Arch. Hydrobiol.	119	1	35–53	Stuttgart, Juli 1990

Benthic community structure and the effect of rotenone piscicide on invertebrate drift and standing stocks in two Papua New Guinea streams

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With 7 figures, 3 tables and an appendix in the text

Abstract

Standing stocks and drift of macroinvertebrates from reaches treated with rotenone piscicide were compared with untreated reaches of two low-altitude streams within the Sepik-Ramu River drainage, Papua New Guinea. Total macrobenthic population densities were similar in both streams, although community composition showed significant inter-stream differences. In addition, certain lotic taxa (e.g. Plecoptera) characteristic of the Asian mainland were absent while others (e.g. naucorid bugs) had diversified in their absence.

Rotenone induced immediate catastrophic drift: total drift densities peaked after 30 minutes and declined subsequently, showing similar trends in both streams. Taxa varied with respect to both the degree and timing of their response to rotenone, but Baetidae (Ephemeroptera) were rapidly affected and were the most numerous drifting taxon. Certain baetid mayflies declined in abundance in rotenone-treated reaches, although not all morphospecies were affected equally. Standing stocks of leptophlebiid mayflies, by contrast, were unaffected by rotenone application and total invertebrate standing stocks in both streams were unchanged. Overall, rotenone induced catastrophic drift but did not cause large-scale mortality and declines in benthic invertebrate abundance.

Introduction

There is little information on the benthic fauna of low-gradient tropical streams and rivers, and data from Wallacea and Papua New Guinea are especially scarce. New Guinea represents a fauna of disparate origins, and various parts of the island are of mixed ages. While the southern part has been connected with Australia (GRESSITT 1982), there have probably been no continuous land connections with the Asian continent or Sunda Islands. Nevertheless, the great majority of the New Guinea fauna seems to be of Oriental derivation (GRESSITT 1982), and the impact of the Australian biota has been largely confined to a limited area in the southeast. For example, the atyid and palaemonid freshwater shrimps of New Guinea include a majority of species with a wide geographical distribution, the island forming the eastern — not

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0003-9136/90/0119-0035 $ 4.75

western — limits of their range (HOLTHUIS 1982). GRESSITT (1982) has emphasized the general poverty of freshwater animals in New Guinea, and major groups of Asian freshwater fish (e.g. Cyprinidae) are lacking. Most of the fish fauna is secondarily freshwater — evolved from marine forms — including Ariidae, Plotosidae, Melanotaeniidae, Eleotrididae and Gobiidae (COATES 1985, 1987; LOWE-MCCONNELL 1987).

To date, information on river ecology in Papua New Guinea has been confined to a few studies undertaken to the south of the Central Highlands (e.g. PETR 1983 a), and virtually nothing is known of benthic community structure. As the Central Highlands is an important biogeographic barrier to fishes and parastacid crustaceans (HOLTHUIS 1982; HAINES 1983; LOWE-MCCONNELL 1987; ALLEN & COATES, in press), river fauna to the north of this divide might be expected to differ in composition from that of the southern drainage. The present study deals with the benthic macroinvertebrates of two streams in the Sepik-Ramu River system which occupies the central intermontane trough of Papua New Guinea. One objective of the investigation was a basic description of macroinvertebrate community structure; a study of the effects of rotenone fish poison on stream benthos was a supplementary goal of this investigation.

Rotenone fish poison, derived from the powdered roots of *Derris elliptica* and *Lonchocarpus* spp. (Papilionaceae), is widely used by indigenous fishermen and fisheries scientists as a means of capturing fish in running water (LEONARD 1939). It has also been employed to clear streams and lakes of unwanted rough fish prior to stocking with selected game and forage fish, and rotenone dust or aqueous suspensions are sometimes sprayed on crops because of the compound's insecticidal qualities (LEONARD 1939; MARTIN 1969). World consumption of rotenone varies between 10,000 and 20,000 kg per year (HALEY 1978).

Rotenone is highly toxic to fishes, causing death by suffocation within minutes (LEONARD 1939). It's effects on other aquatic animals are not well-documented, but there is laboratory evidence of taxon-specific responses to the poison (ZISCHKALE 1952; CLAFFEY & RUCK 1967; ENGSTROM-HEG et al. 1978). Field studies of the results of rotenone application have been concerned mainly with fishes. As one consequence of this work, it is usual for fisheries scientists to dose streams and rivers with potassium permanganate after rotenone application. This neutralizes the poison and reduces fish mortality downstream (HOCUTT et al. 1973).

Field tests of the effects of rotenone on non-target aquatic animals have received little attention (ENGSTROM-HEG et al. 1978), and no such trials have been reported from tropical regions. This is despite the fact that the use of rotenone is pantropical, and that its impact upon non-target organisms will affect the future fisheries potential of a given habitat. The present study documents the short-term influence of rotenone upon drift and benthic invertebrate abundance in two Papua New Guinea streams.

