Biodiversity, Chemistry, and Structure in Streams of the Nepal/Himalaya: Developing Biological Indicators of Change

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Abstract

Despite a continuing perception that Himalayan rivers are sensitive to many environmental changes, there are almost no data on their biodiversity, or on the biological effects of catchment disturbance and pollution. In 1991, we began biological investigations in rivers throughout the whole Hindu Kush-Himalayas. Here, we use data from over 130 sites in Nepal to show the pronounced changes between altitudes, regions, and catchments of different land use. These studies contribute to the development of biological indicators of quality in Nepal's rivers using a powerful and broad array of measurements. With further development, such indicators will help detect failures to manage catchments sustainably.

Introduction

Throughout much of the world, river ecosystems are recognised as important indicators of environmental change (Norris et al. 1995). Their biota respond to influences on habitat character, flow regimes, and chemistry, revealing the effects of brief pollution events often missed by direct chemical sampling. Such indicator value is clear, given the overwhelming importance of rivers to biodiversity (e.g., Dudgeon 1992), to subsistence, and to some commercial activities. So far, however, the principle of using river biodiversity for quality monitoring is undervalued in the less developed world. This is unfortunate because of the cost-effective methods available and applicable to remote locations where other monitoring methods are difficult.

In Nepal, the need for biological monitoring in rivers is great. Catchments are subject to physical, energetic, biological, and chemical changes from urbanisation, deforestation, agriculture, and water-resource development (Ormerod and Juttner 1996). However, there is still debate over the extent to which these activities interact with the natural climatic and dynamic character of Nepal to influence river systems (Eckholm 1975, Ives and Messerli, 1989). If biological monitoring is to develop, therefore, there is a need not only for basic biological data; we need also to identify clear responses to anthropogenic effects against a background of dynamism and spatial heterogeneity.

In 1991, we began a research programme which is assessing how different organisms contribute to biodiversity; examining how stream ecosystems indicate catchment quality; providing a baseline against which changes can be assessed; improving understanding of river structure and function; and providing an impetus to research and relevant training. This contribution describes progress to date, while a companion (Juttner et al. in press) gives specific examples of work from one group.

The Work Programme

The programme has included surveys on over 60 tributaries in the Annapurna, Langtang, and Everest regions (Rundle et al. 1993); 20 tributaries in the Langtang and Trishuli systems (Ormerod et al. 1994; Brewin and Ormerod 1994, Brewin et al. 1995); intensive studies in 5-15 sub-catchments of the Likhu *Khola* and Kathmandu Valley (Tyler and Ormerod 1993; Wilkinson et al. 1995, Ormerod and Juttner 1996, Juttner et al. in press); and a regional survey of 76 sites in the Simikot, Dunai, and Makalu regions (Ormerod et al. 1996, Jenkins et al. this volume; see Fig. 1). Work has involved invertebrates, diatoms, bryophytes, river birds, and stream chemistry, with fish, micro-crustaceans, and stream habitats included opportunistically. Altitudes ranged from 400 to 4,000m, with streams mostly of second to fifth order. Studies involved either independent sites where pattern was assessed *a posteriori* using multivariate statistics (e.g. Rundle et al. 1993, Ormerod et al. 1994; 1996) or replicated *a priori* comparisons among pre-selected streams of certain character (e.g., polluted v. unpolluted).

Downslope Changes

Reflecting trends in habitat structure, chemistry, riparian vegetation, and climate, there are strong downslope changes in Nepalese rivers. In the Langtang-Trishuli, and Likhu *Khola* systems, decreasing altitude is accompanied by increase in the number of species or families of all groups (Fig. 2). For invertebrates, this pattern is variable seasonally, reflecting lower taxon richness in agricultural catchments during the summer monsoon when densities fall drastically (Brewin et al. 1995). It is also variable regionally, with some catchments showing peaks in richness at middle or higher altitudes (see Juttner et al. this volume). There is still marked uncertainty over the extent to which these trends reflect catchment use: some authors suggest that high diversity in lowland Nepal places many species at risk from human activity (Hunter and Yonzon 1993); our data show that some of this increase in rivers may partly be a response to land use (see below).

