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Macroinvertebrate communities of streams in western Nepal: effects of altitude and land use

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SUMMARY

1. The influence of altitude and land-use changes on macroinvertebrate assemblages from riffles in forty-three streams in the Dolpo region of western Nepal were examined. Sampling sites ranged in altitude from 850 to 4250 m, and land-use patterns fell into five categories: alpine, forest, grassland, pasture and agricultural land.
2. TWINSPAN classification of physicochemical data separated streams into groups on the basis of climatic and physical factors. Streams from high, cold, alpine areas were separated from those in warmer, lower, agricultural areas.
3. In all, 138 macroinvertebrate taxa were collected from fifty-three insect families. Ephemeroptera were most common, especially Baetidae.
4. Taxonomic richness declined with increasing altitude. Ten insect families were significantly more abundant in lowland streams, and five were more common in alpine streams.
5. TWINSPAN and DECORANA revealed distinct invertebrate groupings of the forty-three streams surveyed. A high percentage of the variance (79.3%) in ordination space was explained by DECORANA axes 1 and 2. Altitude, temperature, stream width and land use were implicated in structuring invertebrate communities.

Introduction

A fundamental characteristic of river ecosystems is the unidirectional movement of water, nutrients, inorganic materials and organic matter down altitudinal gradients from headwater mountain streams to lowland rivers. Corresponding longitudinal changes in the macroinvertebrate fauna are thought to reflect either trophic-related processes (e.g. Vannote *et al.*, 1980) or changes in hydraulic stress (e.g. Statzner & Higler, 1986). Land-use changes may also alter macroinvertebrate distributions down river systems (e.g. Culp & Davies, 1982; Ward, 1989; Corkum, 1989, 1990). Longitudinal changes in faunal composition are more likely to be found where strong environmental gradients occur (e.g. Hawkins & Sedell, 1981) rather than where they are weak (e.g. Brussock & Brown, 1991), or where small-scale spatial variation disrupts larger scale patterns (Downes, Lake & Schreiber, 1993).

The Nepal Himalaya has the greatest altitudinal gradients on earth, and indeed the Gandaki River system flows through the world's deepest valley. However, until recently, few workers have examined biological communities in rivers flowing down such pronounced altitudinal gradients, either in Nepal or elsewhere (e.g. Egglishaw, 1980; Turcotte & Harper, 1982). Research into the freshwater ecology of Nepal is very limited, and restricted to a few papers describing specific faunal groups (e.g. Dubey, 1971; Stanley, 1975; Malla *et al.*, 1978; Sivec, 1981; Ito, 1986). Ecological studies of rivers in this biogeographical region are few, and restricted primarily to streams in India (e.g. Hora, 1923; Ao, Alfred & Gupta 1984; Chattopadhyay, Saha & Konar, 1987; Gupta & Michael, 1992) or Pakistan (e.g. Ali, 1968a, b). Furthermore, these studies have only considered rivers at low altitudes (<2500 m).

Recently, a number of workers have examined fish (Edds, 1993) and invertebrate communities (Rundle, Jenkins & Ormerod 1993) of streams in Nepal, and altitude has been shown to have profound effects on both their physicochemical conditions and biological communities.

The nature of macroinvertebrate assemblages often appears to be more closely linked with land-use practices than with longitudinal gradients (Ward, 1989; Corkum, 1990). Land use varies considerably in the Himalaya, and watershed degradation as a result of land practices is thought to be occurring on a large scale (Ives & Messerli, 1989). Consequently, stream communities are likely to be influenced by conditions in their catchments, and by changes in waterways resulting from activities such as deforestation and intensive terraced agriculture.

Previous studies of stream invertebrate communities in Nepal have been carried out in the central and north-eastern areas of the country (Rundle *et al.*, 1993; Ormerod *et al.*, 1994), or in Kathmandu Valley (Malla *et al.*, 1978). My study has broken new ground as it considers streams in central-west Nepal. The streams sampled were at a wide range of altitudes, and drained catchments supporting a variety of land uses. The effects of these two variables on benthic invertebrate communities are assessed in this paper.

Study sites

Streams were sampled opportunistically while trekking from Pokhara in central Nepal, to Jumla, in western Nepal (Fig. 1). Sampling was from easily accessible streams, regardless of altitude or land use. Small first- and second-order streams (<2 m wide), larger third- and fourth-order streams (<10 m) and rivers (>10 m) were sampled. Samples were taken from four river systems; the Modi Khola, and the Tila, Bheri and Sani Bheri Rivers, all of which ultimately drain into the Ganges (Fig. 1).

Five discrete land-use types were incorporated in the survey (Fig. 2). At lower altitudes (<2000 m), extensive agriculture was common, with crops such as wheat, rice and maize being grown on heavily

