over the study period.

The other major group of dipteran larvae in the Lam Tsuen River were Chironomidae. Their taxonomy in Asia is poorly known and consequently in this study these larvae were assigned to trophic groups; the Tanypodinae (carnivores) and the rest of the Chironomidae (omnivores or detritivores). The latter grouping comprised mainly Chironominae. In 1976 and 1978–79 Chironomidae were found at all sites in the river (Fig. 33) and there was no significant alteration of distribution pattern with season. However, a very large increase in chironomid numbers took

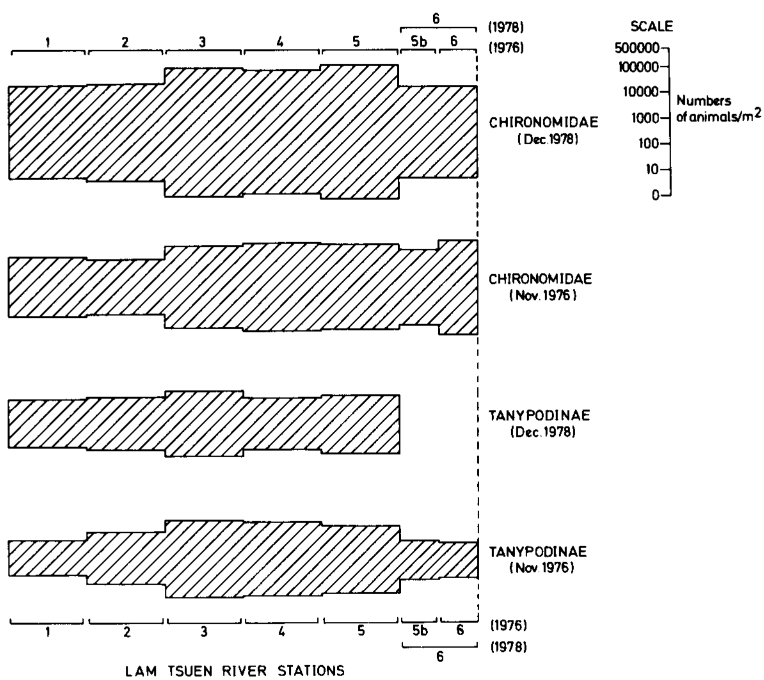


Fig. 33. The distribution and abundance of larval Chironomidae (excluding Tanypodinae) and Tanypodinae (Diptera: Chironomidae) in the Lam Tsuen River in November 1976 and December 1978.

place between 1976 and 1978. The magnitude of this increase was particularly noticeable at Stations 3 (72 fold) and 5 (76 fold). The smallest increase was seen at Station 6 where *Chironomus* cf. *plumosus* L. (Chironominae) comprised 63% of the Chironomidae in 1976 and 80% in 1978. By contrast the Tanypodinae were (excepting Station 1) slightly less numerous in 1978 and were eliminated from Station 6. As a result of decreased Tanypodinae and increases in other Chironomidae, the ratio of Tanypodinae to Chironomidae in 1978 tended to decrease with increasing distance from upstream sites.

(VIII) Coleoptera

The Elmidae and Psephenidae were the most abundant coleopteran larvae in the Lam Tsuen River. In 1976, psephenids were found at Stations 1–4 (Fig. 34) but in 1978–79 were restricted to the two uppermost stations. Elmidae were collected from all sites except Station 5b in 1976, but were subsequently recorded only from Stations 1, 2 and 3. The abundance of both groups at Stations 1 and 2 was greater in 1978. In 1976 a downstream succession of psephenids was observed with *Eubrianax* sp. at Station 1, *Psephenus* sp. at Stations 1–3, and *Psephenoides* sp. at Stations 3 and 4. The latter species was not collected in 1978–79. Elmid distribution patterns were less well defined. Elmidae genus indet. T_1 was restricted to Stations 1 and 2 in 1978–79 but was also recorded at Station 3 in 1976. Elmidae genus indet. T_2 was found at Stations 1 and 2 in September 1978 and March 1979 but was also found at Station 3 in December 1978 and Station 5 in June 1978. This taxon occurred at Stations 2, 4 and 5 in 1976. Three other elmids were found in the study area (cf. *Zaitzevia* sp., cf. *Limnius* sp. and *Stenelmis* T_1) but they were comparatively scarce and showed discontinuous distribution patterns. Overall, elmids were more widely distributed in the Lam Tsuen River in 1976.

(IX) Filter-feeding insects

A general increase in the numbers of Hydropsychidae and Simuliidae was noted in the Lam Tsuen River between 1976 and 1978–79 (Figs. 30 and 32). Consequently, an examination of variations in the distribution, abundance and composition of the filter-feeding component of the insect macrobenthos of the river system was undertaken. It was hoped to demonstrate whether increased numbers of simuliids and hydropsychids represented a general increase in filter-feeding taxa or an increase in those two groups at the expense of other species populations. Four families of filter-feeders were indentified: Hydropsychidae, Philopotamidae, Polycentropidae (Trichoptera) and Simuliidae (Diptera). In 1978–79 three or four families were recorded from Stations 1 and 2 whilst only Hydropsychidae and Simuliidae occurred further downstream (Fig. 35). On June 1978 and March 1979 the lowest site where any filter-feeders occurred (Stations 5 and 4 respectively) was inhabited by simuliids only. In 1976 there were no filter-feeders at Stations 6, and simuliids and hydropsychids dominated at Stations 3–5b. Philopotamidae, which were recorded at Station 3 in the initial survey, were not collected at this site in 1978–79. At Stations 3, 4 and 5 Simuliidae were always the most numerous filter-feeders during 1978–79 except in September 1978 when Hydropsychidae, particularly early instar larvae, were more common. A similar pattern was seen in 1976

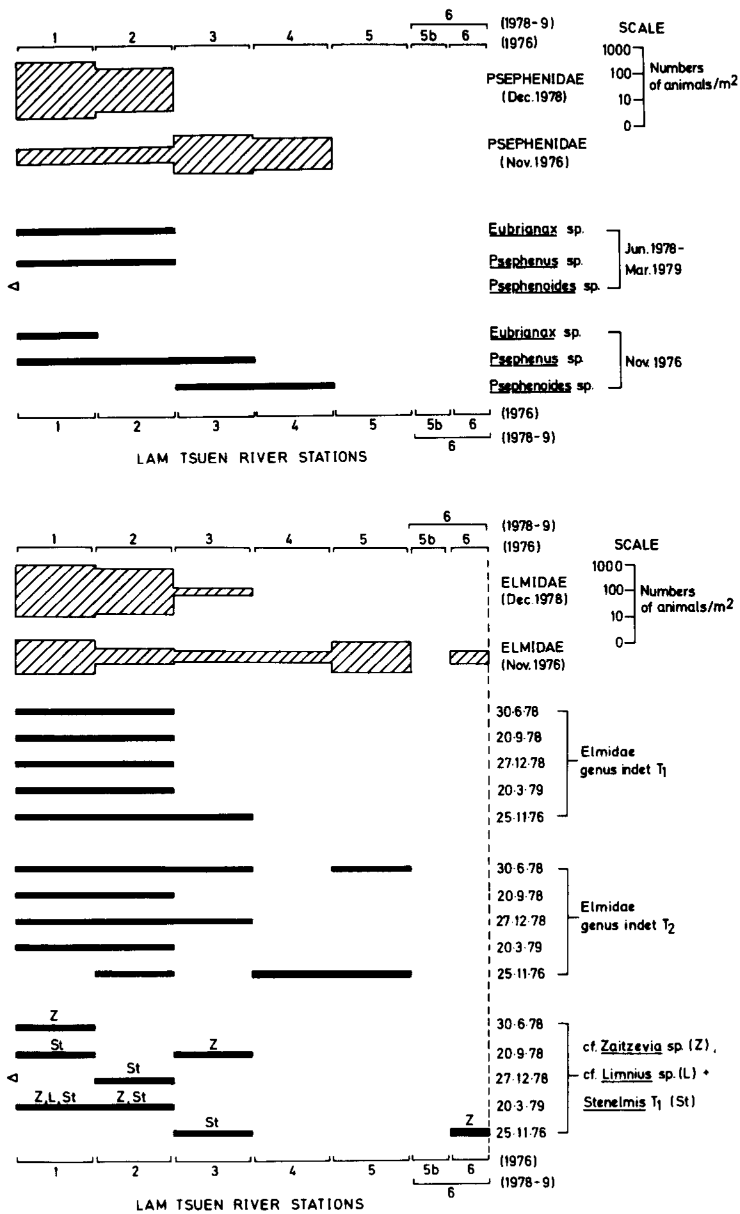


Fig. 34. The distribution and abundance of larval Psephenidae and Elmidae (Coleoptera) in the Lam Tsuen River in November 1976 and December 1978. Also shown is the distribution of individual taxa of these families in 1976 and 1978–79.