Stream communities vary in composition and function with altitude (Ormerod et al. 1994). Primary producers in hill streams are seldom angiosperms, with bryophytes also scarce at the lowest or highest altitudes (Ormerod et al. 1994). Diatoms are abundant throughout, with communities dominated by strongly

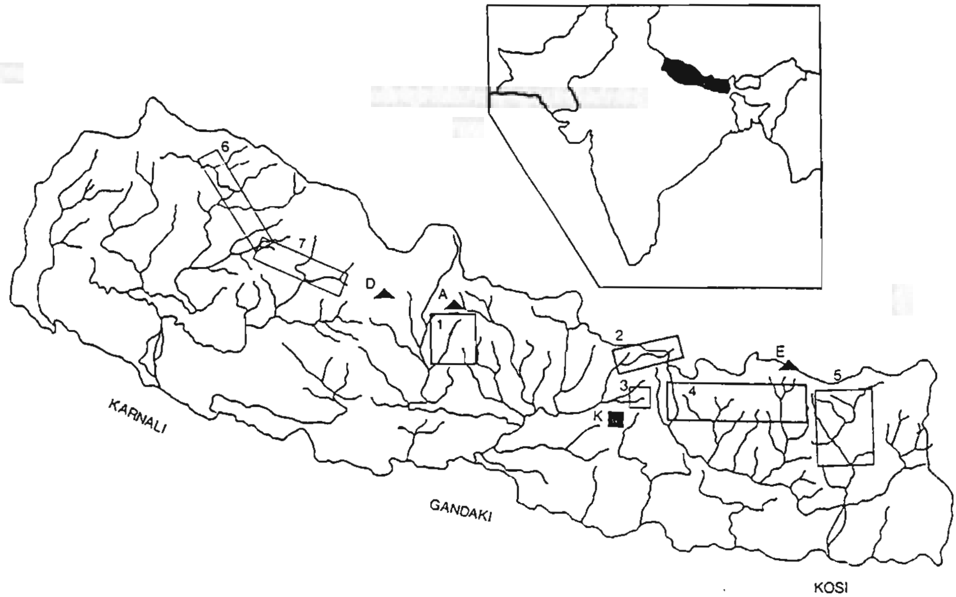

Figure 1: The Major Rivers of Nepal, Showing Sites of Hydrobiological Work in the Annapurna (1), Langtang (2), Likhu *Khola* (3), Everest (4), Makalu (5), Simikot (6), and Dunai (7) Regions. Everest (E), Annapurna (A), Dhaulagiri (D), and Kathmandu (K) are shown.

attached forms in steeper streams (e.g., *Achnanthes minutissima; Fragilaria capucina; Cymbella affinis*), and by motile epipelic and episammic *Navicula* and *Nitzschia* spp at lower altitudes (Ormerod et al. 1994, Juttner et al. in press). Aquatic invertebrates in high altitude streams are predominantly algal grazers, while those in forest or terrace streams mostly filter suspended material from the water column (Fig. 3; Ormerod et al. 1994). This functional change is consistent with the inputs of particulate organic material from forests, while runoff from terraced catchments will be particularly rich in organic particles. Altogether, around 90 invertebrate families have been recorded, with their abundances varying between sites, for example, in different regions (Table 1) .

Catchment Comparisons

As with studies of hydro-chemistry and sedimentology, clear relationships between land use and stream biology are elusive. Geomorphology, chemistry, and biotic communities differ systematically between forest and agricultural streams; however, conclusions about cause-effect links have been confounded by altitude (Rundle et al. 1993, Ormerod et al. 1994, 1996; Brewin et al. 1995, Jenkins et al. 1995). Catchment comparisons at similar altitudes involve limited replication but provide the only data from which assessments are possible.