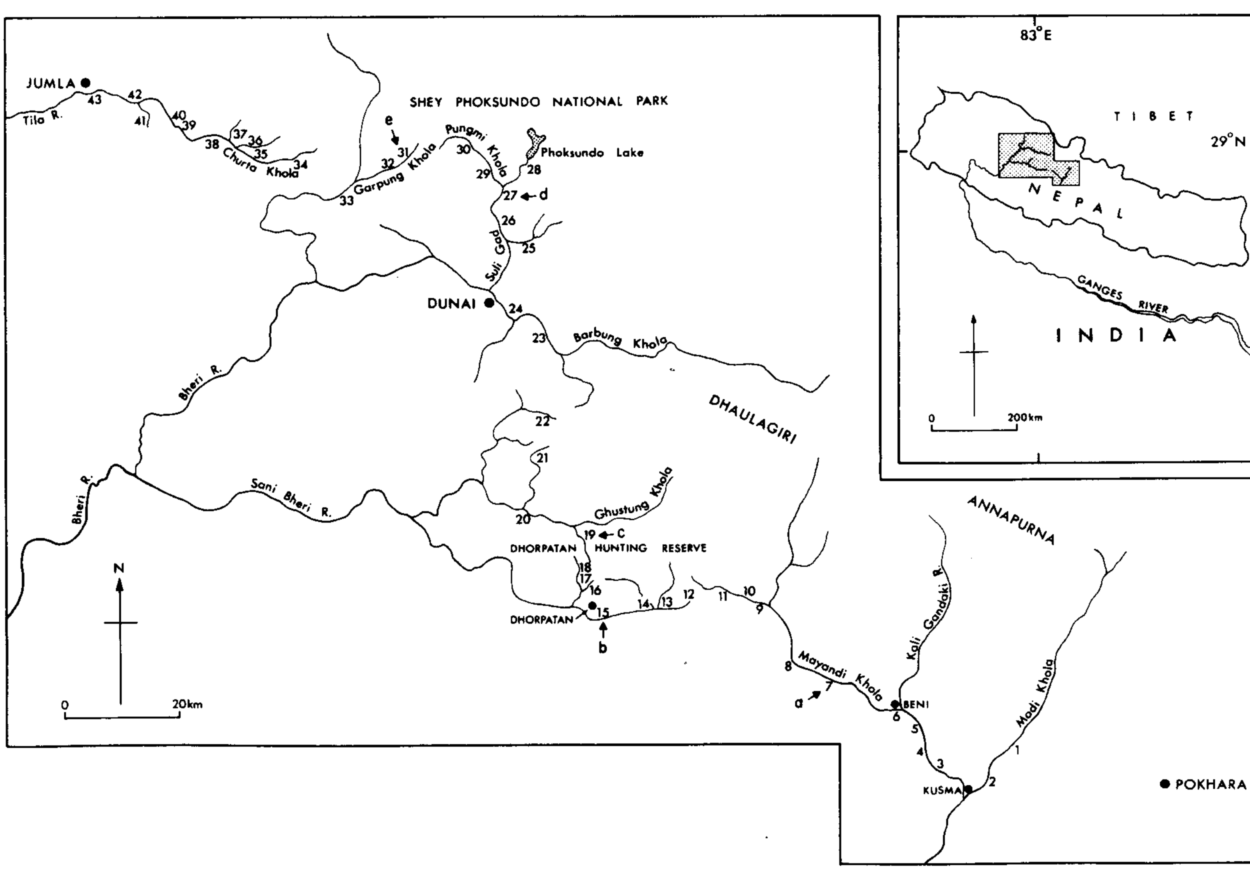


Fig. 1 Study site map of Nepal showing the route taken from Pokhara to Jumla along which macroinvertebrate samples from riffles in forty-three streams were taken. Letters refer to different land-use regimes encountered (see Fig. 2).

terraced land (Fig. 2a) which is fertilized with animal manure dug in at the commencement of each growing season. Irrigation water is often diverted from rivers, and allowed to flow through these terraces. Small villages and towns are common, and nutrient inputs from these to streams are high.

On steeper land at higher altitudes (>2000 m), terraced agriculture is less common, and pasture or grassland is dominant. Pasture is created by grazing, mowing and burning natural grasslands (Jha, 1992), and is used for cattle rearing (Fig. 2b). Grassland, in contrast, is either natural, or has developed in areas that have been cleared of trees for firewood, but are too steep for terracing or intensive cattle grazing (Fig. 2c).

Forests are the fourth major land-use type, and were found mainly in the Dhorpatan Hunting Reserve and Shey Phoksumdo National Park (Figs 1 and 2d). These low temperate vegetation zones (2000–3000 m) support conifers (including pines and cedar), as well as oaks and rhododendron. Higher forests in the sub-Himalayan humid temperate zone (3000–4000 m) support species of birch, juniper, pine, larch and rhododendron.

Above 4000 m, the Himalayan vegetation zone (Jha, 1992) extends above the tree-line into areas of permanent snow (Fig. 2e). Small juniper and rhododendron shrubs occur here, as well as alpine grasses and lichens.

Nepal has a strong seasonal climate which is greatly affected by altitude. Temperature is hottest in May–June and generally coldest in January (Fig. 3). Precipitation is heavy during the summer monsoon June–September), and a smaller, winter monsoon occurs from December to March (Fig. 3). Precipitation generally increases with altitude up to 2000 m, above which it declines. Northern and western areas of Nepal generally receive less precipitation than southern and eastern areas (Jha 1992). Thus, Baglung (975 m) in central Nepal receives more rain, and is warmer than Jumla (2300 m) in western Nepal (Fig. 3).

Materials and methods

Field sampling

Sampling was conducted in March and April 1992 when streamflows were low. No rain fell during the survey. Qualitative kick samples were taken by disturbing substrata in four discrete areas in riffle sections of each stream. Invertebrates clinging to boulders were brushed into the collecting net (mesh size 0.5 mm). Animals were separated from inorganic matter and detritus by elutriation in the field and preserved with 90% alcohol.