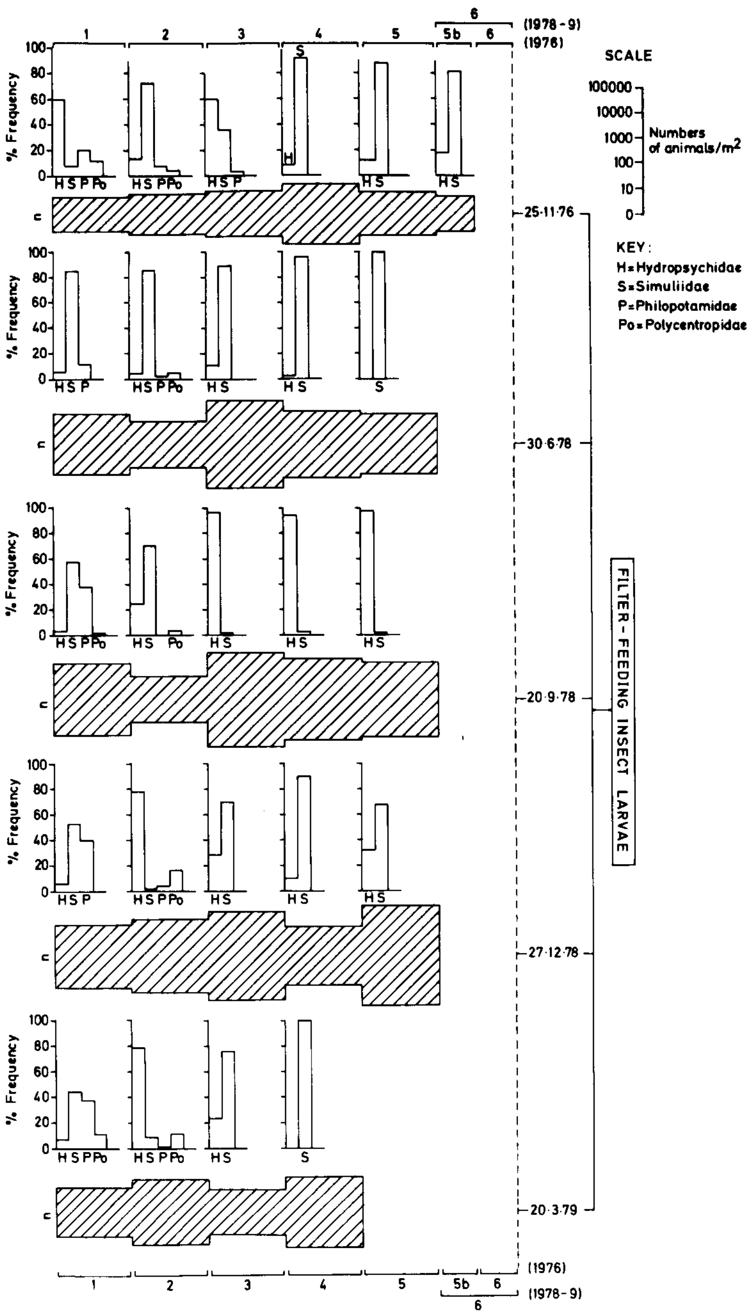


Fig. 35. The distribution and abundance of families of filter-feeding insect larvae in the Lam Tsuen River in 1976 and 1978–79.

when simuliids dominated at Stations 4, 5 and 5b although not at Station 3. In the later survey, simuliids and philopotamids were common at Station 1, with polycentropids being the least abundant filter-feeders. By contrast, hydropsychids dominated at Station 2 in December 1978 and March 1979 and polycentropids were more numerous at this site than at Station 1. The situation was reversed in 1976 with simuliids dominant at Station 2 and hydropsychids more abundant at Station 1 (Fig. 35). Filter-feeders were generally more numerous in the Lam Tsuen River in 1978–79 although the filter-feeding assemblage was generally less diverse in the middle and lower course of the river, as shown by, for example, the elimination of philopotamids at Station 3. Overall, the general increase in filter-feeders reflected higher population densities of hydropsychids and simuliids although only certain species within these taxa were favoured by conditions prevailing in 1978–79 (see Figs. 30–32).

It should be noted that no attempt was made to estimate the importance of chironomid larvae as filter-feeders in this study as these animals can adopt grazing or suspension feeding modes of life according to microhabitat conditions (McLACHLAN 1977).

C. Sediments

Substrate characteristics showed marked downstream variations and seasonal changes. Mean particle size and sediment sorting tended to decrease downstream (Figs. 36 and 37) as a result of increased proportions of smaller particles in the middle and lower course of the river. This increase tended to make the substrate better sorted by comparison with upstream reaches where the sediments comprised mainly coarse particles. By contrast with mean particle size and sorting, skewness and kurtosis showed general downstream increases (Figs. 36 and 37) as the fine "tails" of the sediments increased (thereby increasing skewness) and the "peakedness" of the particle size distribution was reduced (causing kurtosis values to approach 1.00). The downstream decrease in mean particle size and sorting was altered seasonally as a result of increased river discharge volume in the summer wet season. This scoured fine sediments from the middle reaches of the river causing mean particle size and sorting to increase at Station 4 in September 1978 (Fig. 36). With decreasing discharge volume in December 1978 through March 1979, a return to the general pattern of downstream decreases in these parameters was observed (Fig. 37).

Some variations from trends mentioned above were seen at Station 6 reflecting periodic inflation and deflation of a fabri dam immediately upstream of this site (just below Station 5b) which altered discharge volumes and thus patterns of erosion and deposition of river sediments. Overall, the sediments of the Lam Tsuen River were fairly coarse, positively skewed and leptokurtic due to the subordinance of the fine particle fractions.

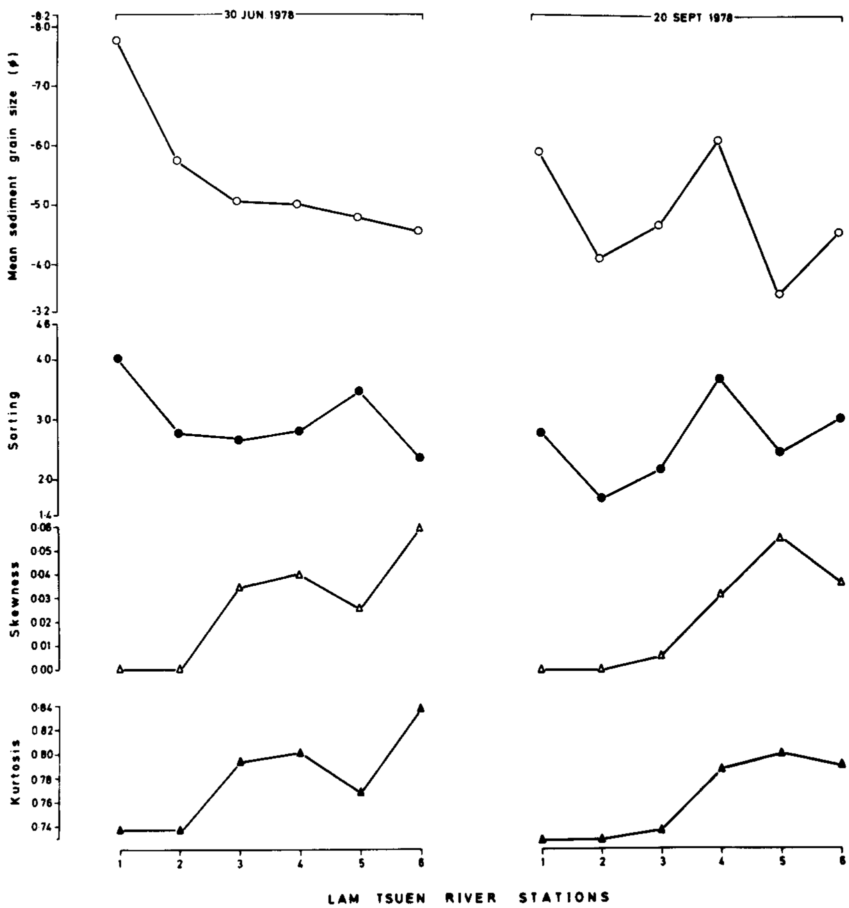


Fig. 36. Mean grain size, sorting, skewness and kurtosis of sediments collected from six stations along the Lam Tsuen River on 30 June 1978 and 20 September 1978.

There was a general tendency for the percentage of organic matter in the river sediments to increase with decreasing particle size and thus the smallest grain sizes (>4 Ø or <63 μm) were the richest in organic material (Fig. 38). Superimposed upon this pattern was a slight downstream trend towards increased amounts of sedimentary organic matter (especially at Stations 4, 5 and 6) which was most marked in the smaller particle sizes. In addition, seasonal changes were apparent, with organic matter increasing in the absence of high discharge volumes. For example, percentages of organic matter were relatively low in June and September 1978, reflecting the effects of the wet season, when compared with those during the remainder of 1978–79. Conversely, the highest values were recorded in March 1979 after a prolonged period without rainfall. At this time downstream increases in sedimentary organics were least noticeable as a result of accumulations of this material in substrates at all sites.

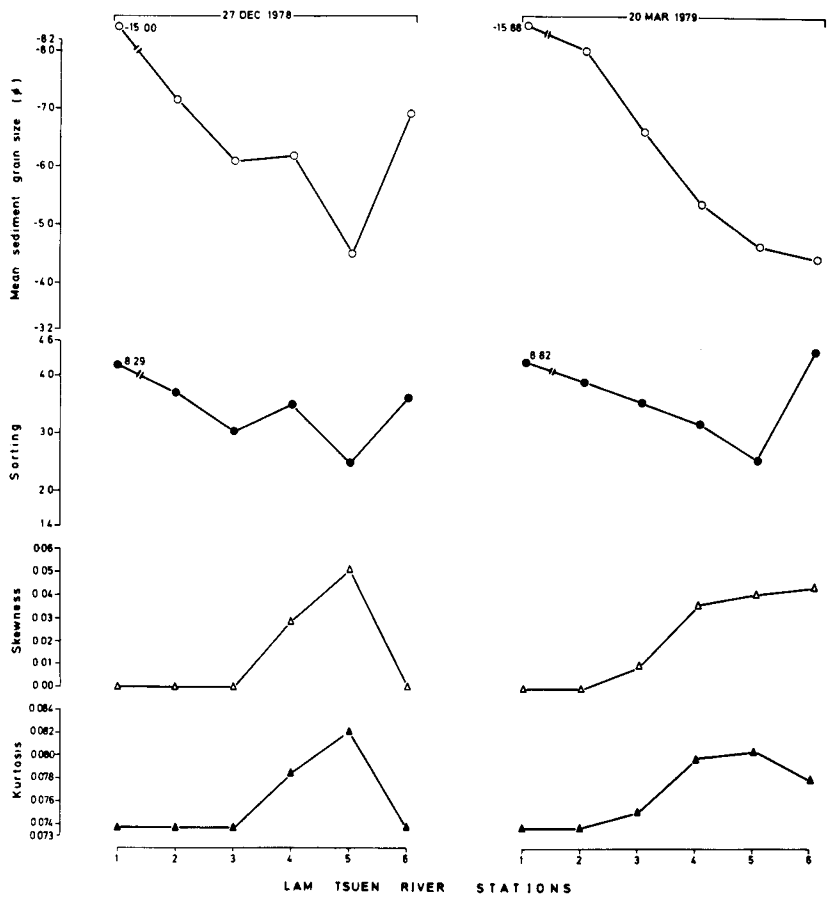


Fig. 37. Mean grain size, sorting, skewness and kurtosis of sediments collected from six stations along the Lam Tsuen River on 27 December 1978 and 20 March 1979.

