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LOTIC MACROINVERTEBRATE ASSEMBLAGES IN NORTHERN THAILAND: ALTITUDINAL AND LONGITUDINAL DISTRIBUTION AND THE EFFECTS OF POLLUTION

Stephen E. Mustow[1]

ABSTRACT

The distribution and composition of invertebrate faunas was studied in upland, lowland and urban sites in the north basin of the River Ping in Thailand. The principal physico-chemical features of 23 sites were measured and the invertebrates in seasonal net-sweeps, bottom kick and dredge samples identified to family level. Canonical correspondence analysis was used to assess relationships between environmental and biological data. Taxon accretion was studied at two sites in order to determine the sampling effort required to collect representative kick-samples. Accretion rates were within the range recorded in temperate rivers. Differences in the fauna amongst the 23 sites were explained by temperature, conductivity, pH, and current velocity. Reductions in diversity at severely polluted sites were smaller than in similarly impacted sites in temperate regions.

INTRODUCTION

The ecology of aquatic invertebrates in Asia as a whole is poorly understood (RUNDLE *ET AL.*, 1993; DUDGEON, 1995), not least in Thailand for which few studies are reported in the literature. The most detailed studies in Thailand have been of a reservoir in the central region (JUNK, 1975, 1977) and of a rice field in the Northeast (HECKMAN, 1979). Work published on the macroinvertebrate fauna of rivers includes a preliminary survey of the Chao Phraya and River Kwai river systems (MIZUNO & MORI, 1970); a study of the trichopteran fauna of upland streams through collections of adults (MALICKY & CHANTARAMONGKOL, 1993); an assessment of river water quality using macroinvertebrate data gathered by standard colonisation units (THORNE & WILLIAMS, 1997); and an investigation of changes in the chironomid fauna in relation to water quality using collections of pupal exuviae (MUSTOW *ET AL.*, 1997).

This paper presents the results of an investigation of the basic structure and composition of macroinvertebrate assemblages in northern Thailand and relationships to key environmental factors. The biological data set obtained for this purpose was produced by analysing samples of macroinvertebrates collected from four main rivers and some smaller tributaries, ranging in altitude from 280 m (all altitudes quoted are above mean sea level) to 2,100 m and in width from 3 m to greater than 100 m.

[1] 9 Knighton Road, Sutton Coldfield, West Midlands, B74 4NY, United Kingdom.
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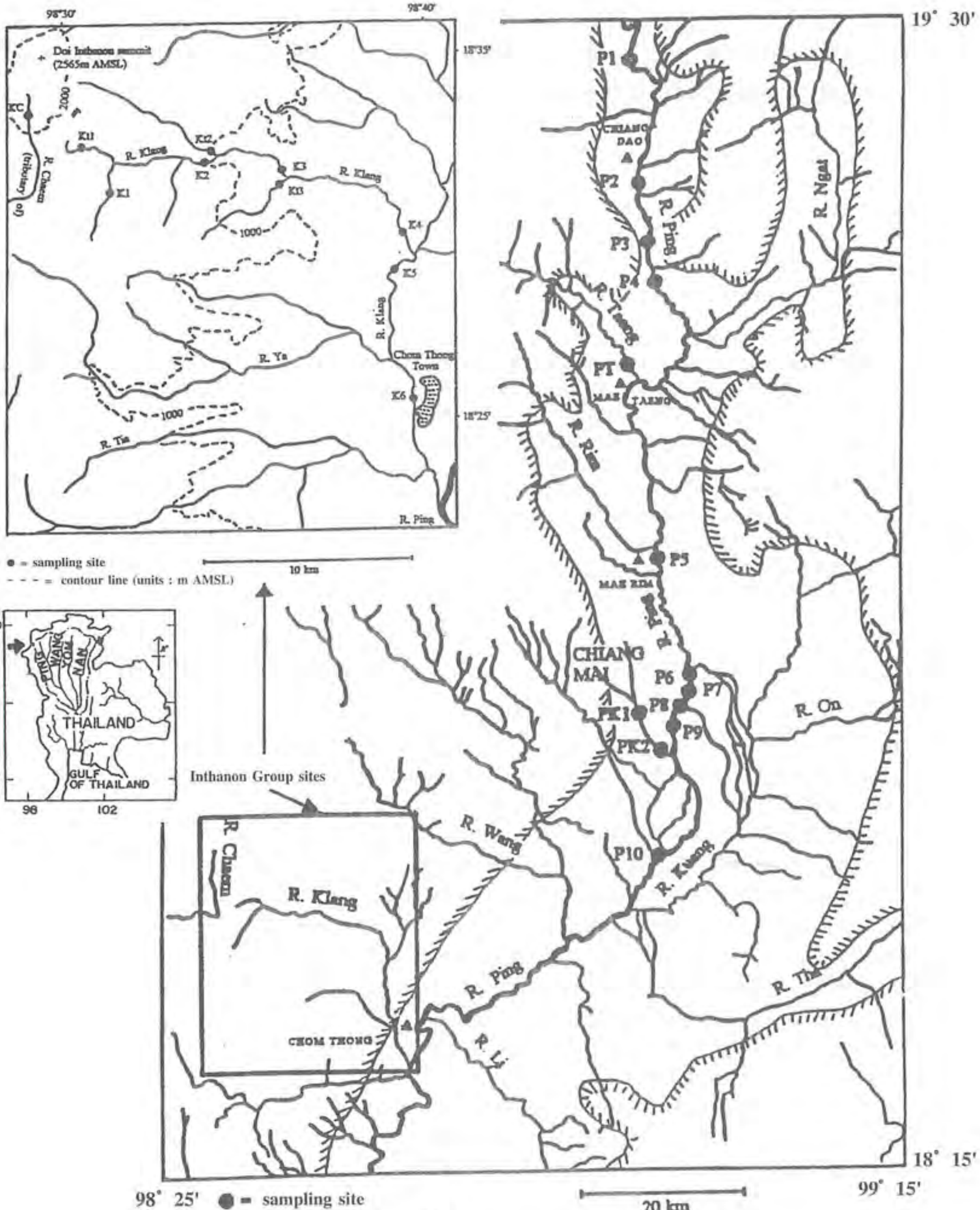

Figure 1. Map of the study area showing the positions of study sites. Insets show the location of the study area and the River Ping within Thailand and detailed locations of the Doi Inthanon Group sites.

In common with the present study, recent investigations of the macroinvertebrate fauna of Nepalese streams (RUTT *ET AL.*, 1990; RUNDLE *ET AL.*, 1993; SUREN, 1994) relied on family-level identification. The family-level approach has also been used successfully in the UK (FURSE *ET AL.*, 1984; ARMITAGE *ET AL.*, 1987; WRIGHT *ET AL.*, 1988), North America (CORKUM, 1989), temperate and tropical parts of Australia (WRIGHT *ET AL.*, 1995; FAITH *ET AL.*, 1995; CHESSMAN, 1995) and recently in Thailand, Ghana and Brazil (THORNE & WILLIAMS, 1997). However, some authors have questioned whether the environmental requirements of particular groups of freshwater invertebrates can be generalized at taxonomic levels above species (RESH & MCELRAVY, 1993). The results obtained in this investigation provide further evidence of the effectiveness of family-level identification when employing macroinvertebrates as indicators of the environmental quality of rivers.

STUDY AREA

The study was carried out in northern Thailand (Fig. 1) in the Northwest Highlands, which include several peaks above 2,000 m. Doi Inthanon (2,565 m) is the highest of these and the highest peak in the country, and lies to the west of the River Ping, southwest of Chiang Mai city. The study area was contained within an area bounded by latitude 18°15'N and 19°30'N and longitude 98°25'E and 99°15'E (Fig. 1). Land within this area falls almost entirely within the River Ping catchment, which in turn is part of the Chao Phraya catchment. Most land up to about 400 m altitude is within the Chiang Mai Basin.

Twenty-three sampling sites were located on the River Ping and several of its tributary systems: the Taeng, Kha, Klang and Chaem. The sites were divided into two groups:

i) The "Ping Group" included sites on the Ping and two of its tributaries, the Taeng and the Kha, between Hang Dong District in the south and Chiang Dao District in the north, ranging in altitude from 280 m to 410 m (Fig. 1).

ii) The "Doi Inthanon Group" included sites on the River Klang and River Chaem systems at 290 – 2,100 m (Fig. 1).