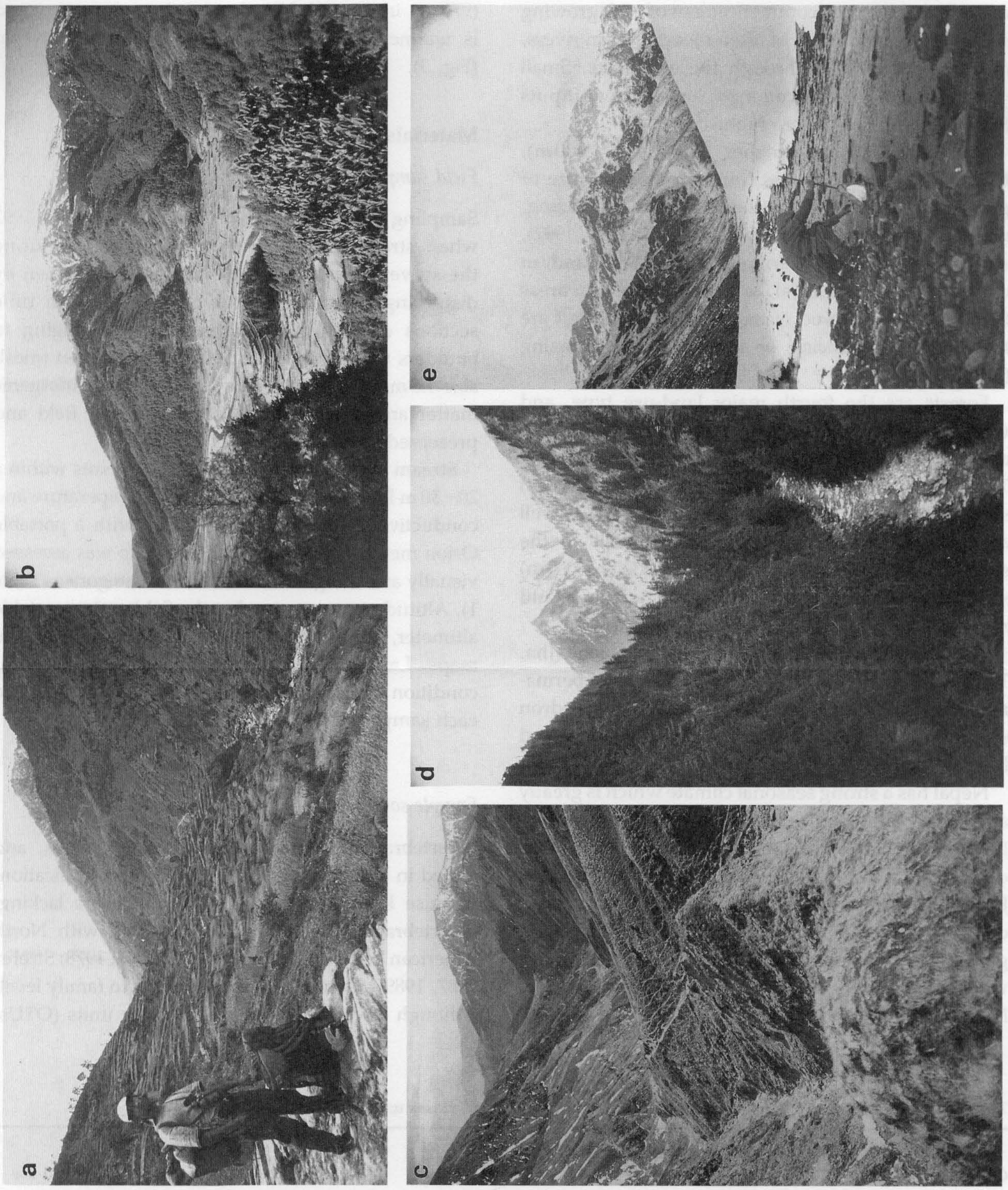
Stream width was measured at five points within a 20–30 m long reach at each site, and temperature and conductivity were measured on-site with a portable Orion meter. Periphyton standing crop was assessed visually and assigned to one of five categories (Table 1). Altitude was measured in the field with a portable altimeter, and confirmed later from topographical maps. Land-use categories reflecting the dominant condition of the surrounding land were assigned to each sampling site (Table 1).

Sample sorting

Invertebrates were collected on nested sieves, and sorted in a Bogorov tray at up to ×40 magnification. Because keys to Asian aquatic insects are lacking, invertebrates were identified primarily with North American keys (e.g. Merritt & Cummins, 1978; Strehr, 1987, 1989). Identification was mainly to family level, although lower operational taxonomic units (OTUs)

Table 1 Groupings of environmental variables into semi-quantitative classes used in TWINSPAN classification

Classes	Altitude (m)	Temperature (°C)	Conductivity ($\mu S\ cm^{-2}$, 25°C)	Width (m)	Periphyton	Land use
1	0–999	0–5	0–50	1–5	Rare	Agriculture
2	1000–1999	6–10	51–100	6–10	Occasional	Pasture
3	2000–2999	11–15	101–150	11–20	Common	Grassland
4	3000–3999	16–20	151–200	21–50	Abundant	Forest
5	>4000	>20	>200	>51	Extensive	Alpine