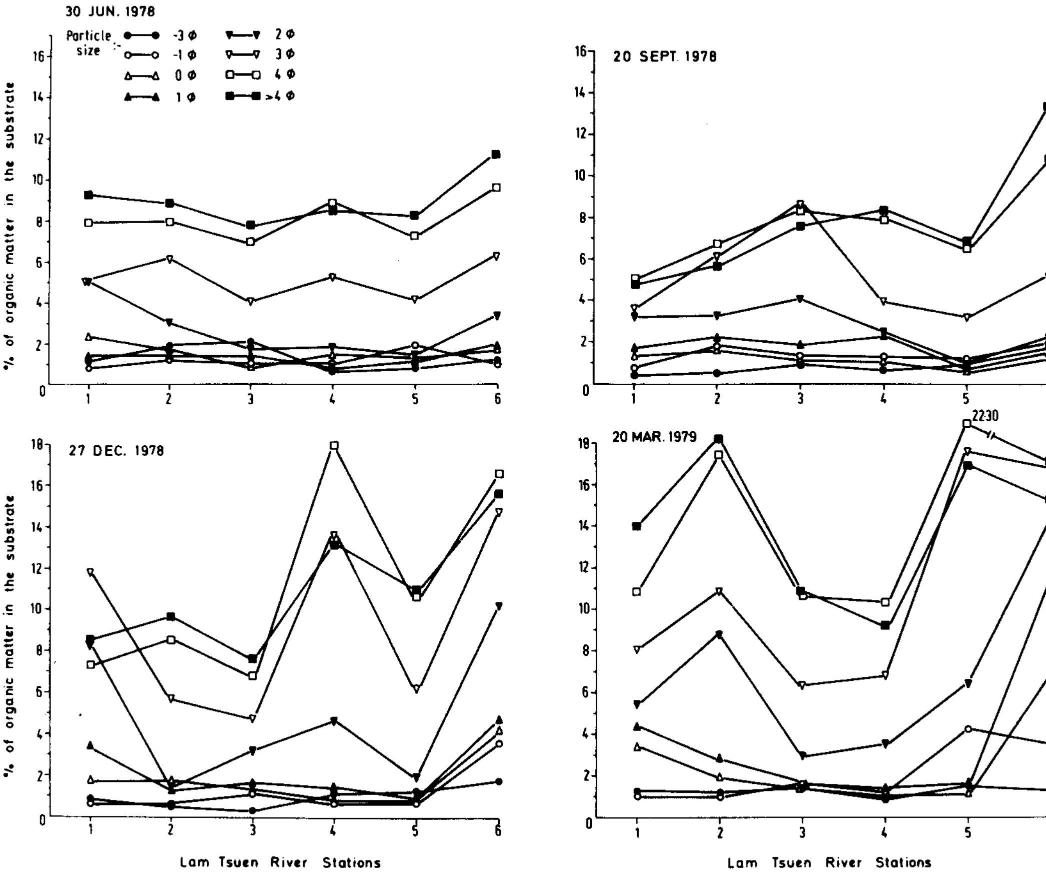


Fig. 38. The percentage of organic matter in eight particle size classes of sediments collected from six stations along the Lam Tsuen River on four occasions during 1978–79.

Discussion

The original condition of the waters of the Lam Tsuen River (prior to extensive settlement and cultivation of the valley) are not known. But, on the basis of available information on freshwater habitats in Hong Kong (e.g. DUDGEON 1982a) and data on the hydrology of the upper reaches of the river, as well as the geology of the drainage basin, an estimate of the original situation can be made. The waters were probably slightly acidic and soft with low hardness levels but rich in dissolved silicates. It is likely that nitrogen and phosphorus compounds were present in small concentrations and low levels of most ions would produce low conductivity values. GOLTERMAN (1975) has discussed the relationship between phosphate and silicate ions in inland waters, recording that an average silicate/phosphate ratio of 110 can be computed. This relationship is based on the assumption that phosphate is eroded in a constant ratio to silicate and thus this value can be used to estimate natural phosphate loading, in contrast to that arising from human impact. Assuming that the concentration of silicates in the Lam Tsuen River in 1976 was not greatly different from the amounts present in the undisturbed drainage basin (which is reasonable as cultivation of the river valley would be unlikely to induce long-term rises in dissolved silicates), then the original phosphate levels can be calculated. On this basis, Station 2 would have experienced mean phosphate concentrations of 0.064 mg/l and Stations 3, 5b and 6 mean concentrations of 0.065, 0.066 and 0.163 mg/l respectively. The large variation between the latter two sites may reflect the fact that the original silicate analyses were undertaken by workers in different laboratories (Table 2).

On the basis of the computed values for "original" Lam Tsuen River water phosphate concentrations and actual phosphate levels in 1976 (Table 2), it is apparent that by 1976 Stations 1 and 2 showed no signs of organic enrichment, whereas at Station 3 there were indications of the presence of small amounts of additional nutrient. Sites further downstream showed amounts of phosphate in excess of naturally expected levels. Thus in 1976 the distribution of benthic macroinvertebrates may have been influenced by the presence of excess dissolved nutrients. Downstream increases in nutrients are not generally characteristic of running waters although they can occur in streams fed by melt-water (SLACK et al. 1979) or those which flow through valleys composed of readily soluble rocks. On the contrary, the tendency for undisturbed catchments to conserve nutrients (BRINSON 1977; VITOUSEK 1977; GOSZ 1978) would probably lead to a downstream dilution of dissolved substances, a trend which would be magnified by the decrease in input area (i. e. the river bed and banks) in relation to the increasing size and volume of the lotic habitat. Additionally the input of extra water from tributaries may further dilute the mainstream (GOLTERMAN 1975). Studies of rivers showing apparently natural downstream increases in dissolved material (BISHOP 1973; GOLTERMAN 1975) as well as those showing no significant change (PETR 1977) are present in the literature. Such changes are rarely of great magnitude and it is unlikely that the downstream increase in nutrient concentrations in the Lam Tsuen River in 1976 were wholly of natural origin.

Significantly, the use of GOLTERMAN's method of ratios to calculate phosphate levels from known silicate concentrations in Tai Po Kau Forest Stream (which is situated in an undisturbed watershed) in Hong Kong, yields a value of 0.16 mg/l of phosphate which is quite close to the actual mean value of 0.10 mg/l recorded between May 1977 and May 1979 (DUDGEON 1982a). Allowing for some variation around the value of the ratio (as suggested by GOLTERMAN 1975), the agreement between observed and expected values is surprisingly good, thereby giving support to the use of theoretically calculated phosphate concentrations to characterize the "natural" hydrology of the Lam Tsuen River.

The observed increases in Lam Tsuen River nutrients in 1978–79 when compared to 1976 reflect increased cultural eutrophication of the river waters. Although the hydrology of Stations 1 and 2 differed only slightly from conditions expected in the undisturbed river (phosphate concentrations at Station 1 were similar to the calculated value obtained using the lower deviation from the mean of GOLTERMAN's ratio), there was a trend for nutrient levels at Station 2 to exceed those upstream. However, this trend was insignificant when compared with the magnitude of the downstream change between Stations 2 and 3 and the high nutrient levels recorded in the middle and lower course of the river. The downstream change in mean nutrient concentrations between Stations 1 and 6 in 1978–79 was substantial, 22.78, 10.45 and 56.33 fold for phosphate, nitrates and nitrites respectively. The maximum downstream change in nitrate concentrations (14.67 fold) occurred between Stations 1 and 5, and a drop in nitrates was recorded at Station 6. This was not regularly associated with a concommitant nitrite increase despite low oxygen tensions at Station 6, and it is possible that the disappearance of nitrate was associated with the activity of aquatic macrophytes at this site. The most abundant of these, *Eichhornia crassipes,* is known to actively remove nitrogen salts from the water column and takes up nitrogen from solution twice as quickly as phosphorus (CORNWELL et al. 1977). Significantly the growth of *E. crassipes* is enhanced by high phosphate concentrations (WIDYANTO 1976) and thus this nutrient may indirectly increase the uptake of nitrogen compounds at Station 6.

In contrast to the dramatic downstream increases in nutrient concentrations in the later survey, changes in pH, conductivity, water temperature and dissolved oxygen were slight and of similar magnitude in 1976 and during 1978–79. pH decreased downstream and was accompanied by increased conductivity. Both parameters showed only small changes possibly indicating that aside from nitrogen and phosphorus compounds there were few other dissolved ions present. Downstream changes in water temperature were slight but the upstream stations tended to be cooler. This trend was reduced in winter when little variation between stations was noted. Similar findings have been recorded for a river in northern England (BOON & SHIRES 1976). Downstream increases in water temperature were also noted by HYNES & WILLIAMS (1962) and PETR (1977) in East African rivers, the magnitude of these changes varying according to altitudinal differences between sites. Indeed, the small height difference between Stations 1 and 6 may account for the rather minor temperature differences along the Lam Tsuen River.

In 1976 and 1978–79 oxygen concentrations decreased downstream. The largest drop was recorded between Stations 5 and 6, oxygen concentrations never falling below 7.2 mg/l at Station 5. The shallow and swiftly flowing river waters would enhance oxygenation and the presence of *Hydrilla verticillata* in the middle and lower reaches would contribute oxygen to the water during daylight. Low oxygen levels at Station 6 reflect slow water flow and decreased turbulence at this site, as well as the large beds of *Eichhornia crassipes* which sometimes covered over

90% of the water surface and would tend reduce gaseous exchange (McLACHLAN 1969; RAI & MUNSHI 1979).