In the Likhu *Khola*, adjacent sub-catchments of two to five square kilometres at 600 to 800m have terracing varying from almost complete cover (91-98%) to catchments with substantial forest (60%). Fish densities and biomass in terraced

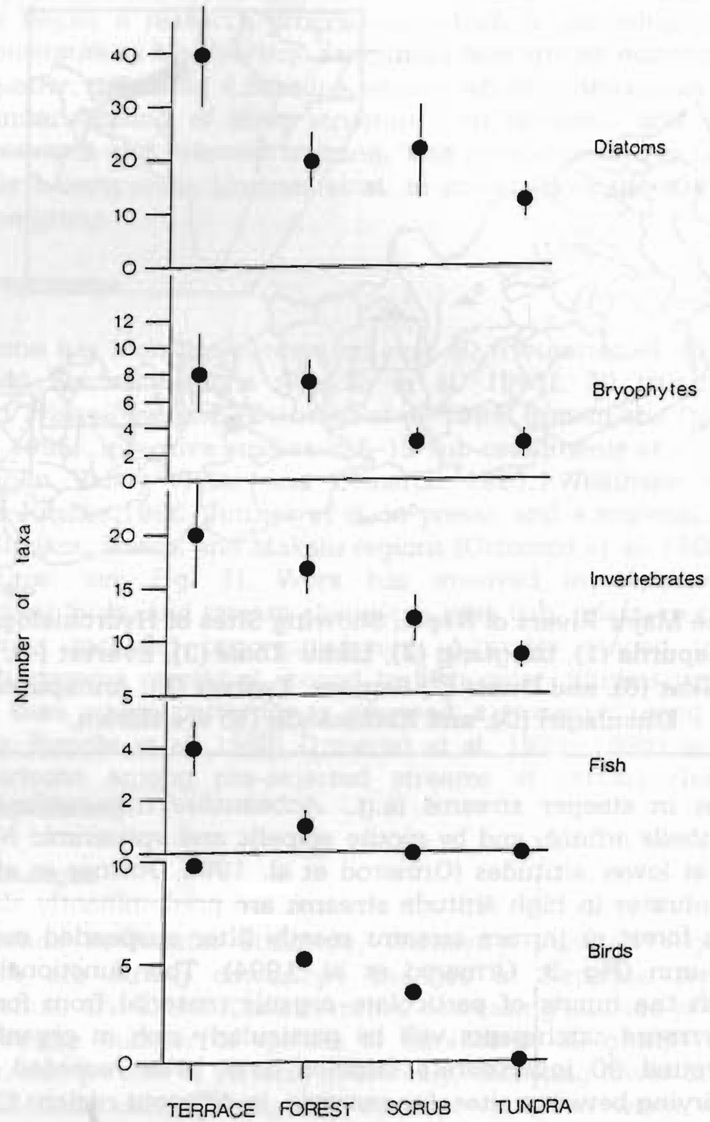

Figure 2: Changes in the Numbers of Species or Families of Various Aquatic Groups in Catchments of Decreasing Altitude from Tundra, Alpine Scrub, Forest and Agricultural Terracing in the Langtang and Likhu *Khola* Valleys in Nepal (winter data from Ormerod et al. 1994)

streams are large by comparison with forest, due mostly to one species, *Opicephalus gachua* (Ormerod et al. 1994). Invertebrate communities differ moderately (Table 1) but include an increased density of filter-feeding hydropsychid caddis from 500m^{-2} in forest streams to approximately 2,300m^{-2} in terraced streams. The unusually species-rich guild of Himalayan river birds was markedly reduced along terraced streams due to reductions among the chats and forktails, all of them insectivores (Tyler and Ormerod 1993). Since aquatic food abundances were not reduced, changes in habitat complexity or food from riparian sources may be responsible. Terrestrial invertebrates are, indeed, scar-

Table 1:

Relative abundances of aquatic macroinvertebrate families from 3 regions of Nepal during November 1994. Abundance categories; ○=<0.1% ●= 0.1-1% ●●= 1-5% ●●●= 5-10% ●●●●= 10-15% ●●●●●= 15-20% ●●●●●●=>20% of the total number of animals sampled in each region.