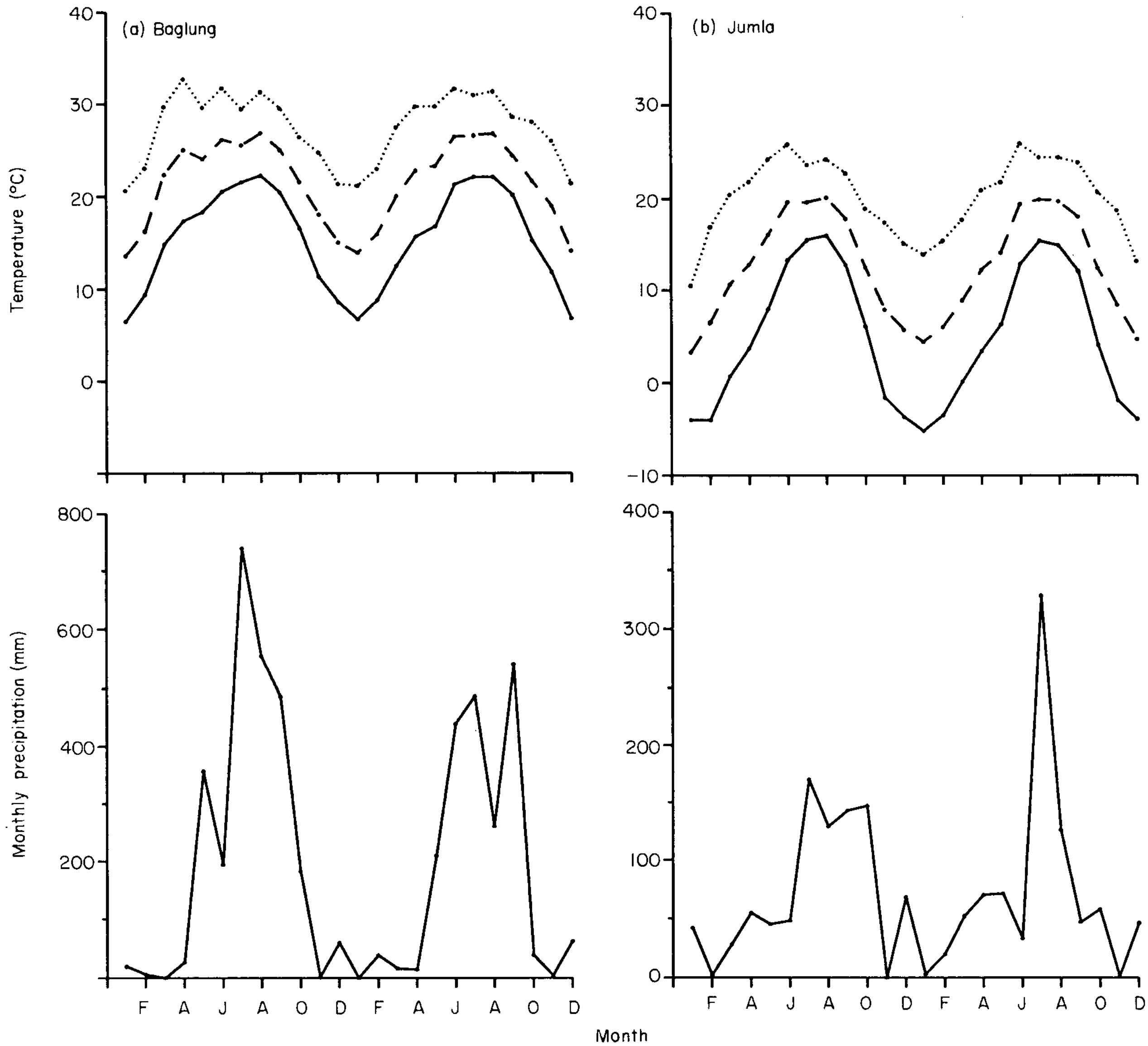


Fig. 3 Average monthly minimum (solid lines), mean (dashed lines) and maximum (dotted lines) temperature and precipitation records taken from (a) Baglung in central Nepal (975 m) and (b) Jumla in western Nepal (2300 m). Both temperature and precipitation are strongly seasonal, reflecting the monsoonal climate of Nepal. Data obtained from HMG Nepal Ministry of Water Resources, Department of Irrigation, Hydrology and Meterology, Kathmandu.

were distinguished and assigned a voucher number. Subfamilies and some genera of Chironomidae were identified using keys by Stark (1989) and Peckarsky *et al.* (1990) following mounting and clearing of head capsules in lactophenol-PVA.

Statistical analyses

Environmental data were examined for normality and $\log_{10}(x + 1)$ transformed where necessary. Invertebrate percentage abundance data were arcsine

Fig. 2 Streams flowed through a variety of catchments of differing land use. Streams at lower altitudes flowed through extensive terraces of agricultural land (a), whereas in steeper and higher areas, pasture (b) and grassland (c) were common. Forest streams (d) flowed through mixed stands of pine, cedar and oak in low temperate vegetation zones (2000–3000 m), and through birch, juniper, pine and larch in the sub-Himalayan temperate zone. Streams above 4000 m flowed through catchments vegetated by small shrubs, grasses and lichens; snow often lay on the ground until late in the season (e).

transformed prior to analysis. Environmental data were first analysed by TWINSPAN (McCune, 1991) to determine whether samples from similar altitudes or land-use categories clustered together. This initial analysis was undertaken using semi-quantitative data only (Table 1). Differences in values of environmental variables among resultant TWINSPAN groups were assessed by ANOVA, using log $(x + 1)$ transformed quantitative data of each measured variable.

Invertebrate data were also assessed by TWINSPAN to determine whether samples formed discrete clusters based on species assemblages. TWINSPAN analysis used percentage abundance data for families at each site. Pseudospecies cut levels (see Rundle *et al.*, 1993) were set at 0.005, 0.01, 0.05, 0.1 and 0.5, as the arcsine transformed invertebrate abundance data were normally distributed at these levels. Resulting TWINSPAN groups were examined by ANOVA for difference in taxonomic composition or associated environmental factors.

DECORANA was used to search for patterns in the entire data set, and taxa were not grouped into families. Values for measured environmental parameters and species abundance scores were regressed against DECORANA axes to determine which parameters, and which species, were correlated with observed sample clusters. Finally, each sample was allocated to an altitude or land-use class, and differences in DECORANA axis scores between these classes were analysed by ANOVA as described by Rundle *et al.* (1993).

Regression analysis was also performed on both environmental and invertebrate community data to determine whether these variables varied with increasing altitude.

Following the multivariate analysis, samples were assigned a priori to one of the five land-use classes to determine differences in community structure with respect to land use. Because altitude was thought to influence both land-use practices and stream invertebrate distributions, data were analysed by ANCOVA with altitude as the covariate. This analysis was performed for both insect orders and families.

Results

Environmental variables

Of the forty-three sites, most (twenty) were in the subalpine region (3000–3999 m), and fewest (three) in the alpine region (>4000 m). The lowest site (No. 6) was in the Mayangdi Khola at Beni (850 m), whereas the highest site (No. 34) was in the Tila Khola, a tributary of the Churta Khola at 4250 m (Fig. 1). Sites were more evenly distributed among land-use categories. Twelve and eleven samples were collected from agricultural land and forest land, respectively, and seven samples came from streams flowing through each of pasture and alpine environments. Six samples were collected from grasslands.

TWINSPAN classified sites into four groups based on semi-quantitative physicochemical data (Fig. 4). Sites in Groups 1 and 2 were significantly higher and colder than those in Groups 3 and 4 ($F_{3,39} = 27.6$ and $F_{3,39} = 17.3$, respectively, $P < 0.05$; Fig. 5). Conductivity also differed among the four TWINSPAN groups ($F_{3,39} = 8.6$, $P < 0.05$) although no significant relationship was found with altitude.

Regression analysis also revealed significant relationships between altitude and temperature ($r = 0.79$, $F_{4,38} = 68.7$, $P < 0.001$), but not between altitude and conductivity ($r = 0.26$, $F_{4,38} = 3.1$, $P > 0.05$).

Invertebrate fauna

In all, 138 OTUs were recognized from the forty-three sites (Appendix 1). Ephemeroptera were most abundant (37.8% of individuals), followed by Trichoptera (30.9%), Diptera (17.1%), Plecoptera (8.9%) and Coleoptera (4.9%). All other insect orders (i.e. Odonata, Megaloptera, Neuroptera) and non-insect taxa (i.e. Ostracoda, Copepoda, Nematoda) contributed less than 1% of invertebrates collected.

Larvae of Baetidae, Heptageniidae and Ephemerel-

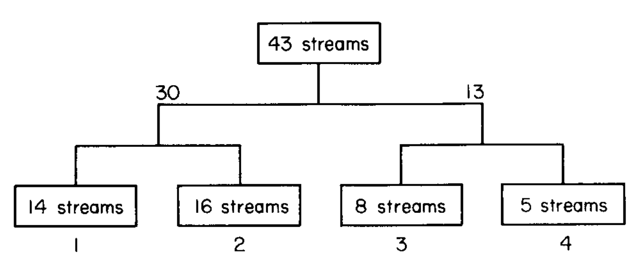


Fig. 4 TWINSPAN classification of stream environments based on semi-quantitative data defining altitude, temperature, conductivity, stream width, periphyton development and land-use categories.