Table 1 gives details of locations, altitudes, mean widths and gradients. Land use in the immediate area of the sampling sites is described in Table 2.

The Ping Group of sites were chosen to provide data on a major low-altitude river, which was reputed to have been degraded as a result of pollution, river regulation, deforestation and intensive farming. Those in the Doi Inthanon Group were selected to provide data on high altitude streams.

The stations on the Ping were located so that the first four were a considerable distance upstream of Chiang Mai city, and could thus be considered to be relatively clean. However, these sites were not entirely unaffected by human activities, as much of the land in the valley floor had been deforested and intensive agriculture was taking place in the area of Chiang Dao town. The remaining sites on the Ping were located so as to straddle Chiang Mai city, in order to detect any associated deterioration in water quality. A sampling site was included on the Taeng, as it is a major tributary of the Ping in the study area. Two sites were also included on the Kha Canal, which is the most polluted of the main Ping tributaries. The Kha Canal is an integral part of the wastewater drainage system in the Chiang Mai municipal area.

Table 1. Location, altitude, slope and mean width of sampling sites.

Site Code	River	Distance (km)[1]	Altitude (m)[2]	Mean width (m)[3]	Slope (‰)[4]
Ping Group					
P1	Ping	0	410	22.3 (3.8)	2
P2	Ping	31	360	18.7 (1.5)	1.5
P3	Ping	37	340	17.7 (1.2)	2.5
P4	Ping	43	330	26.0 (11.1)	2.5
PT	Taeng	3	330	11.6 (5.4)	1.5
P5	Ping	90	310	34.7 (5.9)	0.5
P6	Ping	105	300	50.7 (7.8)	0.5
P7	Ping	107	300	77.0 (8.5)	0.5
P8	Ping	108	300	110.5 (0.7)	0.5
P9	Ping	112	300	54.0 (4.2)	0.5
PK1	Kha	3	300	20.3 (2.5)	0.5
PK2	Kha (arm of)	0.1	290	3.3 (2.5)	0.5
P10	Ping	133	280	83.0 (6.9)	0.5
Doi Inthanon Group					
KC	Tributary of Chaem	N/A	2100	3.5 (1.0)	100
Kt1	Tributary of Klang	2	1360	4.3 (3.2)	50
K1	Klang	0	1270	7.5 (2.7)	40
K2	Klang	5	1010	7.8 (1.0)	30
Kt2	Tributary of Klang	0.5	940	5.8 (1.9)	60
Kt3	Tributary of Klang	0.5	590	4.3 (0.5)	40
K3	Klang	12	560	11.8 (2.5)	20
K4	Klang	21	430	15.0 (2.8)	20
K5	Klang	24	310	8.0 (3.6)	20
K6	Klang	34	290	15.8 (2.6)	2

[1] Distances of sites on the main rivers are from the highest point on the river. Distances of sites on tributaries are from the point of confluence with the main river.
[2] Altitude accurate to ± 10 m.
[3] Standard deviation of mean width shown in parentheses.
[4] Slope calculated through examination of contour patterns in the immediate vicinity of sampling stations.

Table 2. Land use in the immediate area of sampling sites.

Site code	Land use in the immediate area of sampling site
Ping Group	
P1, P2	cultivation of lowland crops
P3	forest (elephant training camp on one side in forest)
P4, PT, P5	cultivation of lowland crops
P6, P7, P8, P9	urban area within Chiang Mai City
PK1	mainly unused scrubland on the edge of Chiang Mai city
PK2	village on one side, unused scrubland on the other
P10	cultivation of lowland crops
Doi Inthanon Group	
KC	deforested area, just downstream of primary evergreen hardwood forest
Kt1, K1	cultivation of upland crops, also some areas of conifer plantations
K2	cultivation of upland crops (mainly rice)
Kt2, Kt3, K3, K4	forest
K5	cultivation of lowland crops
K6	cultivation of lowland crops on one side, edge of Chom Thong town on the other

Sites on Doi Inthanon were located to cover a range of altitudes, from the highest point where a stream could be easily reached, to the lowlands, just before the confluence of the Klang with the Ping. Much of the forest cover remained above 400 m, although parts had been cleared for timber and farming. Below 400 m deforestation was complete and most of the land was cultivated. Sites on several tributaries of the Klang were included for comparison with sites on the main stream. As the Klang itself originated below the summit of Doi Inthanon, a site was also included on a tributary of the Chaem River at 2,100 m.

Mean annual precipitation ranges from approximately 800 mm to slightly more than 1,800 mm in the catchment of the Chao Phraya River (ALFORD, 1992). In northern Thailand rainfall is heavier in the mountains than in the valleys (SMITINAND *ET AL.*, 1978). There are three seasons: the rainy or wet season, in which about 80% of the annual rainfall occurs, lasts from June through October; the cold season lasts from November through February; and the hot season from March through May.

MATERIALS AND METHODS

Physico-chemical Survey

Physico-chemical sampling took place once in each of the three seasons. Measurements were taken between 6:00 and 19:00, with sites commonly being visited in sequential order. Readings were taken over two years (September 1991 to April 1993) other than on the Kha Canal, where the sampling period covered one year (December 1992 to September 1993). Measurements of nitrate and phosphate concentration were taken once, at a limited number of sites. Widths, depths and current velocities were measured or estimated. Near-surface measurements of temperature were made using a thermometer, conductivity, dissolved oxygen (DO) and pH were measured using multi-probe kits (manufactured by Walden Precision Apparatus and Ciba-Corning), and transparency was measured by Secchi disc. Orthophosphate and nitrate nitrogen were analysed from samples taken in September 1993, using a Hach DR/2000 spectrophotometer. Data on calcium hardness were provided by Chiang Mai University's chemistry department.

Physico-chemical data were produced from spot measurements and can therefore only provide a limited picture of conditions at the sampling sites, which would have been highly variable. Temperature and DO change over a daily cycle and most other parameters change with discharge. However, the data are considered adequate for the purpose of classifying sites and for highlighting locations where the macroinvertebrate fauna may be affected by extreme environmental conditions.

Macroinvertebrate Survey

At Ping Group shallow sites (P1-P5, PT) samples were collected over two years, once in each of the three seasons. Elsewhere the sampling period lasted for one year. Kha Canal sites were sampled only twice, in the hot and rainy seasons of 1993. Sampling of shallow sites on the River Ping and the River Taeng began in December 1990 and continued, at approximately four-month intervals, until August 1992. The same schedule was followed for Doi Inthanon Group sites but sampling took place for one year only, ending in September 1991. Sampling of the deep sites (P6–P10) on the River Ping began in August 1991 and continued, again at approximately four-month intervals, until April 1992.

Macroinvertebrate assemblages at shallow sites (P1–P5, PT, PK2, all Doi Inthanon Group sites) were sampled using a pond-net (400 μm mesh, 32 x 20 x 20 cm triangular frame, 50 cm bag depth), fitted to a 1.4 m handle. The 3-min kick-sampling technique described by FURSE *ET AL.* (1981) was employed, with some minor modifications. Between six and eight 3-min kick samples were taken on each sampling occasion at each site and these were combined to give an overall sample. In four cases the full level of sampling effort could not be employed, due to high river flows. Numbers of individuals in each family were estimated using counts of individuals in fractions of the overall sample. All abundance data were converted to the format "numbers per 3-min kick".

To assess how many 3-min kick-samples would be required to produce an adequate overall sample, a series of nine 3-min kick samples was taken at K2 on 8/12/90 and at P1 on 9/12/90. The samples were analysed separately and taxon accretion curves were constructed using ten random combinations of sample order (MUSTOW, 1997). The calculated values were based on the total 27-min catch representing 100%, as a convenient way of comparing the two sites. The curves showed that on average six samples were required to catch at least 90% of the taxa in the 27-min catch, while eight samples were necessary to catch 95% of the taxa, at both sites. Thus, as eight samples would give an almost comprehensive family list and could be collected in an acceptable amount of time by two operators, this was subsequently adopted as the standard sampling effort.