B.O.D. values in 1978–79 were high at Stations 4, 5 and 6, and were on average 5.5 fold higher at Station 3 than those recorded upstream. Mean values from Stations 1, 2 and 3 were little different from those in 1976. B.O.D. showed a marked rise at Station 6 in the later study (an average increase of 4.6 fold) and this is in keeping with increased use of the river for agricultural waste disposal as reflected by changing nutrient loads. Further evidence of the input of materials from the surrounding terrestrial landscape can be seen from variations in seston composition and abundance. Seston loads increased from the headwaters to the lower course probably reflecting greater run-off from disturbed (agricultural) lands (VITOUSEK 1977). Peaks in seston loads were seen at Station 4 although Station 5 also showed heavy loads. Quantities of seston were generally slightly lower at Station 6 reflecting reduced current speeds and the trapping of suspended material on the dangling roots of *Eichhornia crassipes*. Downstream increases in seston have been recorded by CHUTTER (1963) and BISHOP (1973) and may indicate a general characteristic of running waters which is emphasized in habitats affected by the activities of man (e.g. ALLANSON 1961; BRADT 1978). The percentage of suspended organic matter showed quite small changes along the river, mean values varying from 57.57% at Station 1 to 64.34% at Station 6. The higher values in the lower course were probably due to the inputs of particulates rich in organic matter from riverside farms and settlements.

Microscopic examination showed that seston composition changed along the river. The bulk of suspended material at Station 1 consisted of diatoms or was derived from the breakdown of terrestrial plants. By contrast, at Station 6 much of the seston comprised algal (Chlorophyta) unicells, filamentous algae and aquatic macrophyte tissue. Although the relative proportions of the main categories at Stations 1 and 6 varied somewhat with season, there was a constancy in general seston composition. Elsewhere in the river animal derived detritus and unidentified detritus were important seston components. The latter was particularly significant at Station 4 where it made up almost the entire suspended load. This unidentifiable material was different from the detrital aggregates collected at Stations 1 and 2 and although impossible to characterize precisely probably comprised pig and fowl faeces combined with farmyard washings. This suggestion gains support from the association of such detritus in the river with materials such as feathers which were clearly derived from domestic animals, as well as the presence of livestock in the neighbourhood of sites where unidentified detritus was a major seston component (Stations 3, 4 and 5). Significantly, in March 1979 this material comprised over 80% of the seston at Station 4 where a section of the river upstream of the sampling site was used for duck farming. At Station 5 the effects of agricultural activity were less apparent and the water was clearer. Here the sediments were covered with filamentous algae and small areas of *Hydrilla verticillata;* the increased proportions of algae and macrophyte tissue in the seston reflect this change.

Considering the hydrology of the Lam Tsuen River over 1978–79 as a whole (Table 3), a general downstream increase in nutrients, B.O.D.$_5$ and seston can be seen, hydrology at Station 1 (and probably Station 2) indicating "natural" headwater conditions. In general, increased nutrients, B.O.D.$_5$ and seston loads in the middle and lower course of the river can be related to agricultural activities in the surrounding valley and the magnification of downstream nutrient increases when compared to 1976 undoubtably relate to increased settlement and agricultural activity in the surrounding terrestrial environment.

Although samples from the Lam Tsuen River were collected on only four occasions in 1978–79, they were timed so as to include the range of flow and discharge conditions prevailing in the study area. There were no significant seasonal influences on pH, conductivity or oxygen tension in the river. However, seasonal differences in phosphate concentrations were seen with the lowest values recorded in June 1978 (soon after the onset of summer rains), when the difference between concentrations in headwaters and lower reaches was least. The low concentrations in June could be related to spates caused by summer rains which would tend to "flush out" accumulated nutrients. In September 1978 (towards the end of the wet season) phosphate concentrations were higher and showed a regular downstream increase indicating a relatively constant rate of phosphate input throughout the river system. This may reflect the leaching of phosphates from agricultural land (OSBORNE et al. 1980; WENDT & COREY 1980) which are more extensive in downstream areas. Although the late summer rains are less intense than those falling in June and July, they fall on soil "well wetted" by the earlier summer precipitation and in such conditions phosphates which are normally chemically bound in the soil (NELSON 1970) are able to percolate into the river.

A general increase in phosphate levels in the middle and lower course of the river during December 1978 and March 1979 was the result of concentration of nutrient inputs within the small volumes of water flowing in the dry season. This trend was particularly marked at Station 3, phosphate inputs coming from a chicken and a pig farm near to the river. High levels at Station 4 were maintained by a duck farm. Significantly, FISH (1969) has recorded that elevated phosphate concentrations are indicative of the input of faecal matter. Increased phosphates enhanced the growth of *Sphaerotilus* which was common in the river at Station 4 and present at Stations 3 and 5 in March 1979.

Nitrate concentrations generally increased downstream. In June 1978, nitrates exceeded nitrites at all sites, high nitrate concentrations possibly resulting from the wash-off of fertilizers into the river. Additionally, nitrification processes vary with current velocity (ALLANSON 1969) and the spates occurring in June may have enhanced conditions for the oxidation of nitrites to nitrates. Nitrates are fairly easily leached from soils and thus an early summer (June) peak in concentrations was followed by lower values in the river as a whole towards the end of the wet season (September). Decreased discharge increased the magnitude of downstream increases in nitrates in December 1978 as water percolating through the soil into the river, or entering through surface run-off, would contain well oxidized nitrogen salts derived from organic and inorganic fertilizers which had lain on agricultural land during the dry autumn thus receiving a relatively long exposure to air. In March 1979, most of the nitrates and nitrites in the river were probably a result of direct input from farms and riverside dwellings as the lack of rain in the winter would reduce surface and sub-surface run-off and percolation. Consequently, nitrates and nitrites occurred in almost equal proportions in March as wastes from farms and dwellings would be in a variety of oxidation states. Significantly, at Stations 1 and 2, which were not generally affected by the input of nutrients nitrates were always in excess of nitrites. Increased nitrate concentrations at these two sites in March probably reflected the reduced volume of water flowing in the river.

The wash-off of organic material from the surrounding agricultural lands in the Lam Tsuen Valley during the summer rains caused elevated B.O.D. values in June 1978. However, low B.O.D. values at Station 3 in June and September 1978 coincided with low phosphate concentrations and, although other explanations are possible, it is conceivable a lack of phosphates may limit biological oxygen demand. This premise gains support from the increased B.O.D. values at Station 3 in December 1978 and March 1979 when phosphate concentrations were high. Greatest B.O.D. values were recorded at all sites in March when the river volume was least and nutrient loads were high.

HYNES (1960) cites B.O.D.$_5$ values of 1–2 mg/l or less as indicative of clean water, 4–7 mg/l for slight to moderate pollution. On this basis, in 1978–79 Stations 1 and 2 were clean, Stations 4, 5 and 6 were severely polluted, and Station 3 varied between slight pollution in June and September and severe pollution at other times. Such changes in pollution status can be related to rainfall and the concomitant variation in river discharge volume.

Seasonal variations in seston composition can be seen from the decrease in seston organic matter (by a factor of about 30%) during periods of high flow in June and December 1978. During the summer the carrying capacity of the river is increased due to large volumes of swiftly flowing water; additionally, soil particles washed into the river by surface run-off will increase the inorganic load. By contrast, December and March were characterized by a seston rich in organic matter because the reduced discharge volume of the river had little power for the transport of dense inorganic particles.

The overall effects of changes in river discharge volume were most apparent at Station 3. In June and September 1978, water quality resembled that prevailing at Stations 1 and 2; in December 1978 and March 1979 conditions were more similar to those in the polluted reaches represented by Station 4 and 5. There was a tendency for the polluted section of the river to extend upstream during the autumn and winter, the river as a whole being "flushed out" by summer rains thereby shifting the polluted region downstream. Against this background, the seasonal and longer term (1976–78) changes in distribution of macroinvertebrates can be discussed.

Many freshwater biologists have noted that lotic faunal communities display patterns of longitudinal zonation (HYNES 1970; HAWKES 1975), and there have been numerous attempts to classify rivers by dividing their courses into zones with characteristic faunas. Unfortunately such schemes are unlikely to be applicable outside the regions within which they were formulated and a more general approach was proposed by ILLIES (1961) which divides rivers into two zones – the upstream rithron, and the downstream potamon. Families of invertebrates characterizing rithron and potamon zones have been listed by BAYLY & WILLIAMS (1973) and HAWKES (1975).

Findings of the 1976 survey of the Lam Tsuen River are the only information on the longitudinal distribution of macrobenthos in a river in Hong Kong. Although the hydrology showed signs of modification from "natural" conditions, there is evidence that in mildly polluted habitats the natural downstream transition of faunal associations is not greatly altered although inputs of pollutant may cause some marked discontinuities between biocoenoces (ILLIES 1961; THORUP 1966). This contrasts with the general downstream transition of the biota seen in unpolluted rivers (MAITLAND 1966) but, in the absence of other information, the distribution of the Lam Tsuen River macrobenthos in 1976 was considered on the basis of how it fits into the general scheme of the rithron-potamon classification of lotic habitats. It should be emphasized that division of the Lam Tsuen River into rithron and potamon regions follows the methodology of BISHOP (1973) who found that rigid application of temperature criteria, as used by ILLIES (1961) to define rithron and potamon, is inadequate in the tropics. Instead the rithron was characterized on the basis of its physical character and the presence of specialized torrent fauna (e. g. HORA 1930; ROSS 1956). BISHOP (1973) suggested a mean temperature of approximately 25 °C or less as characterizing the rithron, and higher temperatures as indicative of tropical potamon regions. On such bases, Stations 1 and 2 can be said to represent rithron, the potamon including Stations 4, 5 and 6. Station 3 occupies an intermediate position but is physically and topographically akin to the latter grouping.

In 1976, the number of taxa and diversity of benthic macroinvertebrates decreased in a downstream direction. By contrast, MINSHALL (1970) and SLACK et al. (1979) state that the number of species in a river increases as one passes from the headwaters to the mouth. In the Lam Tsuen River downstream increases in nutrients could cause a reduction in benthic diversity (PATRICK 1954; PATRICK et al. 1954; WILHM 1970a). However, taxa associated with the roots of floating *Eichhornia crassipes* and trailing riparian vegetation were not sampled; undoubtably these would have contributed to lower course diversity in the Lam Tsuen River. A possible cause of downstream decreases in numbers of benthic taxa is silt deposition which would clog interstitial pore spaces and tend to reduce the complexity of the substrate habitat (BISHOP 1973; DUDGEON 1982c). Indeed, the detrimental effects of silting on macrobenthic community diversity are well known (CHUTTER 1969; LEUDTKE et al. 1976; WHITE 1977; WILLIAMS & MUNDIE 1979) and may have had an effect on the Lam Tsuen River benthos. There was no obvious correlation of benthic faunal abundance with the number of taxa present at each site in 1976. This reflects the tendency of certain macroinvertebrates to become more numerous and fill niches vacated by other species which are unable to survive under prevailing conditions. (PATRICK 1954; CAIRNS 1974; WILHM 1975).