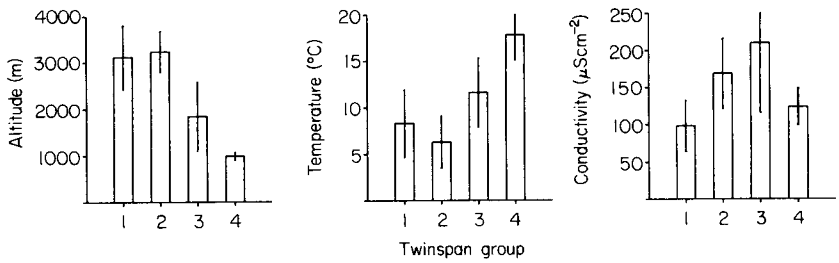


Fig. 5 Mean values (±1 SD) for three environmental variables for the four groups produced at level 2 of the TWINSPAN classification in Fig. 4.

lidae were the most common ephemeropterans. Brachycentridae, Limnephilidae and Lepidostomatidae were the most common trichopterans, and Chironomidae and Simuliidae were the most abundant dipterans.

Relative abundances of the five major insect orders (Ephemeroptera, Trichoptera, Plecoptera, Diptera and Coleoptera) did not differ with altitude ($F_{4,38}$ = 2.5, 2.1, 2.0, 0.6, 1.7, respectively, $P > 0.05$). However, relative abundances of eighteen insect families did differ with altitude, ten families being more abundant at lower altitudes (<2000 m), and three families being more abundant in higher streams. Relative abundances of five insect families showed no consistent trend with altitude. Taxonomic richness also declined as altitude increased ($r = 0.48$, $F_{1,41} = 12.0$, $P < 0.05$; Fig. 6).

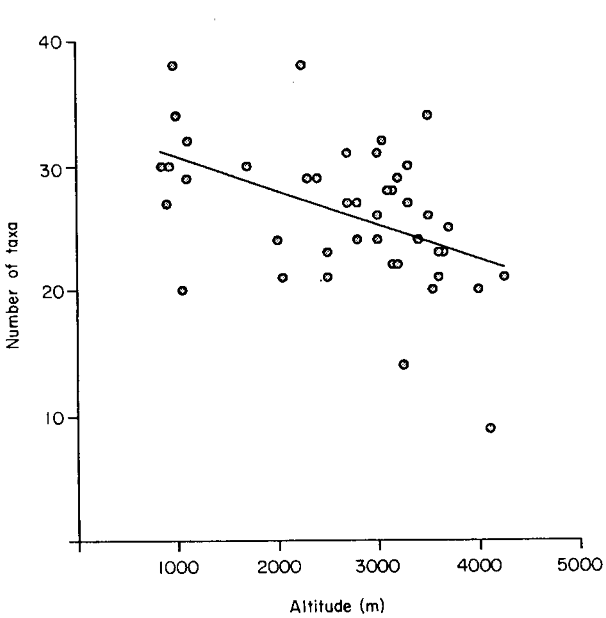


Fig. 6 The relationship between taxonomic richness and altitude for the forty-three stream samples ($r = 0.48$, $P < 0.05$).

Community composition

A TWINSPAN classification based on families present at each site produced four distinct groups after two divisions (Fig. 7). Groups 1 and 2 contained lower and warmer sites than Groups 3 and 4 ($F_{4,38}$ = 16.0, 6.9, respectively, $P < 0.05$; Fig. 8). More families were also found at these lower sites ($F_{4,38} = 5.1$, $P < 0.05$). Relative abundances of fifteen families were significantly different among TWINSPAN groups. Chloroperlidae, Heptageniidae, Nemouridae and Psychodidae were significantly more common at alpine sites ($F_{4,38}$ = 4.8, 5.6, 9.8, 8.0, respectively, $P < 0.05$), whereas Caenidae, Corydalidae, Perlidae, Siphlonuridae and Tipulidae were more abundant in lowland streams ($F_{4,38}$ = 3.9, 3.4, 3.4, 7.3, 3.4, respectively, $P < 0.05$; Fig. 8).

DECORANA was undertaken using data for all invertebrate taxa (OTUs) rather than orders or families. Axes 1 and 2 explained 47.4 and 31.9% of the total variance in ordination space. Axis 1 was correlated strongly with both altitude and temperature (Table 2), indicating that samples with high axis 1 scores were from higher, and colder streams. No significant correlations were found between measured environmental variables and axis 2 scores. Stream width (a reflection of stream size), and land-use categories, were correlated strongly with axis 3, however (Table 2). Sites with high axis 3 scores were from small streams, either in the alpine zone, or in forested catchments.

The strong correlations of environmental variables with DECORANA axes imply that altitude and land use are important in structuring stream invertebrate communities in central-west Nepal. Differences in sample axis scores were therefore analysed by ANOVA by assigning each sample to its appropriate altitude and land-use class (see Table 1). Sample coordinates on axes 1 and 3 when grouped according to altitude class differed significantly ($F_{4,38} = 6.93$,

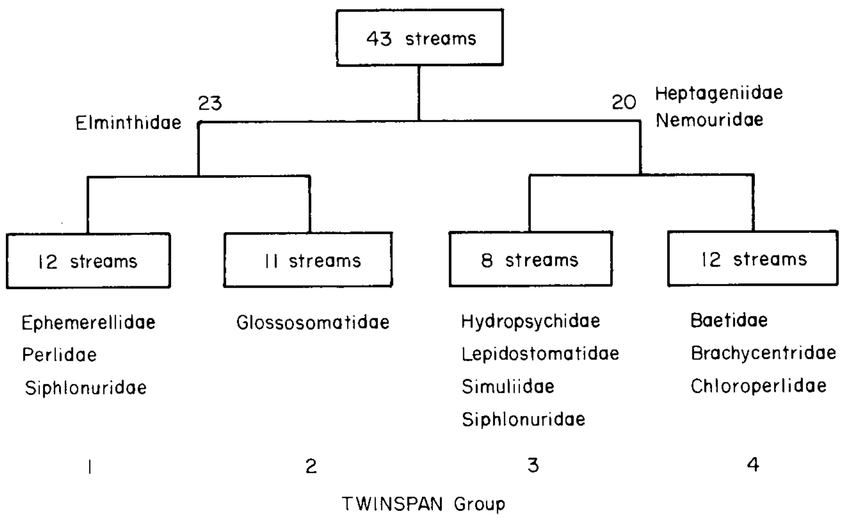


Fig. 7 TWINSPAN classification of macroinvertebrate assemblages found in the forty-three streams showing sample clustering after two divisions. The analysis used taxa grouped into families. Indicator taxa for each division are shown.