Macroinvertebrate assemblages at deep sites (P6–P10, PK1) were sampled using a hand-operated dredge (mouth 9.3 x 31 cm, length 50 cm, mesh opening 500 μm, weight 6 kg) attached to a cable of length 10 m. The dredge was thrown out from the bank and a combined sample was produced from five throws. Samples were taken from submerged marginal vegetation, when present, using a pond-net of the type described above. This was swept through the submerged vegetation for a total of ten minutes. The taxa present in dredge and net-sweep samples were recorded.

Macroinvertebrate samples were preserved in formalin and sorting and identification of specimens took place in the laboratory. Family-level identification was used as standard because:

i. Due to a lack of keys and the large number of undescribed species present in the study rivers, it would have been impossible to identify many specimens to generic or species level with the resources available.
ii. In some cases where keys to Thai species existed, more recent literature showed that they required significant revision (WOODRUFF *ET AL.* (1993), for example, have proposed that 20 nominal *Corbicula* (Corbiculidae, Bivalvia) species from Thailand are junior synonyms of the widespread and conchologically variable *Corbicula fluminea* (Müller)).
iii. The majority of specimens could be identified without difficulty to family level using North American, European and Australian keys.

With some groups, however, identification to family level was impractical. Thus members of the Phylum Nematoda, Classes Copepoda and Ostracoda, Subclass Oligochaeta, Orders Cladocera and Collembola and Suborder Hydracarina were identified no further than these higher taxa.

The morphological characters used in keys did not allow some specimens to be assigned to a single family with confidence, though frequently all but two or three families could be excluded. This difficulty only occurred with certain groups and these were amalgamated to form composite taxa, as follows:

ODONATA
Amphipterygidae + Euphaeidae → Amph/Euph
Coenagrionidae + Platycnemidae → Coen/Plat
Corduliidae + Libellulidae → Cord/Lib

DIPTERA
Empididae + Ephydridae → Empi/Ephyd

TRICHOPTERA
Hydropsychidae + Arctopsychidae → Hydro/Arc (Arctopsychidae was most probably only present in samples taken above 1000 m on Doi Inthanon)
Odontoceridae + Brachycentridae → Odon/Brach
Polycentropodidae + Stenopsychidae + Dipseudopsidae → Poly/Sten/Dip

EPHEMEROPTERA
Baetidae + Siphlonuridae → Baet/Siph

In the following text, when reference is made to the families recorded, the term "family" is inclusive of the amalgamated taxa and higher taxa not identified to family level.

The primary output from the macroinvertebrate sampling programme was a data matrix, 102 samples x 116 families in size. Data from all samples from each site were subsequently combined to reduce any effects related to the season in which samples were collected (note that the results of an analysis of seasonal differences in the communities, using the uncombined data set, are presented by MUSTOW, 1997). An environmental data set corresponding to this modified biological data set was produced for use in multivariate analysis. This consisted of combined data for each site and contained mean values of pH, conductivity, temperature, velocity, width and depth, minimum values of DO concentration, and values of altitude and slope calculated from maps. It also contained nominal values indicating whether samples were from River Ping shallow sites, River Ping deep sites or the Kha Canal (blank values were recorded for Doi Inthanon Group sites in order to follow the format required in multivariate analysis).

Diversity was measured using the Shannon-Wiener diversity index (SHANNON & WEAVER, 1949), values of which are calculated using the following equation:

Shannon's H' = $-\Sigma P_i * \ln(P_i)$

where Pi is the ratio of the i-th species abundance to the sum of abundances of all species in the particular sample.

Shannon's H' could only be calculated for semi-quantitative data sets which were only available for shallow sites. This diversity index is derived from information theory and utilises the distribution of the numbers of individuals per species in calculating values.

Differences in macroinvertebrate community structure amongst sample sites, in relation to environmental variables, were investigated using the macroinvertebrate and environmental data sets. The computer program CANOCO v.3.10 (TER BRAAK, 1987–1992, 1990) was used to carry out Canonical Correspondence Analysis (CCA). The options used in this analysis were: taxonomic data transformed to presence/absence format, no specification of family-weights or sample-weights, no downweighting of rare families, and family scores were weighted mean sample scores. CANOCO automatically tested the environmental variables for colinearity (none was detected). Environmental variables were forwardly selected to find a minimal set of variables that explained the family data virtually as well as the full set. CANOCO tested at each step whether the variable to be added was statistically significant ($p < 0.05$), using a Monte Carlo permutation test. The output diagram displayed an ordination of biplot scores of forwardly selected environmental variables (represented by arrows), and sample scores, which are linear combinations of environmental variables and weighted averages of family scores (note that the corresponding family biplot is presented by MUSTOW, 1997).

RESULTS

Physico-chemical Survey

The maximum and minimum spot values (uncombined data) obtained at different groups of sites during the physico-chemical surveillance programme are shown in Table

3. At most sites substantial seasonal variation in river depth was observed, although width remained relatively constant due to the presence of steep banks, either natural or artificial. On the River Ping below P5 and on the Kha Canal, a series of weirs had been installed which artificially raised the depth at sites P6–10 and PK1. The substrates at the lowest five sites on the River Ping and at PK1 were depositing. Those at the other sites were predominantly eroding.

Water temperatures at Ping Group sites ranged between 19 and 34°C (Table 3). A wider range, 9 to 28°C, was observed on Doi Inthanon (Table 3). A clear downstream increase in temperature was observed on Doi Inthanon, with mean temperature at the lowest two sites being 11°C greater than at the highest site. Mean conductivity values were higher for Ping sites P2–P4, than for other sites on the River Ping and River Taeng. Conductivity levels on the Kha were considerably higher than those recorded at all other sites (Table 3). There was a relatively steady downstream increase in mean conductivity values on Doi Inthanon. Data on calcium hardness were in agreement with the conductivity data, with elevated levels occurring at upstream sites on the River Ping, and sites on Doi Inthanon, in particular those at high altitude, being infertile (Table 3). At all River Ping sites mean DO concentrations were > 5 mg l^{-1} and they were slightly higher at shallow sites than at deep sites. Only at P10 did the minimum recorded DO concentration drop below 4 mg l^{-1}, to 1.5 mg l^{-1}. DO levels on the Kha Canal were considerably lower than those on all other rivers (Table 3). At Doi Inthanon Group sites, mean DO concentrations were above 8.0 mg l^{-1}, other than at K6 where the mean value was 6.5 mg l^{-1}. Water at every site was slightly alkaline, with the mean pH 7.0–8.0, except for KC, the highest site on Doi Inthanon (mean pH 6.5). Both nitrate nitrogen and orthophosphate concentrations were considerably higher on the Kha Canal than on the River Ping (Table 3).

Macroinvertebrate Survey

Table 4 shows the macroinvertebrate data amalgamated for each site. The total number of families recorded at sites ranged from 25 at PK1 to 70 at P1. More than 45 families were distinguished at all but four sites. Of the nine insect orders recorded, seven contained more than two families (Trichoptera, Plecoptera, Odonata, Hemiptera, Ephemeroptera, Diptera and Coleoptera). Figures 2 and 3 show the percentage composition of families in these seven principal orders.

On the River Ping there was a similar pattern of percentage family composition at all sites, with the notable exception that no Plecoptera were recorded from deep sites (Fig. 2). The pattern at the River Taeng site was similar to that at shallow River Ping sites, but the Kha Canal sites differed from all others in that Trichoptera were not recorded at either site, and at PK1 Ephemeroptera were also absent. The pattern of percentage family composition at Doi Inthanon Group sites was similar to that at River Ping shallow sites, although trichopteran and plecopteran families made up a relatively greater proportion of the insect fauna, while Hemiptera were less well represented (Fig. 3). There were no obvious downstream changes.

Bar charts were also drawn for those non-insect groups from which more than three families were recorded (Hirudinea, Decapoda, Gastropoda [Pulmonata and Prosobranchia shown separately] and Bivalvia) (Figs. 4 and 5). The percentage composition of insect

Table 3. Summary of physico-chemical data.