	Simikot	Dunai	Makalu		Simikot	Dunai	Makalu
EPHEMEROPTERA				ODONATA			
Baetidae	●●●●●	●●●●	●●●●	Anisoptera	●●	●	●●
Ephemerellidae	●●●	●	●●	Zygoptera		○	●●
Heptageniidae	●●●	●●	●●●●	HEMIPTERA			
Ephemeridae	○	○	●	Mesoveliidae			●
Siphlonuridae	●		●●	Aphelocheiridae		○	●
Caenidae	●	●	●	Corixidae		○	○
Prosopitoma			○	Norcoridae			○
Leptophlebiidae	○	○	●●	Gerridae	○		●
PLECOPTERA				Notonectidae			○
Perlidae	●●	●	●●	Nepidae			○
Nemouridae	●●●	●●●●	●●	DIPTERA			
Chloroperlidae	●	●	○	Simuliidae	●●	●●	●
Peltoperlidae	○	●●	●	Chironomidae	●●●	●●●	●●●●
Leuctridae	○	○	●	Tipulidae	●●	●●●	●●
Perlodidae	●●●	●●	○	Tabanidae	●	○	●
Capnidae	○	○	●	Blepharoceridae	●	○	○
Taeniopterygidae	○	○	●	Athericidae	●	●	●
TRICHOPTERA				Psychodidae	○	●●	●
Hydropsychidae	●●●	●●	●●●●●	Dixidae	○	●	●
Rhyacophilidae	●●	●●	●●	Ceratopogonidae	○	○	○
Stenopsychidae	●	●	●●	Deuterophlebiidae	○	○	
Philopotamidae	●●	●●●	●	Stratiomyidae	●	●	○
Psychomyiidae	●		○	Amphizoidae			○
Polycentropodidae	●	●	●	Empididae	●		○
Glossosomatidae	●	●	●	Ephydridae		○	
Odontoceridae			○	Rhagionidae		○	○
Leptoceridae	●	○	●	Syrphidae			○
Limnephilidae	●●	●●	●	Osmylidae	○	○	○
Uenoidae	●●	●●	●	Pyralidae	○		○
Brachycentridae	●●●	●●	●	Tortricidae			○
Hydroptilidae	○	○	●	Corydalidae		○	●
Lepidostomatidae	●●	●●	●●	Oligochaeta	●	●	○
Goeridae	○		○	Planariidae	●	●	●
Hydrobiosidae	○	●	●	Collembola		○	○
Sericostomatidae			○	Ostracoda	○	●	
Ecnomidae			○	Freshwater Crab			○
Helicopsychidae			●	Hydracarina	○	○	○
Phryganeidae	○	○		Hirudinea		○	○
Calamoceratidae	●	○	●	Pisidia	●	●	○
COLEOPTERA				Lymnaeidae	○	○	
Psephenidae			●●	Zonitidae	○	○	○
Elminthidae	●●●●	●●●●●●	●●				
Dytiscidae	●	○	●				
Hydrophilidae	●	●	●●				
Gyrinidae			●				
Sphariidae			○				
Hydraenidae		●	●				
Helodidae	○						
Noteridae			○				
Lampyridae			○				
Scirtidae	●	●	○				
Ptilodactylidae			○				
Coleoptera (Larvae)	○	○	○				

cer among downstream drift in the Likhu *Khola*'s terraced streams by comparison with tree-lined streams (Brewin and Ormerod 1994). Diatoms show particularly interesting differences between stream types, increasing in species' richness under agriculture (see Juttner et al. this volume and in press). This result indicates how increased diversity can result from catchment disturbance.

Habitat-specific Distributions

Changes in river habitat structure between catchments or altitudes have been illustrated using river habitat surveys (RHS). Downslope changes include composite trends to wider channels, deeper water, more laminar flow, fewer riffles, more unvegetated mid-channel bars, more unvegetated side bars, and fewer debris dams. In addition to detecting significant effects of catchment land use (Table 2 and Fig. 4), this method provides strong correlates with the diversity of river biota (Ormerod et al. 1996). Changing physical structure thus seems important to organisms, and this is confirmed by reach-scale studies; there are implications for the indicator value of different groups (Tyler and Ormerod 1993; Brewin et al. 1995, Juttner et al. in press). Among invertebrates, some families occurred mostly in riffles (e.g., *Baetidae, Hydropsychidae, Simuliidae, Ceratopogonidae*), while others occurred mostly in complex margins (e.g., *Corixidae, Limnephilidae, Ephemeridae, Perlidae, Anisoptera*) and make an increasing contribution to communities at lower altitudes (Brewin et al. 1995, Wilkinson et al. 1995). Sandy habitats, which are sometimes common in terraced streams, have low invertebrate density and diversity. These data indicate that invertebrates may only provide reliable water quality indicators if effects by habitat structure can be quantified. Among diatoms, differences between habitats involved more moderate variations in abundance (Juttner et al. in press). As a result, diatom response to pollution was consistent across habitats, perhaps a strength in the indicator value of this group.