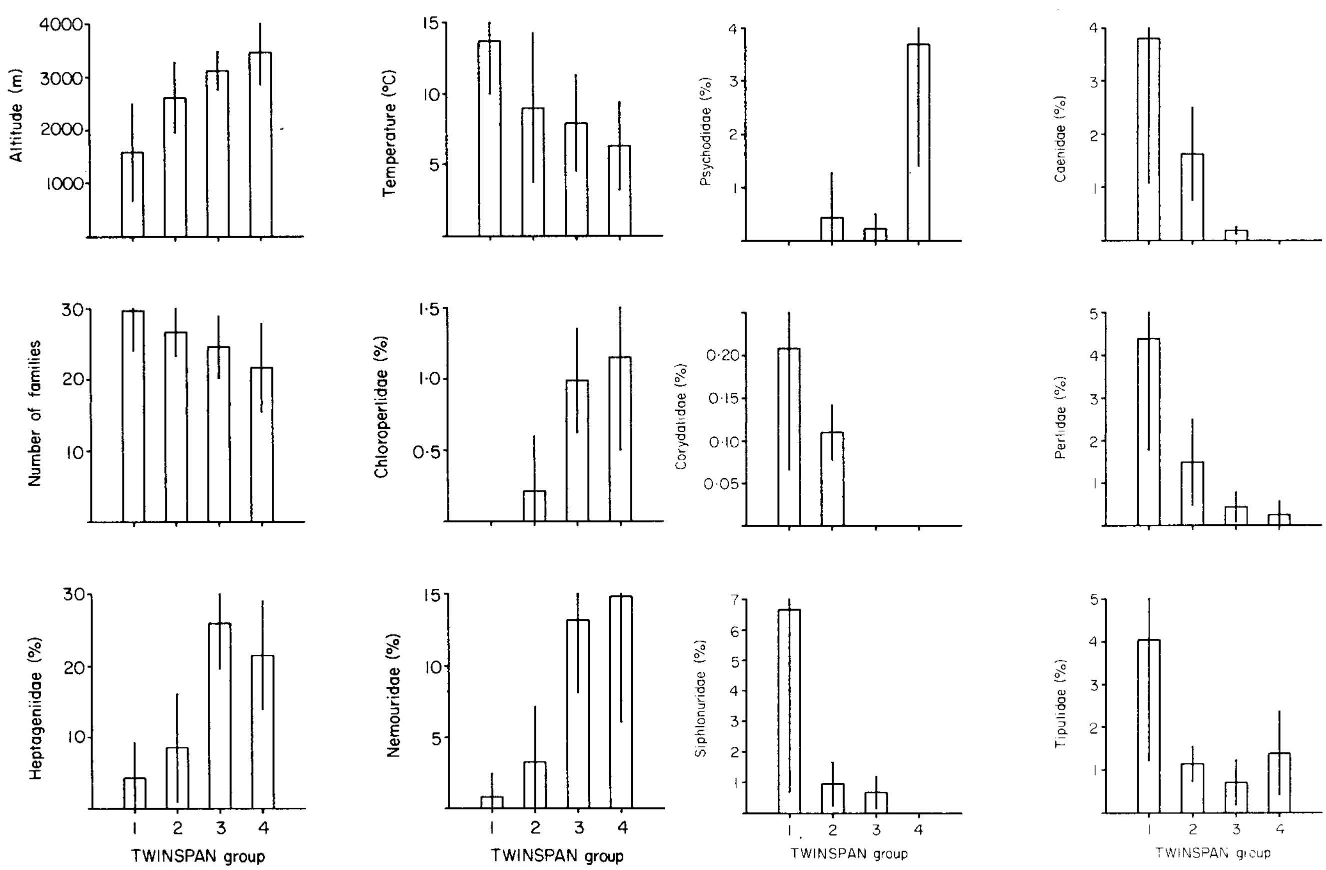


Fig. 8 Mean values (±1 SD) for two physical variables and taxonomic groups [families whose relative abundances differed significantly ($P < 0.05$) between TWINSPAN end groups] for the four groups at level 2 in Fig. 7.

Table 2 Significant correlations ($P < 0.05$) between measured environmental variables and DECORANA axes. No significant correlations were observed with axis 2

Environmental variables	Axis 1	Axis 3
Width		−0.40
Altitude	0.52	
Conductivity		−0.34
Temperature	−0.53	
Land use		0.40

2.85, respectively, $P < 0.05$), with samples from high altitude sites having higher axis 1 and 3 scores. Similarly, sample coordinates on axes 2 and 3, when grouped according to land-use classes, differed from each other ($F_{4,38} = 2.67$, 3.98, respectively, $P < 0.05$). Samples from alpine or forested catchments had higher axis 2 and 3 scores.

Correlations between OTUs and each DECORANA axis indicated which taxa were correlated with sample aggregations from cold, alpine streams, or warmer, lowland streams. Twenty-eight taxa were significantly correlated with samples from low altitude streams flowing through agricultural land (Table 3). In contrast, only fourteen taxa displayed significant correlations with samples from high altitude, alpine streams (Table 3).

Table 3 Invertebrate taxa that were significantly correlated with DECORANA axis 1 and 3 scores. Small, cold, high altitude streams formed clusters with high axis 1 and 3 scores. Consequently, taxa that displayed a positive correlation with these two DECORANA axes were regarded as alpine species. Taxa that displayed a negative correlation with axis 1 and 3 scores were regarded as lowland species

Lowland species	Alpine species
Brachycentridae spp. A, C	Baetidae
Caenidae spp. A, B	Blephariceridae sp. A
Capniidae	Brachycentridae sp. E
Corydalidae	Elminthidae sp. A
Elminthidae sp. B	Glossosomatidae
Gomphidae	Heptageniidae sp. A, B, C
Hydropsychidae	Lepidostomatidae sp. B
Hypolestidae	Limnephilidae sp. G
Lepidostomatidae sp. A	Nemouridae
Leptoceridae	Orthocladiinae sp. G
Limnephilidae sp. A	Ostracoda
Microtendipes sp.	Rhyacophilidae sp. C
Muscidae	
Odontoceridae spp. B, C	
Orthocladiinae spp. A, B	
Pentaneurini	
Philopotamidae	
Perlidae	
Polycentropodidae sp. A	
Polypedilum sp.	
Rhyacophilidae sp. A	
Siphlonuridae sp. A	
Stempellina sp.	
Simuliidae	
Total 28 taxa	14 taxa

Effect of land use

Both TWINSPAN and DECORANA revealed the existence of discrete invertebrate assemblages, and illustrated the importance of altitude in structuring these assemblages. Land-use changes were also thought to influence invertebrate distributions, so all samples were *a priori* classified into one of the five land-use classes previously described (Table 1).