Site Codes	River Ping		River Taeng	Kha Canal	Doi Inthanon Group
	Shallow Sites P1-P5	Deep Sites P6-P10	PT	PK1 & PK2	KC- K6
Period when readings taken	Sep 91– Apr 93	Sep 91– Apr 93	Sep 91– Apr 93	Dec 92– Sep 93	Sep 91– Apr 93
Number of sites	5	5	1	2	10
Altitude (m)	310-410	280-300	330	290-300	290-2100
Width (m)	16-40	35-111	7-15	1-23	2-35
Maximum depth (m)	0.2-2.0	1.0-2.9	0.3-1.7	0.1-1.1	0.1-1.5
Main substratum particles	pebbles & cobbles	silt & sand	sand & gravel	silt, sand & gravel	pebbles, cobbles & boulders
Air temperature (°C)	15-37	16-38	25-37	26-36	8-35
Water temperature (°C)	19-31	21-30	21-34	23-31	9-28
Secchi depth (m)	0.06-0.62	0.11-1.00	0.08-0.64	0.34-0.57	0.10-0.70
Current velocity (m s^{-1})	0.1-1.1	0.0-0.6	0.2-1.0	0.0-0.4	0.0-1.1
Conductivity (μS)	150-430	160-260	100-180	250-640	5-170
Calcium hardness (ppm (as $CaCO_3$))[1]	61.5-115.3	59.5-75.3	49.5-59.5		ND-58.5
Dissolved oxygen (mg l^{-1})	5.8-12.3	1.5-8.5	6.5-10.1	0-1.8	4.7-13.9
Dissolved oxygen (percentage saturation)	67-142	20-114	83-139	0-25	51-152
pH	6.7-8.8	6.6-7.9	6.7-8.3	6.9-8.1	5.1-8.5
Nitrate nitrogen (mg l^{-1})		3.8-5.2		7.9-15.9	
Orthophosphate (mg l^{-1})		0.43-1.06		2.88-6.48	

Values are maximum and minimum values (uncombined data) recorded during the sampling programme.
[1]Readings taken by Chiang Mai University's chemistry department in August 1988, November 1988 and April 1989.
ND = non detectable

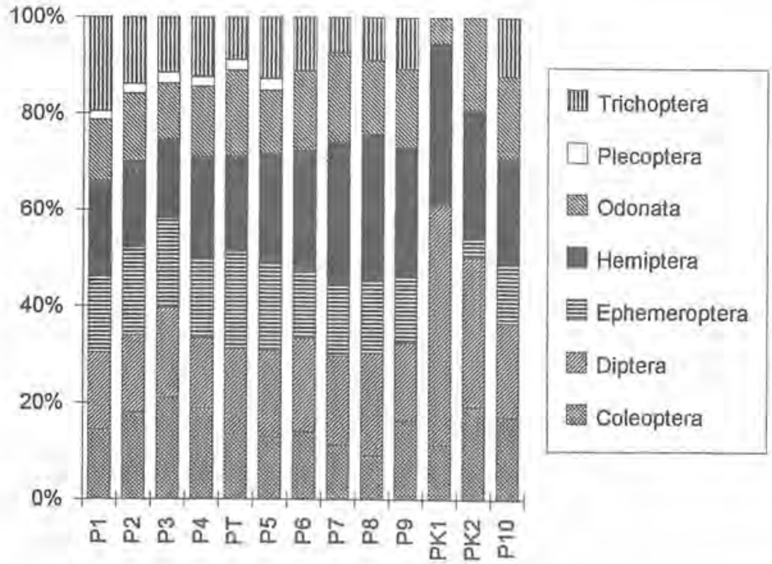

Figure 2. Percentage composition of families in principal insect orders, Ping Group. There is a similar pattern of percentage family composition at all River Ping sites (P1–P10) and on the River Taeng (PT), with the important exception that Plecoptera were not recorded from deep sites (P6–P10). Kha Canal sites (PK1 & PK2) differ from all others in that Trichoptera were not recorded at either site and at PK1 Ephemeroptera were also absent.

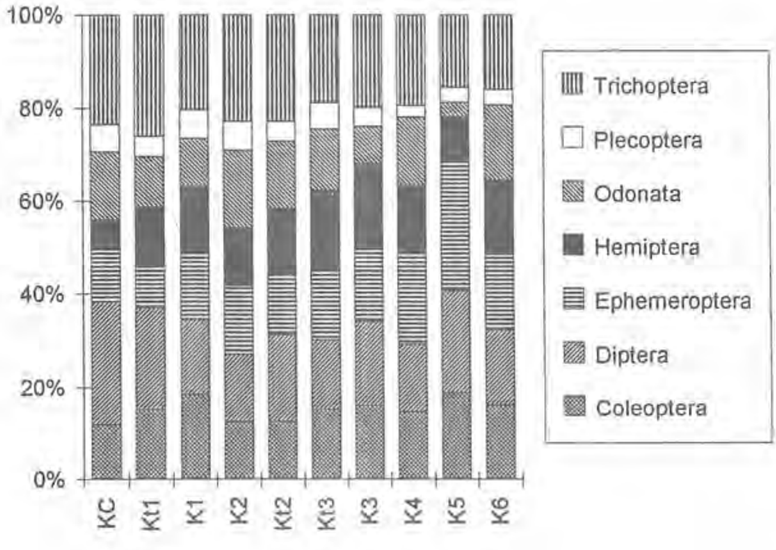

Figure 3. Percentage composition of families in principal insect orders, Doi Inthanon Group. There is a similar pattern of percentage family composition at all Doi Inthanon Group sites. The pattern is similar to that observed at River Ping shallow sites.

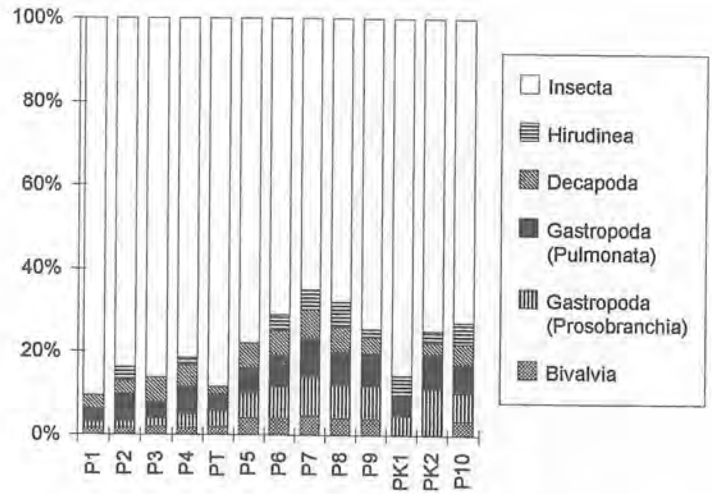

Figure 4. Percentages of insect families and families in selected non-insect groups, Ping Group. On the River Ping the ratio of the number of families in the non-insect groups to the number of insect families was greatest at the deep downstream sites (P6–P10). This was primarily due to an increase in the relative abundance of families of molluscs and leeches. The Kha Canal sites, PK1 and PK2, differ from all others in that bivalves were not recorded at either site. Also, at PK1 decapods were not recorded, which were present at all other Ping Group sites. The River Taeng site (PT) is similar in composition to the shallow River Ping sites (P1–P5).

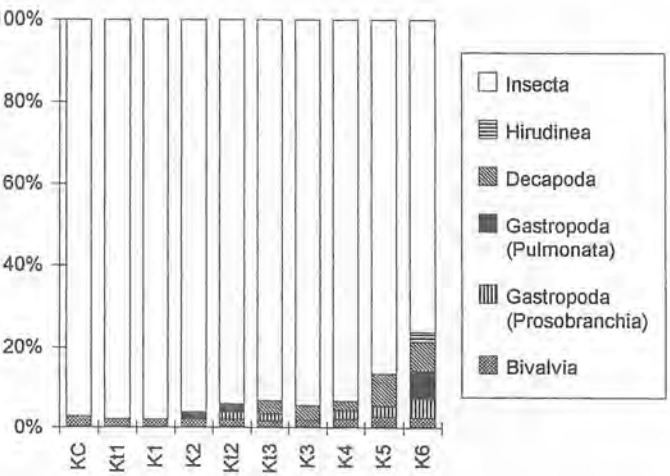

Figure 5 Percentages of insect families and families in selected non-insect groups, Doi Inthanon Group. The ratio of the number of families in non-insect groups to the number of insect families increased with decreasing altitude (i.e. between KC and K6). Bivalves occurred at all sites, while gastropods were only recorded below K1, decapods only below Kt2 and leeches only at the lowest site, K6. Families in the selected non-insect groups were poorly represented compared to Ping Group sites, other than at the two lowest sites (K5 & K6).

families was included in these charts, in order to indicate changes in the ratio of the number of insect families to the number of non-insect families.