Table 2: Selected Differences (means with [SD])in River Biota between Catchments in Different Land Use in the Likhu *Khola*, Nepal

	Afforested	Intermediate	Agricultural Stream	All Streams
Microinvertebrates				
Family richness	15 (6)	21 (6)	19 (4)	18 (5)
Relative abundance (%) of				
Ephemeroptera	36.9 (3.8)	47.4 (22.1)	39.3 (12.4)	41.5 (14.1)
Plecoptera	3.8 (3.3)	0.7 (0.5)	0.8 (1.3)	1.6 (2.3)
Trichoptera	39.8 (14.7)	38.1 (14.0)	42.6 (7.8)	40.0 (11.4)
Coleoptera	10.5 (6.3)	2.0 (1.7)	9.9 (7.8)	6.9 (6.4)
Diptera	6.4 (3.1)	7.6 (3.6)	4.2 (1.1)	6.1 (5.4)
Fish				
Species' richness	6	5 (1)	6 (1)	6 (1)
Winter biomass (g.100m^2)	152	266 (157)	1,212 (98)	563 (517)
Summer biomass	685	398 (170)	1,187 (371)	709 (435)
Winter density (n.100m^2)	84	63 (37)	243 (19)	126 (94)
Summer density	267	348 (71)	460 (76)	372 (94)
Riparian birds				
Species' richness	6 (1)	5 (1)	3 (0)	4 (2)
Abundance n. km	11.5 (1.4)	9.0 (0.7)	1.5 (0)	6.5 (4.8)

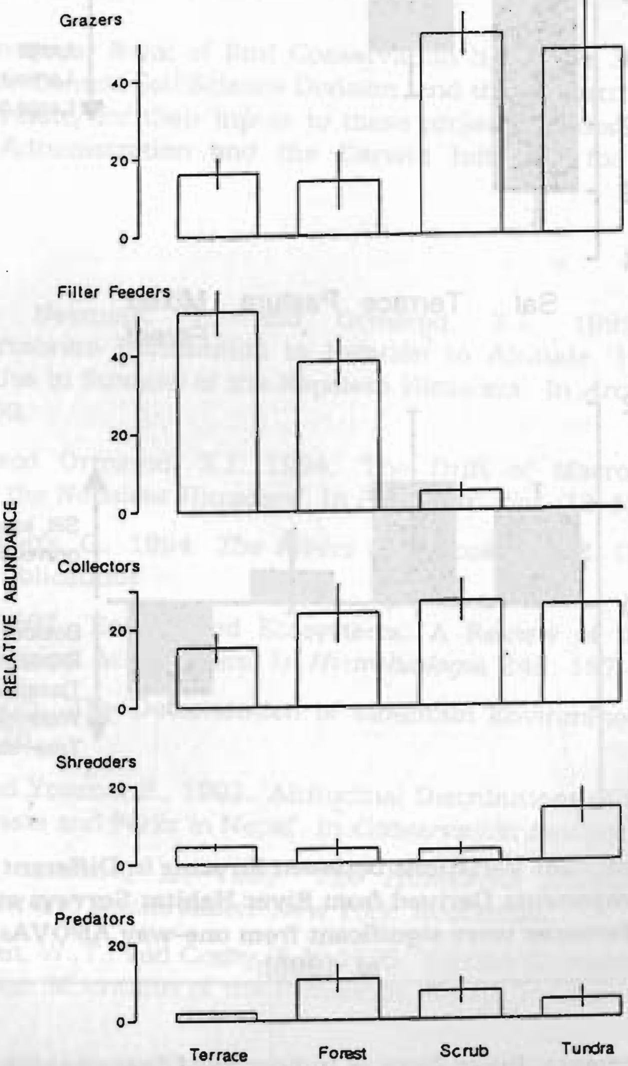

Figure 3: Changes in the Functional Feeding Guilds Represented among Invertebrates in the Same Catchments as in Figure 2 (after Ormerod et al. 1994).