The distribution of individual taxa along the river in 1976 was rarely continuous and few taxa occurred at all sites. Benthic crustaceans were represented by Ostracoda which showed discontinuous distribution patterns. Less common were the decapods *Macrobrachium hainanense* (PARISI) (Palaemonidae), *Caridina lanceifrons* YU and *Neocaridina serrata* (STIMPSON) (Atyidae), and *Potamon* sp. (Potamonidae) all of which were usually associated with trailing roots and fronds of riparian vegetation.

Immature insects dominated the macrobenthos of the Lam Tsuen River and Ephemeroptera were particularly well represented by 30 taxa. 31 ephemeropteran taxa have been recorded from Tai Po Kau Forest Stream, Hong Kong (DUDGEON 1981); 10 of these did not occur in the Lam Tsuen River. These totals are similar to 44 mayfly species collected by BISHOP (1973) in the Sungai Gombak, Malaysia, and 42 noted by SOWA (1975) in Polish Rivers. The totals of ULFSTRAND (1968) and BAGGE & SALMELA (1978) in Lapland and Finland respectively are somewhat lower. Clearly, ephemeropteran diversity in the Lam Tsuen River is comparable to that of other regions where downstream zonation of these animals has been observed (e.g. HYNES 1961; MAITLAND 1966; WISE 1976; TOWNS 1979). Such distribution patterns were noted for mayflies in the study area in 1976. Heptageniids were generally restricted to the upper course. *Epeorus*, a torrent dwelling genus adapted to clinging onto boulders (HORA 1930), was restricted to Stations 1 and 2 although one species also occurred at Station 3. *Ecdyonurus* spp. were also found at Stations 1–3 although *Ecdyonurus* T_2 occurred in small numbers at Station 5. Heptageniids could be generally classified as rithron inhabitants and several studies indicate that they are characteristic of stony streams and the upper course of rivers (MACAN 1957; HARRISON 1965; BISHOP 1973).

Baetidae were recorded throughout the study area in 1976 and were especially common at Stations 3, 4 and 5 where lush growths of periphytic algae may have served as an abundant food source (cf. BROWN 1961). *Pseudocloeon* T_1 was most abundant in the rithron but many taxa were potamon dwellers (*Baetis* cf. T_3, L_6, L_7 and L_8) whilst others were collected throughout the river (*Baetis* T_1, T_2, T_3 and T_5, *Pseudocloeon* T_2) or showed no obvious habitat preferences (*Baetis* T_4, *Pseudocloeon* T_3). These distribution patterns may reflect ecological divergence within the Baetidae and this suggestion gains support from species-specific patterns of baetid distribution recorded from a variety of rivers and streams (MACAN 1957; BISHOP 1973; WISE 1976; DUDGEON 1982b). Significantly, LINDUSKA (1942) has shown that different species of *Baetis* show varying responses to current velocity.

The Caenidae were favoured by conditions in the middle and lower course of the Lam Tsuen River in 1976 and *Caenis* L_2 and L_3 were found only at Stations 3–6. Conversely, *Caenis* T_1 and T_2 were more common in the middle and upper reaches although caenid abundance was greatest in the middle and lower course. This pattern of abundance can be accounted for by the unusual structure of the second gill (which forms an operculum over the succeeding pairs) and the pattern of gill beating (EASTHAM 1932) which allow these insects to survive in silty habitats without clogging of the respiratory surfaces. Such animals are clearly adapted to life in the potamon and yet also occur (in smaller numbers) in the rithron region.

Ephemerellids were less numerous than the Caenidae or Baetidae. Downstream reaches were occupied by *Ephemerella* L_3 but, by contrast, *Ephemerella* T_1 was restricted to Station 1 and *Ephemerella* T_2 occurred at Stations 1–4. Although temperature effects on life-history patterns have been cited as a factor determining the longitudinal zonation of ephemerellids in Japan (MIYATA 1976), variations in water temperature along the Lam Tsuen River were not sufficiently great to have had such an effect. Clearly these animals cannot be described as restricted to either rithron or potamon habitats.

Leptophlebiid mayflies were represented by three taxa in the Lam Tsuen River in 1976; five taxa were recorded from Tai Po Kau Forest Stream (DUDGEON 1981). *Choroterpes (Euthraulus)* L_1 was found at Stations 3–6 and was replaced at Stations 1 and 2 by *Choroterpes* T_1 and *Isca* sp.

The restriction of *Isca* sp. to the upper course of the Lam Tsuen River results from the tendency of such animals to occupy the central portion of the stream bed where the currents are swiftest (DUDGEON 1982b). This observation indicates that *Isca* is a rheophilic taxon and BISHOP (1973) notes that this genus is generally characteristic of headwater sites in Malaysia. *Choroterpes (Euthraulus)* L_1 was the most numerous leptophlebiid in the river although was not collected in Tai Po Kau Forest Stream. Significantly, several potamon dwelling species of Baetidae, Caenidae and Ephemerellidae were not recorded from Tai Po Kau Forest Stream where the trophic base appears to be allochthonous leaf litter (DUDGEON 1982d, 1983c). By contrast, periphytic algae was abundant in the unshaded middle and lower course of the Lam Tsuen River in 1976 and may favour the proliferation of certain herbivorous mayflies.

Any attempt to fit the distribution of Lam Tsuen River mayflies into the rithron-potamon scheme of classification is confused by the range of habitats occupied by the same or closely related genera. Heptageniidae were generally restricted to the upper course of the Lam Tsuen River, thus supporting their status as rithron inhabitants (BAYLY & WILLIAMS 1973; HAWKES 1975). By contrast, Baetidae and Caenidae occurred throughout the river and the classification of caenids as rithron inhabitants (HAWKES 1975) does not accurately reflect conditions prevailing in the study area. Indeed, when the rithron-potamon classification is applied to the Ephemeroptera of the Lam Tsuen River, observed distribution patterns do not always follow those predicted by the system. Such divergence has also been recorded in a Malaysian river (BISHOP 1973). The index used to establish habitat preferences for a particular taxon is of prime importance; in the case of Leptophlebiidae and Ephemerellidae, different conclusions as to preferences for rithron or potamon regions can be drawn according to whether the number of species or abundance of individuals is used as a measuring unit. In this context, the significance of high nutrient levels and algal standing stock in the middle and lower course should be considered, as the availability of food would probably allow the maintenance of artificially high mayfly population densities in such localities.

Although Odonata have sometimes been classified as potamon dwellers, *Euphea decorata* SELYS (Eupheaidae) is restricted to upstream areas of lotic habitats (cf. FURTADO 1969; BISHOP 1973) and this is also true of *Heliogomphus sinicus* in the Lam Tsuen River. *Ictinogomphus pertinax* inhabits the potamon of Lam Tsuen River and lentic habitats in Hong Kong, whilst a third gomphid, *Onchogomphus* T_1, was widespread throughout the study area. The libelluid *Zygonynx iris* was also widely distributed and is generally found clinging to rock surfaces (FURTADO 1969). Clearly, the Odonata as a whole cannot be fitted into any simple scheme describing patterns of zonation.

Plecopterans were a relatively small component of the Lam Tsuen River macrobenthos and only two families, the Perlidae and Nemouridae, were collected. These animals were restricted to the upper reaches of the river and could be considered as rithron inhabitants. A similar distribution pattern is recorded by TOWNS (1979) who found that plecopterans were largely restricted to cool river tributaries in New Zealand or were only common in mainstream areas during the winter. Although the Nemouridae are generally regarded as rithron inhabitants (HARRISON 1965; BISHOP 1973; HAWKES 1975), perlids are often classified as potamon dwellers (HAWKES 1975) despite the fact that they may also occur in the rithron (BISHOP 1973). MAITLAND (1966) and KERST & ANDERSON (1975) state that there is a natural tendency towards downstream decreases in plecopteran diversity in certain river systems, and ROBACK (1974) records that stonefly nymphs are sensitive to high B.O.D. and elevated nutrient levels. It is therefore possible that the restriction of perlids to the rithron of the Lam Tsuen River in 1976 reflected unfavourable water quality in downstream areas.

Trichoptera were common in the Lam Tsuen River and although only 24 taxa were recorded (compared to 43 from Tai Po Kau Forest Stream), they were widely distributed between Stations 1 and 5b. Certain taxa were restricted to the upper reaches, including the Polycentropidae, Philopotamidae and some species of Hydropsychidae, as well as the scarcer Rhyacophilidae, Glossosomatidae, Psychomyidae and Odontoceridae. Only *Hydroptila* sp. (Hydroptilidae) was exclusive to the potamon, and this is in accordance with HAWKES (1975) classification of hydroptilid habitat preferences. The Rhyacophilidae and Philopotamidae are considered as rithron inhabitants (HARRISON 1965; BAYLY & WILLIAMS 1973; HAWKES 1975) and this is supported by the research of BISHOP (1973) and TOWNS (1979). BAYLY & WILLIAMS (1973) and HAWKES (1975) consider that *Chimarra*, the commonest philopotamid genus in Hong Kong, should not be considered as typical of rithron regions. Despite this, *Chimarra* spp. were found in the upper course of the Lam Tsuen River and have been recorded from the headwaters of other tropical rivers (HYNES & WILLIAMS 1962; BISHOP 1973). The exclusion of this genus from lists of rithron inhabitants by HAWKES and BAYLY & WILLIAMS is probably related to the occurrence of *Chimarra* in tropical and warm-temperate rivers (ROSS 1956) and indicates the futility of applying temperature as a criterion for defining rithron and potamon reaches.

The Polycentropidae and Psychomyidae have been recorded as being most common in the middle and lower course of rivers (e. g. BISHOP 1973) in contrast to their distribution in the study area. North American members of these families lack tolerance for waters affected by organic enrichment (ROBACK 1974), which may account for their absence from the lower course of the Lam Tsuen River. However it is unclear why these animals should occur in the upper course of the study area as well as in small, swiftly flowing hill-streams elsewhere in Hong Kong.