On the River Ping, the ratio of the number of families in the selected non-insect groups to the number of insect families was greatest at the deep downstream sites, P6–P10 (Fig. 4). This was primarily due to an increase in the relative abundance of families of molluscs and leeches. The percentage composition of families at the River Taeng site was similar to that at the shallow River Ping sites, P1–P5. The Kha Canal sites, PK1 and PK2, differed from all others in that bivalves were not recorded at either site. Also, at PK1 decapods were not recorded. These were present at all other Ping Group sites. Perlidae (Plecoptera), Simuliidae (Diptera), Ephemerellidae, Prosopistomatidae (both Ephemeroptera), Aphelocheiridae (Hemiptera) and Psychomyiidae (Trichoptera) appeared at every River Ping shallow site, but were absent from River Ping deep sites (Table 4). In contrast, Corallanidae (Amphipoda) and Ampullariidae (Gastropoda) occurred at every River Ping deep site, but were absent from River Ping shallow sites (Table 4).

On Doi Inthanon, other than at the two lowest sites, the ratio of the number of families in the selected non-insect groups to the number of insect families was lower than at Ping Group sites (Fig. 5). The ratio increased with decreasing altitude and there were altitudinal differences in distribution. Bivalves occurred at all sites, while gastropods were only recorded below K1, decapods only below Kt2 and leeches only at the lowest site, K6. All bivalve molluscs were in the family Pisidiidae, other than at the lowest two sites. The limited occurrence of non-insect families at Doi Inthanon Group sites, compared to Ping Group sites, can additionally be appreciated through observation of the upper quartile of Table 4.

The most abundant taxa at shallow sites (semi-quantitative data were not collected from deep sites) were Elminthidae (Coleoptera), Chironomidae, Simuliidae (both Diptera), Baetidae/Siphlonuridae (Ephemeroptera), Corixidae (Hemiptera) and Ostracoda. These appeared at more than 10 individuals per 3-min kick sample at two or more sites (Table 4). The higher taxa which occurred at greatest abundance in samples were the Coleoptera, Diptera, Ephemeroptera, Hemiptera and Trichoptera.

Shannon diversity (H'), calculated for sites where semi-quantitative data were obtained, ranged between 1.2 and 1.5 at River Ping shallow sites, and between 1.1 and 1.9 at Doi Inthanon Group sites (Table 4). At sites on the River Klang, diversity increased from 1.2 at K1 to a maximum of 1.6 at K2 and then decreased progressively downstream to a minimum of 1.1 at K6. Diversity at PK2 on the Kha Canal (0.7), was considerably lower than at all other sites.

The first (horizontal) axis (λ_1 (first eigenvalue) = 0.273) of the CCA ordination diagram (Fig. 6) clearly separates Doi Inthanon Group sites, Ping Group deep sites and Kha Canal sites into three clusters, thus indicating differences in faunal composition. Shallow River Ping sites also form a separate cluster. This is ordinated more closely to low altitude stations on Doi Inthanon and to the River Taeng site, than to the deep River Ping sites. The four forwardly selected environmental variables which best explained the differences in macroinvertebrate composition were conductivity, temperature, pH and velocity. The directions of the environmental arrows in the ordination diagram show that samples from the following sites were associated with the following environmental variables: River Ping deep sites and Kha Canal sites with higher conductivity; Doi Inthanon Group low altitude

Table 4. Shannon diversity and families occurring in combined samples for each site.

	Sites																							
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	PT	PK1	PK2	KC	Kt1	K1	K2	Kt2	Kt3	K3	K4	K5	K6	Occurrences
TRICLADIDA																								
Dugesiidae	0	0	0												0		0		0				0	7
NEMATODA	0	0	0	0	0	+		+					0					0		0	0			11
OLIGOCHAETA	2	2	4	3	2	+	+	+	+	+	0	+	3	1	2	0	2	0	1	0	0	1	8	23
HIRUDINEA																								
Erpobdellidae		0											0											2
Glossiphoniidae						+	+	+		+													0	5
Hirudidae								+		+														2
Piscicolidae		0		0		+	+	+	+	+		+												8
BIVALVIA																								
Amblemidae					0	+	+	+	+	+														6
Corbiculidae	4	3	2	3	3	+	+	+	+	+	0											0	0	13
Pisidiidae														0	0	0	1	0	4	0	2			8
GASTROPODA (PROSOBRANCHIA)																								
Ampullariidae						+	+	+	+	+		+	0											7
Bithyniidae					0	+	+	+	+	+			0											7
Thiaridae	6	7	7	16	9	+	+	+	+	+	0		0					0	7		0	0	1	17
Viviparidae				0	0	+	+	+	+	+	0		0										0	10
GASTROPODA (PULMONATA)																								
Ancylidae		0		0	0	+	+	+	+	+			0										0	10
Buccinidae		0		0		+	+	+	+	+														7
Lymnaeidae	0	0	0	0	0	+	+	+	+	+	0	+	0										0	14
Planorbidae	0	0	0	0	1	+	+	+	+	+	0		0				1	3					0	15
HYDRACARINA	0	0	0	0	0	+		+	+	+	0	+						0	0	0			0	15
CLADOCERA						+	+	+		+		+	16				0		0					8
OSTRACODA	12	2	2	12	1	+	+	+	+	+	34		8		1	0	0	0	0	0	0	1	11	21
COPEPODA						+	+						8											3
AMPHIPODA																								
Corallanidae						+	+	+	+	+														5
Talitridae						+	+	+	+			+	0											6
DECAPODA																								
Atyidae			0	0	0	+	+	+	+	+												0	0	10
Palaemonidae	0	0	0	0	0	+	+	+	+	+									1	0	1	0	0	15
Parathelphusidae	0	0	0	0	0	+	+	+		+	0		0									4	0	13
Potamidae																			0	0				2
COLLEMBOLA	0	0	0		0	+		+	+	+	0		0	0				0	0	0	0	0	0	17
MEGALOPTERA																								
Corydalidae	0	0													0	0	0	1	0	0	0			9
Sialidae										+									0					2
EPHEMEROPTERA																								
Baet/Siph	26	30	36	20	43	+	+	+	+	+	7		3	20	24	48	27	15	17	23	28	46	7	22
Behningiidae											0											0		2
Caenidae	3	4	2	3	9	+	+	+	+	+	3					0	1	1	3	3	3	1	8	19