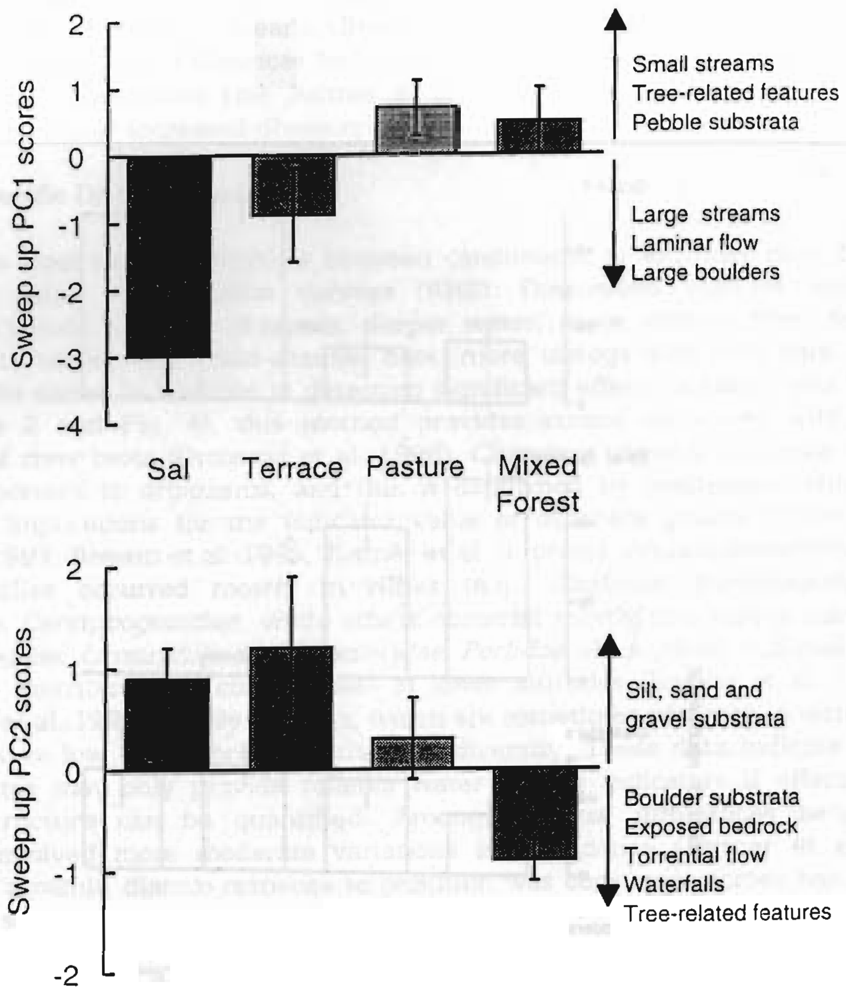

Figure 4: Significant Variations between Streams in Different Land Use on Principal Components Derived from River Habitat Surveys at 76 Sites in Nepal. All differences were significant from one-way ANOVAs (Ormerod et al. 1996).

Concluding Comments: River Biota as Indicators of Sustainability

Both the socio-political difficulties in attaining sustainable development, and the current limitations on understanding catchment processes, will be familiar to readers of this volume. Under these circumstances, how can we judge whether sustainable catchment management is being achieved? We believe that river ecosystems and their biota provide important leads (Ormerod and Juttner 1996). Increasingly, there is recognition that rivers integrate processes in whole catchments, and their biota are regularly monitored to detect change on this scale (e.g., Norris et al. 1995, Calow and Petts 1994). They are regarded as indicators of ecosystem health, degradation, and integrity (e.g., Karr 1993), providing the targets towards which sustainable catchment management may be directed. Our own work shows that there is scope for such biological surveillance in Nepal. There is now a need for the development of a monitoring strategy and an institution, that will enlarge and develop this baseline.

Acknowledgements

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