The Hydropsychidae were widely distributed within the Lam Tsuen River although individual species were often restricted to one part of the course. The tendency for hydropsychids to occur in a variety of conditions within a single river has been recorded by BISHOP (1973), HILDREW & EDINGTON (1979) and TOWNS (1979). PHILIPSON (1954, 1969) and EDINGTON (1965, 1968) have noted that water flow and oxygen concentration can affect the physiology and net-spinning activities of these animals, thereby restricting some species to torrential localities and others to less swiftly flowing waters. Due to their reliance on current for supplying food and oxygen, hydropsychids were not recorded from Station 6 where the current was rather sluggish. Overall, the Hydropsychidae were found in both the rithron and potamon although individual species were usually associated with one or other zone.

Most aquatic coleopteran larvae were confined to the upper or middle course of the Lam Tsuen River in 1976. The Elmidae have been categorized as rithron inhabitants (BAYLY & WILLIAMS 1973; HAWKES 1975) and this is in broad agreement with the findings of the present study. However, elmids were found in small numbers in parts of the lower course of the Lam Tsuen River and this is in accordance with the rather wide distribution recorded for elmids in other river systems (HYNES 1961; BISHOP 1973; TOWNS 1979). Helodidae and Psephenidae were largely restricted to the upper course of the Lam Tsuen River which is in agreement with the records of other workers (BAYLY & WILLIAMS 1973; BISHOP

1973; HAWKES 1975; TOWNS 1979). Only *Psephenoides* sp. (Psephenidae) occurred in significant numbers below the Lam Tsuen River rithron.

Chironomidae (Diptera) are ubiquitous inhabitants of lotic habitats and, at the level of taxonomic resolution employed in the present study, showed no marked discontinuities in their distribution within the Lam Tsuen River. *Chironomus* cf. *plumosus* was, however, most abundant at Station 6 where relatively low dissolved oxygen levels prevailed. The presence of haemoglobin in the haemocoel of *Chironomus* spp. enables them to survive in conditions where other chironomids would be caused respiratory stress (EWER 1942); this capacity could account for the dominance of *Chironomus* cf. *plumosus* at Station 6. There was a tendency for the ratio of Tanypodinae/Chironomidae to decrease in a downstream direction. Cultural eutrophication affecting the lower course of the river in 1976 allows Chironominae, which are able to rapidly exploit the increased food supply, to multiply (HYNES 1960; BRYCE et al. 1978; GOWER & BUCKLAND 1978). Such an increase would account for the observed downstream change in the ratio between these two chironomid trophic groups.

Simuliidae have frequently been classified as rithron dwellers (HARRISON 1965; BAYLY & WILLIAMS 1973; HAWKES 1975) but were collected from all but the lowest Station in the Lam Tsuen River. Similar larval blackfly distribution patterns are recorded by BISHOP (1973) and TOWNS (1979). Many factors can affect the distribution of Simuliidae, including temperature, current speed (ZAHAR 1951; PHILLIPSON 1956) and food availability (BISHOP 1973; CARLSSON et al. 1979). It is not clear why simuliids should be so widespread within the Lam Tsuen River, but increased food availability as a result of mild eutrophication may have allowed these animals to establish themselves in the potamon.

On the basis of a survey of the Lam Tsuen River in 1976, it is apparent that the details of river zonation and classification schemes only apply on a regional or local basis. The incidence of individual species possessing quite different distribution patterns within a genus of family indicate that even closely related taxa respond differently to a mosaic of environmental factors and it is unwise to state that all species within a given taxon will occur in a similar type of river habitat. However, there were general trends towards downstream changes in the composition of Lam Tsuen River macroinvertebrate communities which indicate that the concept of faunal zonation can be useful in a general descriptive way. Clearly, every river should be properly regarded as a complex and individual example and MAITLAND (1966) believes that the wide variety of organisms and interacting factors in rivers will defy attempts at classification.

The effects of increasing land use in the Lam Tsuen Valley between 1976 and 1978 have been discussed above with respect to changing water quality. There were also marked changes in the macrobenthic communities of the river, with diversity declining between 1976 and 1978–79. Decreases in diversity were most apparent at Stations 3–6, where there had been a significant deterioration in water quality.

Only minor changes in the macrobenthos of Stations 1 and 2 were observed and may have been the result of sampling variability.

At Stations 3 and 4 approximately 50% of the species present in 1976 were not recorded in 1978–79. By contrast, population densities increased by an average value of 15 fold. These changes were associated with elevated nutrient concentrations, B.O.D. values and seston loads. Significantly, REGER & KEVENS (1981) state that organic enrichment increases benthic standing crop and decreases diversity. Increased macroinvertebrate abundance can result from a rise in food availability, in the sediments (WARREN et al. 1964; BENNINGTON 1979) or in the water column (GODFREY 1978). Downstream increases in both sedimentary organic matter and seston load were noted in the study area during 1978–79.

WILHM (1970a, 1970b) has stated that macrobenthos diversity ($\bar{d}$) for a particular habitat is indicative of the prevailing degree of pollution. In December 1978 and March 1979, Stations 3–6 had $\bar{d}$ values similar to those quoted by WILHM for rivers polluted by oil, brine, chlorides, acids and a variety of industrial waters. In September 1978, diversity at Stations 3–6 was relatively high and in excess of that recorded by WILHM in polluted habitats. Spates in the river resulting from summer rains (June–September) increase drift rates of benthic taxa (e. g. WATERS 1972) thereby extending the downstream distribution of macroinvertebrate taxa confined to the "clean" headwaters with high faunal diversity. In addition these spates "flush out" the river and cause an improvement in water quality thus allowing "clean water" taxa to colonize the middle and lower course. For example, filter-feeders, especially Hydropsychidae, were abundant at Stations 3–5 in September 1978 and the density of such animals at Station 4 was the highest recorded at any time during this study. By contrast, in March 1979 Simuliidae were the only filter feeders recorded at Station 4 and both hydropsychids and simuliids had been eliminated from Station 5.

The responses of individual benthic taxa to deteriorations in the quality of Lam Tsuen River water were rather variable. Large oligochaete populations were found at Stations 4, 5 and 6 in 1978–79; these animals were not found in 1976. Oligochaetes typify conditions of considerable organic enrichment (RICHARDSON 1925, 1928; HARRISON 1958a; HYNES 1960; BRYCE et al. 1978) and feed upon the organic fraction of the sediments and associated microflora (BRINKHURST & KENNEDY 1965). Ostracods also increased in range and abundance in the study area and were most numerous at Stations 3–6 where the effects of cultural eutrophication were observed. One ostracod taxon was found only in the later survey. MCCLAY (1978) records that ostracods consume detritus and microflora, and such trophic "generalists", like oligochaetes, are undoubtably favoured by eutrophication and the concomitant increase in food supply. Gastropods were generally favoured by eutrophication and increased in abundance and diversity in 1978–79 (DUDGEON 1983b). Again food availability seemed an important factor and it is of interest that the exotic schistosome vector *Biomphalaria straminea* (DUNKER) (Planorbidae) colonized the Lam Tsuen River in 1978.

While non-insectan elements of the macrobenthos were generally favoured by increased organic enrichment, the responses of the insect taxa were widely varying. Within the Baetidae, species found in upstream and middle reaches in 1976 (*Baetis* T_1, T_2, T_3 and T_4, *Pseudocloeon* T_1) were confined to Stations 1 and 2 in 1978–79 with occasional records from Station 3 during the wet season. By contrast, species found in the middle or lower course of the river in 1976 (*Baetis* L_5, cf. T_3, L_6, L_7 and L_8, *Pseudocloeon* L_2) were able to extend their previous range to include one or more sites further upstream. However this extension was balanced by local extinctions in the lower course when water quality was particularly poor (e.g. March 1979). Most of the baetids in middle and lower course sites increased in abundance several fold between 1976 and 1978–79, the increases reflecting maintenance of high population densites probably as a result of greater food availability. Those baetids restricted to upstream sites were generally less abundant in the river as a whole during the later survey. Similar differential responses to pollution by closely related ephemeropteran taxa have been noted by HARRISON (1958a) and BRYCE et al. (1978). *Baetis* and *Pseudocloeon* inhabit waters of widely varying quality (ROBACK 1974) and numerous studies indicate that certain baetids are favoured by organic enrichment until their survival is limited by lack of oxygen or some other parameter (HARRISON 1958a; ALLANSON 1961; BISHOP 1973; BRYCE et al. 1978).

There is little detailed information on heptageniid pollution tolerances. BRADT (1978) records that *Stenonema* is found in the upper reaches of rivers and this is in line with morphological adaptations to torrential life of a variety of heptageniid genera in Hong Kong (e. g. *Iron, Thalerosphyrus, Epeorus*). Heptageniids were restricted to Stations 1 and 2 in 1978–79 which is in accordance with the observations of BISHOP (1973) on the decline in numbers of such animals in the polluted tributaries of a Malaysian river. Certainly the nitrite, phosphate and B.O.D. levels at middle course sites in the Lam Tsuen River during 1978–79 were far in excess of those tolerated by North American heptageniid nymphs (ROBACK 1974). Similarly, the extent of the river inhabited by leptophlebiids declined in 1978–79. In view of the similar modes of feeding of heptageniids and leptophlebiids (MERRITT & CUMMINS 1978) it is plausible that smothering of rock surfaces in the middle and lower course of the river by filamentous algae, *Sphaerotilus* and detritus could restrict these animals to upstream sites with relatively clean rock surfaces.

Ephemerella spp. were recorded at Stations 1–5 in 1976 but were only common at Stations 1 and 2, and scarce at Station 3, in 1978–79. The absence of ephemerellids from sites experiencing organic enrichment is predictable in view of their narrow water quality tolerances (ROBACK 1974). Caenidae were widespread in the Lam Tsuen River throughout the study period although *Caenis* T_1 and T_2 were restricted to the upper course in 1978–79. *Caenis* L_2 and L_3 were abundant at Station 3 and 5 and increased markedly in abundance between surveys thereby showing their ability to tolerate a wide range of environmental conditions (cf. ROBACK 1974). BISHOP (1973) has noted that *Caenis* spp. abundance is enhanced by increased food availability and COETZER (1978) records an increase in Caenidae (along with a decline in Ephemerellidae and Leptophlebiidae) accompanying organic enrichment. *Caenis* spp. occurred at different sites within the River Lee (U.K.) (BRYCE et al. 1978) indicating possible species-specific microhabitat preferences. Such preferences are also apparent in the varying distribution patterns of Lam Tsuen River Caenidae.