	Sites																							
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	PT	PK1	PK2	KC	Kt1	K1	K2	Kt2	Kt3	K3	K4	K5	K6	Occurrences
Ephemerellidae	3	8	3	1	0						0			1	2	1	3	2	0	1	0	0		15
Ephemeridae	0	0	0	0	0	+	+	+	+	+	1					0	0	1	1	4	7	0	0	19
Heptageniidae	0	0	1	1	1	+	+	+	+		0			2	5	2	1	2	5	2	2	2	0	20
Leptophlebiidae	3	3	2	1	0	+		+	+	+	0			0	1	1	1	3	4	2	2	0	2	20
Oligoneuriidae		0														0								2
Potamanthidae	1	0		0						+	0								1	0	0	0		9
Prosopistomatidae	0	0	0	0	0																0			6
Tricorythidae	0		0								0						0		0	0		0		7
ODONATA																								
Aeshnidae													0	0	0	0	0	1	0	0	0			9
Amph/Euph	0		0								0				0	0	0	0	0					8
Calopterygidae	0	0	0	0						+	0					0	1	1	0	0	0			12
Chlorocyphidae	0	0		0	0	+	+	+	+	+	0			0				0			0		0	14
Coen/Plat	0	0		0	0	+	+	+	+	+	0	+	0	0	0		0		0	0				17
Cord/Lib	0	0	0	1	0	+	+	+	+	+	1		0		0		0	0	0		0		0	18
Cordulegastridae														1		0	0							3
Gomphidae	0	0	1	1	0	+	+	+	+	+	1		0	1	0	0	1	1	0	2	1	1	1	22
Macromiidae		0		0		+			+	+	0						0	1	0		0		0	11
Protoneuridae	0	0	0	1	0	+	+	+	+	+	0		0										0	13
PLECOPTERA																								
Nemouridae														6	1	0	0		0	0				6
Peltoperlidae																0	0	0	0					4
Perlidae	1	1	2	1	1						0			2	3	2	2	4	1	1	1	4	0	16
HEMIPTERA																								
Aphelocheiridae	1	1	1	0	0						0			0	1	1	1	1	0	1	0	1	0	16
Belostomatidae	0			0				+		+		+	1											6
Corixidae	0	0	0	1	12	+	+	+	+	+	28	+	0			0	1	0	0	7	1	7	6	21
Gerridae	0	0	0	1	0	+	+	+	+	+	1		0	1	1	0	0	0	0	1	0		0	21
Hebridae	0	0							+		0				0	0								6
Hydrometridae	0					+		+	+	+			0						0	0				8
Mesoveliidae	0	0	0	0	0	+	+	+	+	+	0	+	0											13
Naucoridae	0	0	0	0	0	+	+	+	+	+	0		0		0	0	1	1	0	0	0	0		20
Nepidae				0	0	+	+	+	+		0	+						0	0	0				11
Notonectidae	0	0		0	0	+	+	+	+	+		+			0				0	0			0	14
Pleidae	0	0	1	0	0	+	+	+	+	+	0	+	0		0	0	0	1	1	0	0		0	21
Veliidae	0	0	0	0	0	+	+	+	+	+	0					0	1	0	1	0	0			17
LEPIDOPTERA																								
Pyralidae	0	0	0	1		+	+	+	+	+	0		0	0	0	0	0		0	0	0		0	19
TRICHOPTERA																								
Calamoceratidae																	0	2	0	0			0	5
Ecnomidae	0					+			+	+														4
Glossosomatidae	0														0	1	0	0		0				6
Goeridae															1	1	4	1	0	1	0			7
Helicopsychidae	0																							1
Hydro/Arc	4	3	2	0	1	+		+	+	+	0			1	4	2	1	1	1	1	1	2	0	20
Hydroptilidae	1	1	1	1	0					+	2				0	0	1	0	0	0	1			14
Lepidostomatidae	0													2	2	1	2	3	0	1				8
Leptoceridae	0	0	0	1	0	+	+	+	+	+	1			0	0	0	3	1	6	6	2	0	0	21

	Sites																							
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	PT	PK1	PK2	KC	Kt1	K1	K2	Kt2	Kt3	K3	K4	K5	K6	Occurrences
Limnocentropodidae														1										1
Molannidae														0		0	0							3
Odon/Brach	1	0	0	1							0				0		0	2	0	0	0		0	12
Philopotamidae	0	0													1	0		0	1	0	0	0		9
Phryganeidae														0										1
Poly/Sten/Dip	0	0		0	0	+	+	+	+	+				1	1	0	1	1	0		0	0	0	18
Psychomyiidae	0	0	0	0	0										0	0	1	1	1	1	0	0		13
Rhyacophilidae														1	0									2
Uenoidae															1									1
COLEOPTERA																								
Chrysomelidae		0														0								2
Curculionidae			0			+				+			0			0			0					6
Dryopidae	0	0	0	0					+		0				1	1	0	1	3	0	0	0	0	15
Dytiscidae	0	0	1	1	0	+	+	+	+	+	0	+	0	0		0			0	0	0	0	0	20
Elminthidae	16	12	18	8	1	+	+	+	+	+	1		0	2	6	10	5	6	5	7	4	2	5	22
Gyrinidae	0	0	0	0	0				+		0			1	1	1	0	0		0				13
Haliplidae				0																				1
Helodidae	0	0	0	0						+	0		0		1	1	0	0	1	0	0			14
Hydraenidae																0								1
Hydrophilidae	0	0	0	0	0	+	+	+	+	+	0	+	1	0	1	1	0	2	2	1	0	0	0	23
Lampyridae	0	0	0	0						+									0					6
Psephenidae	1	0	0	0	0	+			+	+					0		0	0	1	1	1	0	0	16
Ptilodactylidae															0					0		0		3
DIPTERA																								
Athericidae			0	0											1			1	0	0	0			7
Blepharoceridae																				0				1
Ceratopogonidae	0	1	0	1	0	+	+	+	+	+	0	+	0	1	1	0	1	1	1	1	0	0	0	23
Chaoboridae												+												1
Chironomidae	8	14	11	17	10	+	+	+	+	+	15	+	58	28	18	14	22	20	18	24	30	19	46	23
Culicidae	0				0	+	+	+	+	+	0	+	0	0									0	12
Dixidae														1				0	0	0				4
Dolichopodidae		0												0	0							0		4
Empi/Ephyd	0	0	0	1	0	+		+	+	+	0	+	0	1	1	1	0	0	0			0		19
Muscidae		0			0					+		+		0										5
Psychodidae	0					+				+	0	+	0		0		0	0		0	0			11
Sciomyzidae									+						0	0								3
Simuliidae	0	1	0	0	0						0			24	12	6	9	11	5	2	5	1	0	16
Stratiomyidae	0		0	0		+	+	+	+	+	0	+	1			0								12
Syrphidae												+	0											2
Tabanidae	0	0	0					+					0		0	0	0	0	0	0		0		12
Tipulidae	1	1	1	0	1	+	+	+		+	0			1	1	1	1	1	1	1	0	4	0	20
Number of families	70	68	57	64	55	61	49	58	57	65	56	25	43	38	52	54	56	57	66	60	50	40	47	
Shannon H'	1.4	1.4	1.3	1.5	1.2						1.1		0.7	1.5	1.8	1.2	1.6	1.9	1.7	1.6	1.5	1.2	1.1	

Numbers represent percentage abundance for semi-quantitative data, to the nearest whole number (hence numbers less than 0.5 are rounded to 0; note that diversity was calculated using non-rounded data); + = present for qualitative data.

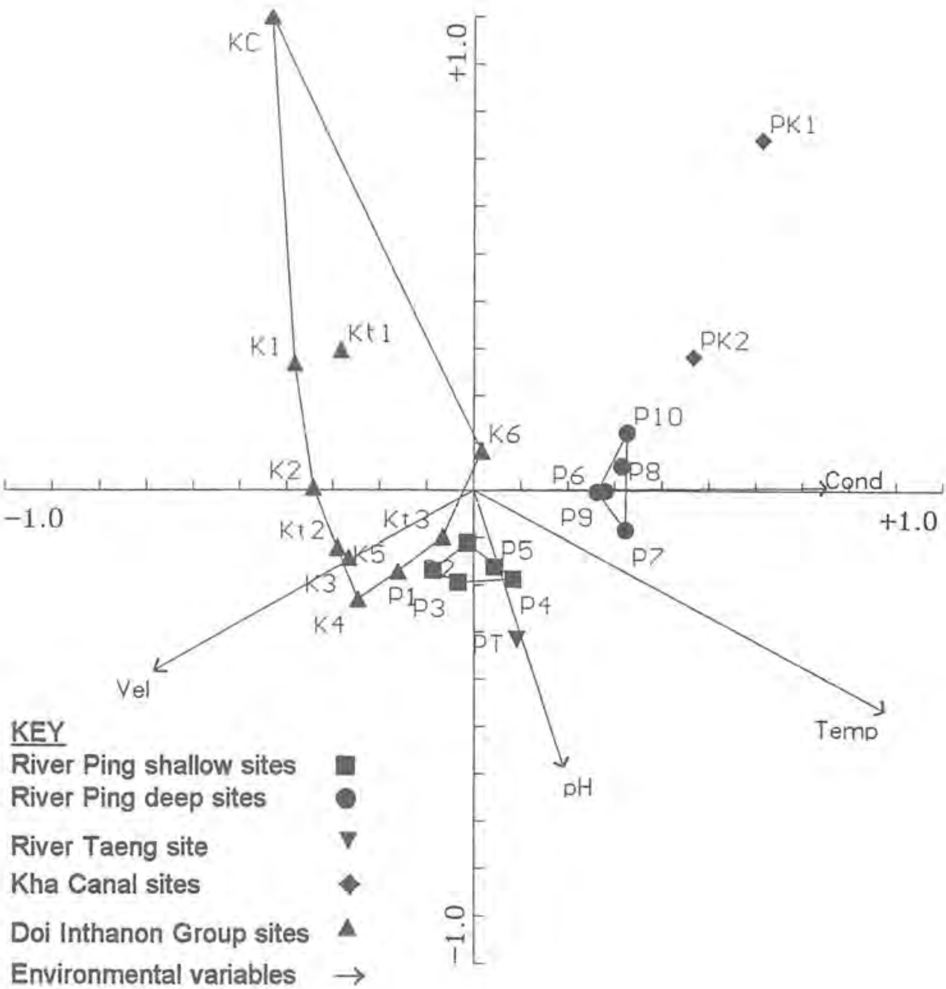

Figure 6 CCA ordination diagram of sample and environmental biplot scores (λ_1 = 0.273, λ_2 = 0.127).

sites and River Ping shallow sites with higher velocity, River Ping shallow sites and the River Taeng with higher pH, and River Ping sites in general with higher temperature.