ANCOVA showed that relative abundances of the five major insect orders did not differ among land-use categories ($P > 0.05$). However, relative abundances of five insect families did differ among land-use categories (Fig. 9). Streams draining grassland had the greatest relative abundances of Baetidae, Ephemerellidae and Rhyacophilidae, whereas streams draining catchments in pasture and alpine land had the highest proportions of Brachycentridae and Psychodidae, respectively (Fig. 9). Streams flowing through terraced agricultural land had the lowest representation of Baetidae, Psychodidae and Rhyacophilidae, whereas streams in alpine areas had the lowest relative abundances of Brachycentridae (Fig. 9). Ephemerellidae were absent from all alpine streams sampled.

Discussion

This is only the third investigation of invertebrate communities of Himalayan streams, and the first to survey the Dolpo region of western Nepal. The taxonomic composition of this fauna was similar to that reported by Rundle *et al.* (1993) and Ormerod *et al.* (1994) in central and north-east Nepal. Ephemeroptera, in particular Baetidae, dominated the fauna in all three studies, and Trichoptera, Diptera and Plecoptera were also common. I also recorded ten families that were not found in the earlier studies, and ident-

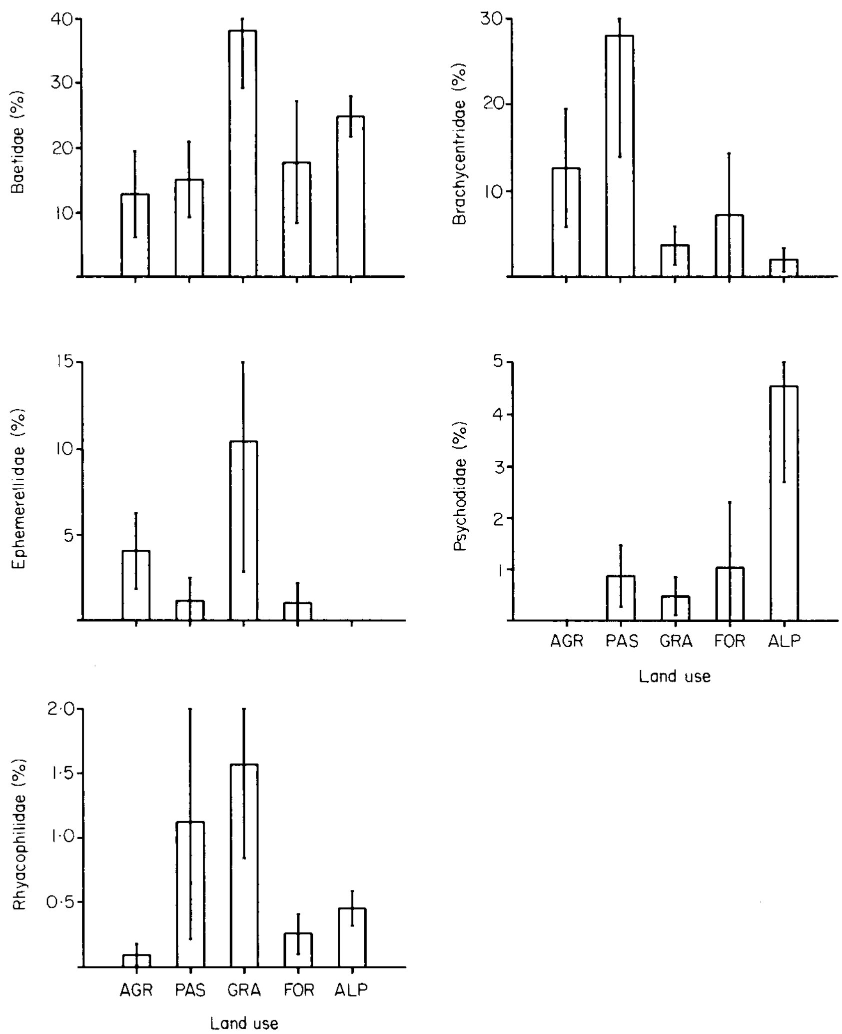


Fig. 9 Relative abundances of the five insect families that differed with respect to land use when analysed by ANCOVA with altitude as the covariate ($\bar{x}$ + 1 SD). *n* as shown in parentheses below: agriculture = (AGR, 12), pasture = (PAS, 7), grassland = (GRA, 6), forest = (FOR, 11), alpine = (ALP, 7).

ified fifteen lower taxa of Chironomidae, which had not been recorded before (Appendix 1).

The wide-ranging distribution and numerical dominance of Baetidae in Nepalese streams parallels that of the leptophlebiid mayfly *Deleatidium* in New Zealand streams (Winterbourn, Rounick & Cowie, 1981; Mackay, 1992). Many of the Nepalese streams encountered in my survey had steep, unstable boulder and rubble beds, and some of the larger streams and rivers had braided channels which presumably alter course during spates. The instability of substrata reflects the high erosion rates in the Himalayas, possibly the highest of any mountain system in the world (Ives & Messerli, 1989). A similar situation is found in New Zealand where steep mountain streams often have highly unstable substrata, and carry a very high sediment load (Duncan, 1987; Winterbourn & Ryan, 1994). Rainfall in the Himalaya is, however, highly seasonal and predictable, whereas precipitation in much of New Zealand is high, and spread less predictably through the year.

An asynchronous life cycle and year-round oviposition appears to enable many *Deleatidium* species to maintain populations in 'harsh', often flood-prone environments (Winterbourn, 1978; Towns, 1983; Mackay, 1992; Scarsbrook & Townsend, 1993). *Deleatidium* also feeds on stone surface biofilms which often persist and/or rapidly regenerate after floods (Rounick & Winterbourn, 1983). Similarly, species of *Baetis* have been reported to feed in this way (Winterbourn, Hildrew & Box, 1985; Boulton, Spangaro & Lake, 1988; Palmer, O'Keeffe & Palmer, 1993). Some *Baetis* species have also been found to be early colonizers of artificial and disturbed substrata, and like *Deleatidium* are considered to be highly resilient in the face of physical disturbance (Mackay, 1992).