Range reductions of certain ephemeropteran taxa in 1978–79 did not cause an overall decrease in the numbers of mayflies in the river. Apparently, vacant niches left by the elimination of sensitive species in the middle and lower course are rapidly occupied by members of more tolerant taxa. Such a process is evident from the increased abundance and upstream range extensions of certain taxa (e.g. *Baetis* cf. T_3 and L_8) in 1978–79. By contrast to the Ephemeroptera, plecopteran nymphs showed no marked response to increased organic enrichment and were restricted to Stations 1 and 2 throughout the study. Although some increase in numbers was seen when abundance in December 1978 was compared with that in November 1976, this could have reflected nymphal recruitment as small perlids were particularly common on the later date. Plecopterans are generally regarded as pollution intolerant (GAUFIN 1958; HYNES 1960; ROBACK 1974) and are scarce in polluted river reaches (BISHOP 1973; BRYCE et al. 1978). ULFSTRAND (1975) has suggested that the differences between ecological parameters controlling mayfly and stonefly communities may be integrated in terms of differential selective pathways (MAC ARTHUR & WILSON 1967). The strategy of ephemeropterans is one of copious output of relatively unspecialized young which can thrive in situations where mild organic enrichment has increased the availability of food. A certain amount of intraspecific resource division can be achieved through a great variation in body size at any point in time. According to ULFSTRAND (1975), plecopterans have narrower feeding specializations, less violent numerical fluctuations and strong interspecific interactions; characteristics which would not be favoured in the course of community fluctuations associated with organic pollution. Plecoptera and Ephemeroptera seem to be placed far apart on the r to K selection scale and it is the r-selected mayflies which would be expected to fare better in habitats influenced by cultural eutrophication. Evidence based on the distribution and abundance of these animals in the Lam Tsuen River suggests that, for certain ephemeropteran taxa, this is indeed the case.

Odonate distribution and abundance did not change markedly over the study period, reflecting the wide range of water qualities tolerated by these animals (ROBACK 1974). Only *Zygonyx iris* showed a tendency towards a reduction in abundance in downstream reaches during 1978–79. This species clings to rock surfaces (FURTADO 1969) and its elimination from the lower course during much of the later survey is probably the result of extensive growths of filamentous algae and *Sphaerotilus* upon these substrates. The studies of BISHOP (1973) and BRYCE et al. (1978) indicate that the effects of organic pollution do not severely affect odonates, and burrowing taxa (e.g. Gomphidae such as *Onychogomphus* T_1) are apparently not directly influenced by siltation or enhanced periphyton growth.

For the sake of brevity, the response to increasing organic enrichment by the major trichopteran group (Hydropsychidae) and the Simuliidae will be discussed below when filter-feeding taxa are considered. The Chironomidae (Diptera) showed only minor changes in distribution between 1976 and 1978; the most significant of these was the elimination of Tanypodinae from Station 6 in 1978. According to ROBACK (1974), Tanypodinae are less tolerant of hydrological extremes than Chironominae, and oxygen may have been a limiting factor for these animals. Marked increases in abundance of other chironomids were recorded in the later study. Much of this increase comprised *Chironomus* cf. *plumosus* which was very abundant at Stations 3–6 but was not collected from upstream sites. *Chironomus* spp. characteristically occur in rivers and streams receiving organic enrichment (e.g. GAUFIN 1958; HYNES 1960; BISHOP 1973; PESEK & HERGENRADER 1976; BRYCE et al. 1978; COETZER 1978; GOWER & BUCKLAND 1978) and are considered indicative of organic pollution (RICHARDSON 1925, 1928; GAUFIN 1958; WILHM 1975); their distribution and abundance in the Lam Tsuen River during 1978–79 gives support to this assumption.

Coleopteran distribution was restricted in 1978–79 and all taxa were confined to the upper three sites, in particular Stations 1 and 2. This reflects what is known of the hydrological requirements of these animals (ROBACK 1974) and their need for clean, silt-free surfaces (LESAGE & HARPER 1976); the latter point is particularly relevant to the Psephenidae which are epilithic browsers. *Psephenoides* sp., which was recorded at Stations 3 and 4 in 1975, was not found in the later survey reflecting the effects of increased organic enrichment in the middle course of the river. Significantly, Psephenidae and Elmidae are usually poorly represented in localities affected by cultural eutrophication (e.g. RICHARDSON 1925, 1928; BISHOP 1973; ROBACK 1974; BRYCE et al. 1978).

The large increase in the numbers of filter-feeders (Simuliidae and Hydropsychidae) between 1976 and 1978 was a result of increased population densities at Stations 3–5. Greatest abundance was noted at Stations 3 and 5 and the lower densities at Station 4 may have reflected the high nutrient and B.O.D.$_5$ loads prevailing in 1978–79. High B.O.D.$_5$ is known to restrict the distribution of *Hydropsyche* spp. (ROBACK 1974), as is low oxygen tension (ROBACK 1974; PESEK & HERGENRADER 1976) which could have acted through a night-time oxygen sag. The overall increase in simuliid and hydropsychid populations may be a direct result of high seston loads which are known to enhance the abundance of these animals (ALLANSON 1961; CHUTTER 1963; ERMAN & CHOUTEAU 1979; OSWOOD 1979). Significantly, WARD & DUFFORD (1979) noted that seasonal rises in seston load in a Colorado spring-brook system corresponded with increased filter-feeder densities.

Indeed, such increases have often been associated with organic enrichment of lotic habitats (BISHOP 1973; PESEK & HERGENRADER 1976; BRADT 1978; GODFREY 1978) and the effects of organic pollution may be favourable for some Hydropsychidae (NIELSEN 1976; BRYCE et al. 1978; GODFREY 1978) and Simuliidae (BISHOP 1973). SCHWOERBEL (1972) records that downstream of a reach covered with *Sphaerotilus* in a West German brook, *Simulium* larvae established themselves at a distance from the *Sphaerotilus* such that dissolved fragments of the filament forming bacterium had broken into particles small enough to be collected and ingested. In this situation larvae attained densities of 120000/m^2 and were apparently limited by space rather than food availability.

In common with the findings of NAIMAN & SEDELL (1979) in North America, the proportion of seston organic matter in the study area decreased downstream, possibly indicating a general improvement in food quality. For Simuliidae, such an increase may have been a crucial factor in the maintenance of high population densities as these animals have a very low assimilation ratio (WOTTON 1978). Significantly, the seston included a large proportion of unidentifiable detritus at sites where simuliids and hydropsychids were particularly abundant. Most of this component was derived from farmyard washings which were rich in organic matter (up to 80% by weight) and contained nitrogenous wastes which would lower the C/N ratio of the suspended material. The latter feature would increase food quality (NAIMAN & SEDELL 1979) and tend to enhance hydropsychid growth rates (cf. FULLER & MACKAY 1981). This is in contrast to seston derived from allochthonous plant litter which predominated at Stations 1 and 2 where there were relatively few filter-feeders. Such material typically has a high C/N ratio and may contain a considerable proportion of refractory nitrogen (NAIMAN & SEDELL 1979).

Simuliids were generally the numerically dominant filter-feeding taxon in the middle and lower course of the Lam Tsuen River during 1978–79. ROBACK (1974) presents data indicating that water quality tolerances of Simuliidae are wider than those of hydropsychids; consequently, hydropsychids are less likely to survive in the middle and lower course of the Lam Tsuen River during the dry season when the effects of organic enrichment are most extreme. The size difference between larval Simuliidae and Hydropsychidae could also account for the numerical dominance of the former family. Each hydropsychid larva requires a significant amount of space on a rock surface for the construction of a capture net and shelter. This space is maintained by territorial behaviour involving larvae stridulating (rubbing the foreleg against grooves on the underside of the head capsule) to warn off members of the same species (EDINGTON 1965; TACHET 1977) thereby effecting a strict restriction of population densities. In the present study hydropsychid larval densities did not exceed 3672 individuals/m^2. This is in excess of hydropsychid densities recorded by GODFREY (1978) (2768/m^2), ALLANSON (1961) (1788–1807/m^2) or BISHOP (1973) (generally less than 1000/m^2) but far below those recorded for larval Simuliidae in comparable habitats (e.g. LADLE et al. 1972; BISHOP 1973). Simuliids occupied a greater range of substrates than hydropsychids in the Lam Tsuen River, settling on rocks, small stones, macrophytes, trailing vegetation and even beds of filamentous algae. BISHOP (1973) has described how simuliid larvae settle directly on unstable muddy bottoms where food resources in the water column are very rich. Thus, where food is not limiting, it is likely that the numbers of Simuliidae will usually exceed those of the Hydropsychidae, and this was certainly the case in areas of the Lam Tsuen River receiving significant organic enrichment.

CUMMINS (1974, 1975) has stated that the trophic structure of lotic invertebrate communities changes from a predominance of scrapers in the headwaters (wich are primitively shaded by riparian scrub or forest) to collectors and microgatherers in the lower course (cf. HAWKINS & SEDELL 1981) where shading has been reduced by the activities of man (e. g. land clearance for agriculture). CUMMINS considers such a change to indicate a transition from a heterotrophic to an autotrophic mainstream community. This transition has clearly been altered by land use patterns in the Lam Tsuen Valley. The heterotrophy of the land highland regions has been extended downstream to incorporate much of the course of the river. The high nutrient, B.O.D.$_5$ and seston loads are a direct contribution from the surrounding terrestrial landscape and, through their use as food, microbial substrate, or a source of nutrients for plant growth, assume the same importance to the freshwater community as does allochthonous leaf litter in heterotrophic stream sections (e. g. HYNES 1975). This is particularly noticeable with respect to the abundant Simuliidae and Hydropsychidae in the river which feed directly upon suspended material largely derived from the terrestrial environment. Oligochaetes are probably also ingesting this material as it settles out in the lower course of the river. The fact that increased enrichment of the river alters benthic community structures, increasing or decreasing the range and abundance of some species and even eliminating others, merely emphasizes the importance of this transfer of terrestrial materials. However, the process is essentially the same as the input of autumn-shed leaves to streams to rivers, the main difference lying in the observer's evaluation of the effects on the aquatic community.