DISCUSSION

Physico-chemical survey

The temperature range was similar to that of other tropical rivers and lakes. BISHOP (1973), for example, recorded temperatures in the range of 18.0–34.5°C along a stream in Malaysia below 250 m in altitude, using weekly maximum-minimum temperature readings over a 60-week period. CROWTHER (1982) found that average temperatures of rivers at midday in three areas of Malaysia ranged from 24.0 to 30.4°C. BISHOP (1973) predicted that temperature in headwaters at >1000 m in Malaysia might be as low as 15°C, from consideration of the adiabatic lapse rate. The present study shows that minimum temperatures at around 1000 m do reach this level and that at >2,000 m they fall as low as 9°C.

Elevated levels of conductivity, calcium hardness and pH at upstream River Ping sites were attributable to an input of calcium and bicarbonate ions from an area of limestone in the vicinity of Chiang Dao. Low conductivity and calcium hardness of the water at Doi Inthanon group sites suggest that the water is infertile, particularly in the high altitude zone where levels were lowest. The lowest pH was recorded at the highest site on Doi Inthanon, where conductivity, and hence buffering capacity, was very low. Conductivity data only provide evidence of significant pollution on the Kha Canal. The high conductivity levels recorded on the Kha Canal were a result of inflows of domestic and industrial wastewater and irrigation drainage water. Nutrient measurements, albeit from a single occasion, indicated an enriched state of the River Ping and, to an even greater extent, the Kha Canal.

There was evidence of a sustained deficit in DO where mean values fell below 8.0 mg l^{-1}. At the deep Ping sites and K6, the deficit was probably mainly due to the fact that water velocity was lower and depth was greater than at other sites. This would result in decreased turbulence and therefore decreased physical aeration of the water. However, inputs of organic pollution from the city of Chiang Mai and from Chom Thong town may have depleted DO levels further, by increasing levels of microbial respiration. The lowest DO concentrations on the River Ping were recorded at P10, about 18 km downstream of the organically polluted Kha Canal inflow. On the Kha Canal itself the DO deficit was severe, as a result of the heavy organic pollution. The variation in DO concentration and conductivity observed at PK2 probably occurred because this site received water from the main canal and an irrigation outflow, in variable ratios. Effects on the fauna are considered in a later section.

There have been few studies on the effects of low oxygen concentration on the aquatic fauna of tropical rivers (examples include work by HASSAN, 1981, PEARSON & PENRIDGE, 1987 and REDDY & RAO, 1991). Following a study on the effect of pollution by organic sugar mill effluent on the macroinvertebrate fauna of a tropical Australian stream, PEARSON & PENRIDGE (1987) proposed the following pollution categories: severe, with sustained DO < 3.5 mg l^{-1}; moderate, DO 3.5–5.0 mg l^{-1}; mild, DO 5.0–6.5 mg l^{-1}; and clean water with DO > 6.5 mg l^{-1}. By these criteria the River Ping shallow

Figure 7. Site P1, River Ping, view downstream, 410 m above MSL, mean width 22 m, 6 December 1992. Riffled appearance of water indicates high current velocity and shallow depth.

Figure 8. Site PT, River Taeng (tributary of the River Ping), view upstream, 330 m above MSL, mean width 12 m, 6 December 1992. Note giant grasses on the river bank.

Figure 9. Site P8, River Ping, view downstream, 300 m above MSL, mean width 111 m, 7 December 1992. Note urban setting.

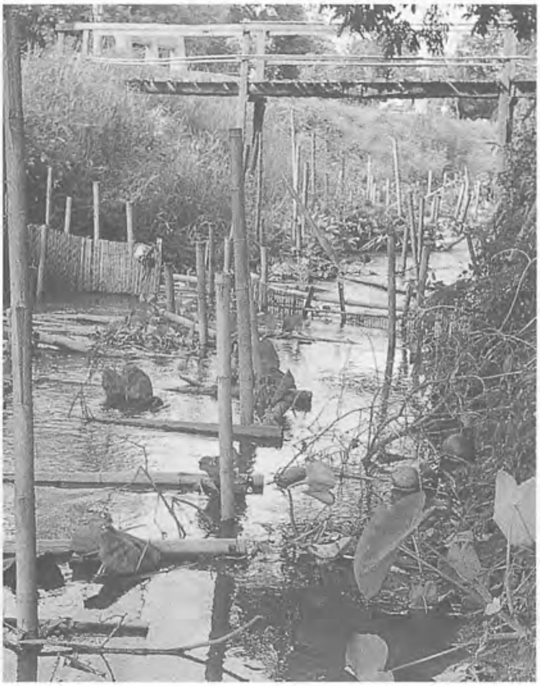

Figure 10. Site PK2, Arm of the Kha Canal (tributary of the River Ping), view downstream, 290 m above MSL, mean width 3 m, 7 September 1993. Note bamboo screens for trapping fish.

Figure 11. Site P10, River Ping, view upstream towards site, 280 m above MSL, mean width 83 m, 7 December 1992. At times of low flow floating clumps of water hyacinth sometimes covered the water surface at this site.

Figure 12. Site K1, River Klang, view down stream, 1270 m above MSL, mean width 8 m, 1 April 1993. Highest site on the River Klang.

Figure 13. Site Kt2, tributary of the River Klang, view upstream, 940 m above MSL, mean width 6 m, 1 April 1993. Note the dense forest from which the stream emerges.

Figure 14. Site K6, River Klang, view downstream, 290 m above MSL, mean width 16 m, 26 July 1992. Note the turbidity of the water at this time of relatively high flow.

sites, the River Taeng and the Doi Inthanon Group of sites were clean, although K6 was on the margin of being classified as mildly polluted. The Kha Canal was severely polluted and deep River Ping sites were mildly polluted, with P10 bordering on a moderate pollution classification.

Macroinvertebrate Survey

General composition of the macroinvertebrate fauna

The general composition of macroinvertebrate assemblages recorded in this study was similar to that which would be expected in streams and rivers the world over (see DUDGEON, 1995). Relatively few families have primarily tropical or subtropical distributions. The exceptions were: Corallanidae (Amphipoda), Corbiculidae (Bivalvia), Ampullariidae, Thiaridae, Buccinidae (all Gastropoda), Lampyridae (Coleoptera), Atyidae, Palaemonidae, Parathelphusidae, Potamidae (all Decapoda), Prosopistomatidae (Ephemeroptera), Amphipterygidae, Euphaeidae, Chlorocyphidae, Macromiidae, Protoneuridae (all Odonata), Dipseudopsidae, Limnocentropodidae and Uenoidae (all Trichoptera) (information on family distributions from BANARESCU (1990, 1991)). The main differences from temperate streams and rivers were similar to those recorded from tropical Asian lotic systems in general (DUDGEON, 1995). Thus, there was relative under-representation of stoneflies (Plecoptera) and isopod and amphipod crustaceans, and a greater representation of freshwater shrimps, prawns and crabs (Decapoda) in comparison with temperate streams.