Taxonomic richness of Nepalese streams declined with increasing altitude, as was found by Rundle *et al.* (1993) elsewhere in Nepal, and by Egglishaw (1980) and Ao *et al.* (1984) in other parts of Asia. Although taxonomic richness declined with altitude, relative abundance of the major insect orders (Ephemeroptera, Trichoptera, Plecoptera, Diptera and Coleoptera) was similar in all streams. Nevertheless, family composition differed significantly with altitude; ten insect families were more common in lowland streams and three were more common in alpine streams.

The reduction in taxonomic richness with increasing altitude presumably reflects changes in the stream environment. Alpine streams are generally smaller, steeper and colder than those at lower altitudes, and they are more likely to be covered with snow and ice at times. Thermal regimes are known to have strong effects on distributional patterns within drainage systems (Vannote & Sweeney, 1980; Culp & Davies, 1982), and many of the faunistic differences observed between alpine and lowland streams may reflect differences in temperature tolerances, or thermal requirements for development of invertebrate species.

Water chemistry and flow conditions also differ altitudinally, although contrary to the findings of Rundle *et al.* (1993), conductivity was not negatively correlated with altitude in my study. This may reflect geological differences in the streams of western Nepal compared with those included in surveys made in central and north-eastern Nepal.

The invertebrate communities in the streams sampled in western Nepal are thus exposed to a wide variety of environmental perturbations, many of which change with altitude. TWINSPAN demonstrated the existence of discrete communities in streams at differing altitudes, and assigned various indicator taxa to sample clusters. Among these, the Limnephilidae were characteristic of high altitude streams, whereas Caenidae, Hydropsychidae, Lepidostomatidae and Elminthidae were characteristic of low altitude streams. These families showed similar altitudinal trends in the Anapurna, Everest and Langtang regions of Nepal (Rundle *et al.*, 1993; Ormerod *et al.*, 1994)

Although altitudinal gradients assert a marked influence on Nepalese stream invertebrate assemblages, land use also appears to influence animal distributions. Many catchments have been extensively terraced for agriculture, or have undergone deforestation to provide materials for fuel and housing. Changes in land use are thought to be responsible for some of the watershed degradation associated with river systems in Nepal (Ives & Messerli, 1989), especially on a small ($<50\,km^2$) scale. Such degradation includes increases in nutrient loadings in lowland rivers (e.g. Gupta & Michael, 1992), increases in fine sediments (e.g. Egglishaw, 1980), and changes to habitat or substratum diversity (Ormerod *et al.*, 1994). Differences in land use explain why invertebrate faunas are often different in streams draining different catchments in India and the Himalaya (Ao *et al.*, 1984; Rundle *et al.*, 1993; Ormerod *et al.*, 1994), and probably account for some of the between-stream differences I observed. For example, some Ephemeroptera in north-eastern India appear very sensitive to changes in substratum heterogeneity and sand deposition, and show reduced taxonomic richness in streams flowing through catchments modified by logging, quarrying and mining (Gupta & Michael, 1992). Species of Leptophlebiidae, Heptageniidae and Ephemerellidae are particularly sensitive to catchment modification, and were less common in agricultural than forested catchments. Similarly, I found that Baetidae and Ephemerellidae were least common in streams draining agricultural land, as were Rhyacophilidae.

In summary, the composition of stream invertebrate communities in western Nepal appears to be controlled by similar environmental variables to those in the central and north-eastern parts of the country (Rundle *et al.*, 1993; Ormerod *et al.*, 1994). Environmental factors associated with altitudinal gradients have strong effects on the invertebrate fauna, and land-use changes (closely correlated with altitude) are also implicated. Although localized land-use changes may have a significant impact on stream faunas, large scale effects are likely to be masked by natural processes of erosion, sedimentation and flooding to which these streams are exposed.

Acknowledgments

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Appendix 1 List of invertebrate taxa collected in my survey of forty-three streams in western Nepal ranging in altitude from 850 to 4250 m. Most of these taxa have been reported previously by Rundle *et al.* (1993) and Ormerod *et al.* (1994) in central and north-eastern Nepal. Some taxa are reported for the first time, however. + = taxa reported for the first time in Nepal; * = taxa recorded in other studies but not found in my survey

Odonata
- Gomphidae
- Hypolestidae

Ephemeroptera
- Baetidae
- Caenidae spp. A, B
- Ephemerellidae spp. A–D
- Heptageniidae spp. A–C
- Leptophlebiidae
- Siphlonuridae spp. A–C
- Tricorythidae+

Plecoptera
- Capniidae
- Chloroperlidae
- Leuctridae
- Nemouridae
- Perlidae
- Perlodidae
- Taeniopterygidae

Trichoptera
- Brachycentridae spp. A–K
- Glossosomatidae
- Goeridae*
- Hydrobiosidae+
- Hydropsychidae
- Hydroptilidae
- Lepidostomatidae
- Leptoceridae
- Limnephilidae spp. A–G
- Odontoceridae spp. A–C
- Philopotamidae
- Phryganeidae
- Polycentropodidae spp. A–F
- Psychomyiidae
- Rhyacophilidae spp. A–C
- Stenopsychidae*

Megaloptera
- Corydalidae+

Neuroptera
- Unidentified taxon

Coleoptera
- Elminthidae spp. A–J
- Gyrinidae+
- Scirtidae spp. A–C
- Hydrophilidae
- Psephenidae spp. A–C

Diptera
- Athericidae+
- Blephariceridae spp. A–B+
- Ceratopogonidae
- Chironomidae
  - *Apsectrotanypus* sp.+
  - *Asheum* sp.+
  - Boreoheptagyni+
  - *Cryptochironomus* sp.+
  - Diamesinae spp. A–E+
  - *Microtendipes* sp.+
  - Orthocladiinae spp. A–K+
  - *Paracladopelma* sp.+
  - Pentaneurini spp. A–B+
  - Podonominae+
  - *Polypedilum* sp.+
  - *Rheocricotopus* sp.+
  - *Stictochironomus* sp.+
  - *Stempellina* sp.+
  - *Tanytarsus* sp.+
- Deuterophlebiidae+
- Dixidae
- Empididae spp. A–C
- Muscidae+
- Mycetophilidae+
- Psychodidae spp. A, B
- Simuliidae
- Tabanidae+
- Tipulidae
  - *Antocha* sp.+
  - *Dicranota* sp.+
  - Hexatomini+
  - Tipulidae sp. B

Ostracoda

Copepoda

Nematoda