The influence of inputs of terrestrial material to the Lam Tsuen River is altered by river volume (i. e. dilution potential) and therefore the seasonal incidence of rainfall. As mentioned above, seasonal changes in water quality were apparent in the Lam Tsuen River, increased nutrient loading during the dry season leading to range restriction of certain taxa. Consequently, a diverse benthic community in the middle and lower course was replaced in the dry season by one comprising relatively few species in large numbers. This was most apparent at Station 4. By contrast, at Stations 1 and 2 there was little or no organic enrichment and the dry season conditions paralleled those seen other geographic regions experiencing seasonal rainfall, with stable water flow and high community diversity (e. g. OLIFF 1960, OLIFF et al. 1965; ALLANSON 1961; CHUTTER 1963). By contrast, there is disturbance of the river bed with low faunal abundance in the wet season (HARRISON 1958b). In summer 1978 the number of gastropods (DUDGEON 1983b) and oligochaetes were markedly reduced as a result of wash-out during spates; this was also the case for hydropsychids in June 1978. In September 1978 hydropsychid larval recruitment took place thereby increasing population densities of these insects. Summer spates were associated with a general "flushing" of the river allowing taxa less tolerant of organic enrichment to recolonize downstream reaches. Consequently, the latter stages of the summer monsoon (September) were associated with the highest diversity of macroinvertebrates in the Lam Tsuen River. Similar trends have been recorded by BECKETT (1978) who states that during relatively high discharge in a polluted North American River, a great degree of faunal similarity occurred between far upstream and far downstream stations. During low flow conditions a biotic homogeneity was evident among all downstream stations as a result of maximization of pollutional influences and subsequent domination of tolerant species.

Studies upon the influence of organic pollution of river sediments, and the subsequent effects on the benthic fauna, are scarce although some valuable observations have been made by ALLANSON (1961), HARRISON et al. (1963) and BENNINGTON (1977). Regarding physical characteristics, there was a tendency for mean substrate particle size in the Lam Tsuen River to decrease in a downstream direction although mean current velocity was not greatly reduced until Station 6. Generally, the river sediments comprised cobbles or boulders (according to the classification of CUMMINS 1966), boulders predominating at Stations 1 and 2. The downstream decrease in mean particle size could not be explained solely in relation to variations in current velocity and HYNES (1970) considers that a correlation exists between particle size and slope which is related to the decreased ability of a river to move particles in downstream reaches. Whatever the cause, it is frequently the case that the mean particle size of river sediments decreases in a downstream direction (e. g. ALLANSON 1961) and this will, in turn, lead to downstream variations in sorting, skewness and kurtosis. These phenomerna will be noted in both polluted and unpolluted rivers, unless pollution is accompanied by large inputs of sediment.

The prevalence of large particles in the Lam Tsuen River bed reflects the hardness of the granitic rocks making up the river valley. Boulders entering the river have well-weathered outer layers; fine particles from these layers are rapidly eroded and carried downstream to be deposited in the lower course. However, the remaining granitic material is hard and erodes slowly, thus ensuring that much of the river bed comprises large particles. This will tend to be reflected in rather poor sorting, positive skewness and strong leptokurtosis. Smooth downstream decreases in mean particle size were associated with the dry season and the onset of the wet season. However, at the end of the wet season (September) this smooth downstream trend was interrupted due to erosion and scouring of the sediments during spates. ALLANSON (1961) has noted a similar shift in the median value of sediments in the Jukskei-Crocodile River System in southern Africa during the wet season. Sediments at Station 6 deviated in character from those in the remainder of the Lam Tsuen River, reflecting periodic inflation and deflation of a fabri dam immediately upstream. Only fine particles remained in suspension in water flowing past the inflated dam and consequently sediments at Station 6 comprised cobbles overlain by a thin film of fine silt.

In view of the extensive literature on the effects of substrate composition upon freshwater macrobenthos (Cummins 1966; Cummins & Lauff 1969; Hynes 1970; Minshall & Minshall 1977), it is likely that a proportion of the downstream variation in community composition in the river could be attributed to changes in sediment characteristics. However, although some seasonal alterations in the physical nature of the sediments were noted, the magnitude of seasonal variations in water quality in 1978–79 indicate that the latter may be of more significance in determining patterns of macroinvertebrate distribution. There can be no doubt that hydrological, rather than sediment, changes were responsible for changes in the benthic communities of the Lam Tsuen River between 1976 and 1978.

Downstream trends in the physical characteristics of Lam Tsuen River sediments were independent of water quality. However, the effects of cultural eutrophication were evident from the deposition of organic particles on the river bed. This was reflected by a general increase in the percentage of organic matter with decreasing sediment particle size and can be attributed to the small size of organic particles carried in the seston as well as the tendency for invertebrates at upstream sites to fragment the rather small allochthonous leaf input (cf. Dudgeon 1982c, 1982d). Significantly, the percentage of sedimentary organic matter increased downstream and could be related to the degree of organic enrichment experienced in the middle and lower course. The amounts of sedimentary organics were maximal in March 1979 when water quality was poorest. Particularly high levels of sedimentary organics at Station 4 were reflected by high nutrient and B.O.D.$_5$ loads at this site indicating a close association between cultural eutrophication and sediment condition. In the absence of significant stands of riparian vegetation, high levels of sedimentary organics at Stations 3–5 can be directly attributed to the input of agricultural wastes into the river, as well as to the presence of benthic algae, the growth of which is enhanced by high nutrient concentrations.

Increased sedimentary organic matter has been reported from rivers affected by cultural eutrophication (Allanson 1961; Harrison et al. 1963; Bennington 1977), variations occurring according to river discharge volume (Allanson 1961; Bishop 1973). Increased sedimentary organic matter may not be directly deleterious and can provide a valuable food source for those animals able to exploit it (e. g. oligochaetes and ostracods in the Lam Tsuen River). Other macroinvertebrates are probably excluded from enriched substrates by a variety of limiting factors (such as night-time oxygen sags), and Bennington (1977) has shown that Ephemeroptera and Trichoptera will rapidly colonize enriched substrates transfered from polluted sites to unpolluted stations.

In conclusion, it is clear that changing patterns of land use between 1976 and 1978–79 have had profound effects on the ecology and structure of benthic invertebrate communities in the Lam Tsuen River. These changes are characteristic of those reported from other lotic habitats affected by cultural eutrophication and they serve to emphasize the links between aquatic and terrestrial components within the ecosystem, particularly the importance of transfers of material between these two subsystems.

Summary

An investigation of a series of sites along the Lam Tsuen River, New Territories, Hong Kong, was undertaken in November 1976 and seasonally during 1978–79. Analyses of water quality and sediment characteristics were carried out, and samples were taken of the macrobenthos at each site.

Water quality varied along the river, middle and lower course sites showing signs of slight cultural eutrophication in 1976. In 1978–79, the extent of organic enrichment of the river had increased at all but two upper reach stations. This change was reflected by increased nutrient, $B.O.D._5$ and seston loads.

Temporal variations in water quality in 1978–79 were associated with changing river discharge resulting from Hong Kong's seasonal rainfall. In general $B.O.D._5$ and nutrient loads fell in the summer wet season so that conditions at the uppermost mid-stream site resembled those prevailing in the head waters. During the dry season, river volume was reduced and all of the middle course was affected by severe organic pollution. Overall, pollution of the river became more extensive during the autumn and winter, and the river as a whole was "flushed out" by the summer rains thereby shifting the polluted region downstream.

The number of taxa and the diversity ($\bar{d}$) of macrobenthic communities decreased downstream in 1976 and 1978–79. Faunal abundance exhibited no such trends.

The effects of increased cultural eutrophication in 1978–79 were reflected by large increases in macrobenthic population densities and a general decrease in faunal diversity. Seasonal reductions in faunal diversity were associated with deteriorating water quality in the middle and lower course during the autumn and winter months.

Longitudinal zonation of individual taxa was examined with reference to the classical rithron-potamon scheme of classification of lotic fauna, as well as with regard to the responses of these animals to changing water quality. In 1976, a downstream succession in the occurrence of different taxa was noted. However, within single families or genera, variable patterns of zonation were detected indicating that the classification of higher taxonomic groupings as rithron or potamon inhabitants may not be widely applicable. In response to deteriorating water quality in 1978–79 many species were eliminated from the middle and lower reaches and were restricted to upstream stations. Tolerant taxa were able to increase in range and abundance, for example certain Baetidae, Caenidae, Hydropsychidae, Simuliidae, Chironomidae, Gastropoda, Oligochaeta and Ostracoda.

Seasonal changes in macroinvertebrate distribution reflected changes in water quality. Those taxa mainly restricted to the two upper-most sites were largely unaffected by season, whereas certain caenid and baetid mayflies were eliminated from downstream sites in the dry season, as were some Hydropsychidae. By contrast, non-insectan taxa were favoured by organic enrichment, increasing their range and abundance in the dry season. Overall, macrobenthic communities in the Lam Tsuen River were most diverse in September (the latter part of the wet season) and least diverse in March (the end of the dry season).

Lam Tsuen River sediments showed downstream changes in physical characteristics, tending towards decreased mean grain size, increased sorting and decreased skewness and kurtosis. During the wet season the river sediments become coarser and less well sorted. Downstream increases in sedimentary organic matter were also recorded, reflecting cultural eutrophication in the middle and lower course of the river. There was a general trend for sedimentary organic matter to increase during drier months of the year, summer spates tending to "flush out" accumulated organic material from the river channel.

The patterns of macroinvertebrate zonation, and sedimentary and hydrological characteristics of the Lam Tsuen River, can be interpreted as reflecting transfers of material (nutrients, agricultural wastes, sewage) to the aquatic habitat from the surrounding terrestrial environment. It is clear that land use patterns around the Lam Tsuen River profoundly affect aquatic communities through the medium of such transfers by altering community structure as well as the distribution and abundance of individual taxa.

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