Values of H' (range 0.7–1.9) were relatively low compared to values that have been recorded by PINDER *ET AL.* (1987) at a single site on a UK chalk stream. The range of values of H' recorded on the chalk stream for different sample types, using family level data, was 0.63–3.76. However, this does not necessarily indicate that diversity was lower on the Thai rivers as values of H' would have been artificially lowered because not all groups were identified to family level. PINDER *ET AL.*'S (1987) study also demonstrated that values of H' increased by approximately 15–110% when species level rather than family level data were used.

Relation to longitudinal and altitudinal gradients

There were clear longitudinal changes in macroinvertebrate faunal composition along the River Ping and the River Klang on Doi Inthanon (Figs. 2–6). An abrupt transition took place between the shallow upstream sites and the deep downstream sites on the River Ping, which was most clearly marked by the absence of Plecoptera and an increase in the number of families of molluscs and leeches at the deep sites. In contrast longitudinal changes on the River Klang were gradual as illustrated by the restriction of gastropods to sites below K1, of decapods to sites below Kt2 and of leeches to the lowest site, K6.

A large number of methods to classify river zones have been proposed (HELLAWELL, 1986), based on physico-chemical features and/or on the distribution of faunal groups. MALICKY & CHANTARAMONGKOL (1993), in their study of the trichopteran fauna of Doi Inthanon, adopted an approach based on ILLIES' (1961) physico-chemical classification system. If the same approach is applied to the results obtained in the present study, the highest eight sites on Doi Inthanon are classified as rhithron (montane) and all others as potamon (foothill and plain). However, there were no obvious changes in the composition of the macroinvertebrate fauna associated with this division. Indeed, several of the mid-altitude sites on Doi Inthanon were found to have faunal compositions closely related to those at the shallow River Ping sites. In contrast, MALICKY & CHANTARAMONGKOL (1993) determined changes in the trichopteran fauna on Doi Inthanon at the species level, based on the transition from rhithron to potamon. This suggests that the changes in faunal composition are subtle and may only be observed at the species level. However, the usefulness of a rhithron / potamon classification system is thus called into question, if it does not correlate with major changes in river faunas.

Conductivity, as related to dissolved calcium concentration, would almost certainly be the variable that determined the downstream increase in the numbers of families of molluscs and crustaceans on Doi Inthanon. These animals require calcium to form shells and for many species the minimum concentration required is around 20 mg l^{-1} (HYNES, 1960), a level which was only reached at the lowest sites on Doi Inthanon. At the highest three sites the only molluscs present were pea-mussels (Pisidiidae), one of the few types of molluscs to occur in very soft waters (HYNES, 1960).

The actual patterns of altitudinal zonation observed on Doi Inthanon differed from those that have been recorded in the Himalayas, probably because in comparison to elevations further north, the summit of Doi Inthanon is at low altitude (SUREN (1994), for example, classified rivers at < 2,500 m as low altitude). Thus in Nepal, Limnephilidae are characteristic of high altitude streams, whereas Caenidae, Hydropsychidae, Lepidostomatidae and Elminthidae are characteristic of low altitude streams (RUNDLE *ET AL.*, 1993; SUREN, 1994). On Doi Inthanon Limnephilidae were not recorded in the present study (although adults have been captured (MALICKY & CHANTARAMONGKOL, 1993)) and Caenidae, Hydropsychidae, Lepidostomatidae and Elminthidae were present at the majority of sites.

Taxonomic richness has also been found to be negatively correlated to altitude in other parts of Asia (EGGLISHAW, 1980; RUNDLE *ET AL.*, 1993; SUREN, 1994). This may be because, as elsewhere in the world, highland streams are generally smaller, steeper and colder than those at lower altitudes (SUREN, 1994). Reduced taxonomic richness and diversity at the lowest two sites (which were outside the national park) probably resulted from the effects of human disturbance of the catchment. Changes in land use were also found to influence faunal zonation in the Himalayas (RUNDLE *ET AL.*, 1993; SUREN, 1994). On Doi Inthanon, although taxonomic richness changed with altitude, relative abundance of the major insect orders was similar at all stations, a phenomenon also noted by SUREN (1994) in Himalayan streams.

The abrupt downstream change in macroinvertebrate community composition observed on the River Ping (Figs. 2, 4 & 6) could not be ascribed to a natural progression, as it was directly associated with the fact that the five sites furthest downstream on the River Ping were deep and slow flowing, due to the presence of weirs. The principal effect was to shift the fauna from one more characteristic of the rhithron to one more characteristic of the potamon. Thus several insect families more typical of habitats with eroding substrates and high water velocities (e.g. Perlidae, Simuliidae and Prosopistomatidae) disappeared and macroinvertebrates associated with depositing substrates and slow-flowing water, in particular molluscs, became more abundant.

Effects of pollution

The major dissimilarity between the macroinvertebrate fauna of the two grossly polluted Kha Canal sites, and all other sites, was lower family richness (particularly at PK1, the most polluted of the two sites). The following higher taxa were absent from the canal: Bivalvia, Trichoptera, Ephemeroptera (this order was present at PK2, however, but was only represented by Baetidae/Siphlonuridae) and Caridea. Also, larvae of Syrphidae, which are aeropneustic and commonly associated with organically enriched water were only recorded at the two Kha Canal sites. These results are generally consistent with the well-known effects of organic effluents on temperate streams and thus agree with DUDGEON'S (1992) statement that "the effects of pollution in tropical Asian rivers are essentially the same as those recorded in north-temperate regions".

However, there are some differences between the detailed patterns observed in this study and those which have been recorded elsewhere. Firstly, there are zoogeographical differences in the taxa involved. For example, the families Parathelphusidae and Protoneuridae, which occurred on the Kha Canal, are not found in the north temperate zone. Likewise, several of the taxa that were present elsewhere in the study area, but were absent on the canal, have a primarily tropical or subtropical distribution. Secondly, a relatively high number of taxa were recorded on the Kha Canal, despite the fact that DO levels were extremely low. In Spain, for example, only five major macroinvertebrate groups were found at a site directly below a fish farm effluent (Oligochaeta, Mollusca, Hirudinea, Diptera and Megaloptera) (CAMARGO, 1992), compared to the 10 recorded at PK1 and the 16 recorded at PK2. This was despite the fact that DO levels were slightly higher on the Spanish river. Several tropical and subtropical studies have also revealed drastic reductions in taxonomic richness associated with severe organic pollution. On a tropical Australian river, for example, it was found that where DO was sustained below 3.5 mg l^{-1}, the only taxa present were Oligochaeta, *Chironomus* sp. and air-breathers (PEARSON & PENRIDGE, 1987). In South Africa heavy organic pollution led to the replacement of the normal fauna by a new association consisting mainly of larger Oligochaeta, including *Tubifex* spp., red *Chironomus* larvae and numerous ciliate protozoa (HARRISON, 1959). In Nigeria the inflow of a sewage plant effluent led to the elimination of all but five macroinvertebrate groups: Oligochaeta, Diptera, Mollusca, Odonata and Ephemeroptera, with the former three dominant (HASSAN, 1981). In an urban sewage canal in tropical India, however, nine macroinvertebrate groups were recorded (Oligochaeta, Ephemeroptera, Hemiptera, Megaloptera, Coleoptera, Odonata, Diptera, Hydracarina and Mollusca) (REDDY & RAO, 1991), a figure similar to that recorded at PK1.

A simple explanation for the high number of taxa recorded from the Kha Canal may be that the submerged marginal vegetation was comprehensively sampled, as well as the canal bottom. This led to the collection of neustonic dwellers (Collembola, Mesoveliidae, Hydrometridae and Gerridae), semi-aquatic forms (Talitridae, Curculionidae, Pyralidae, Erpobdellidae, Parathelphusidae), floaters with breathing tubes (most of the Diptera), air-breathing molluscs (Pulmonates and Ampullariidae) and swimmers with plastrons (many of the Coleopteran adults). These could obtain oxygen directly from the atmosphere and/ or avoid critical conditions in the water. However, it is possible that a greater number of taxa actually do occur in heavily organically polluted rivers in Thailand than in other regions. Further work on this subject is recommended. The results also demonstrate the importance of collecting samples from both the bottom substrate and the submerged marginal vegetation, if a comprehensive survey is desired.

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