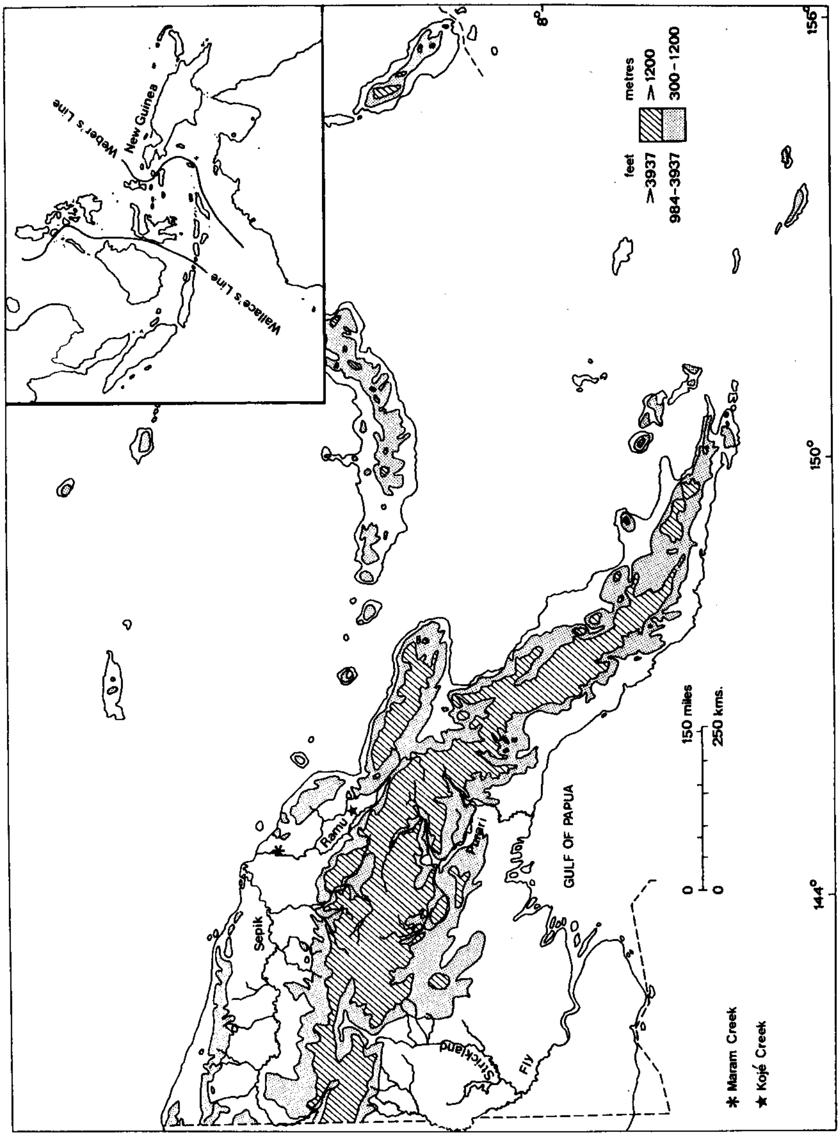

Fig. 1. The Sepik-Ramu River system showing Kojé and Maram Creeks and the location of Papua New Guinea within the region (inset). The stippled area is land above 300 m elevation and includes the Central Highlands separating the region into northern (Sepik/Ramu) and southern drainages.

The study areas

The 1100 km long Sepik River has a mean discharge in the range of 4000–7000 $m^3 s^{-1}$ (Mitchell et al. 1980; Petr 1983 b and pers. comm.). In terms of area drained (78,000 km^2), it is the largest river system in Papua New Guinea. The flood plain is up to 70 km wide (7600 km^2) and consists mostly of backswamps. The Sepik drains the western part of the central intermontane trough, which lies to the north of the main Papua New Guinea ranges (the Central Highlands), and is occupied by the Sepik, Markham and Ramu rivers. The latter is 720 km in length. The floor of this great trough is gradually sinking (LÖFFLER 1977), and gradients in the depression are very gentle. During the flood season, the whole region near the mouths of the Sepik and Ramu may be inundated so that the rivers are conjoined. Thus for part of the year, the Ramu functions as a major tributary of the Sepik river.

Together, the combined Sepik-Ramu drainage receives water from the Torricelli Mountains in the north, the Finisterre Range in the south east, and the Central Highlands in the south and south west. Each of these ranges has rather distinct, although complex, geology (LÖFFLER 1977; BLEEKER 1983) which will influence water chemistry. The Finisterre Range is largely made up of Tertiary volcanics and Miocene limestone. Streams draining the latter empty directly into the sea along the northern coast; those draining volcanic rocks join the Ramu River. Both streams included in this study were part of the latter group. Although detailed consideration of the hydrology of the Sepik-Ramu drainage was beyond the scope of the present investigation, determinations of *p*H during sampling indicated that waters draining the Finisterre range were slightly acid to neutral (*p*H 6—7). PETR (1983 b) provides some data on concentrations of dissolved ions in the Sepik which are above the average of world rivers. These results probably reflect rapid chemical weathering under a moist, tropical climate. A study of the water chemistry of the Sepik-Ramu drainage has been undertaken (COATES, OSBORNE & VAN ZWIETEN, unpublished).

Both study streams were part of the Ramu River basin (Fig. 1). Kojé Creek was unshaded, draining secondary forest and gardens. The channel was approximately 5 m wide, but the stream occupied only 1—2 m of this. Water depth was 10—25 cm, and current velocities ranged from 0.3 m sec^{-1} in runs to 0.5 m sec^{-1} in riffles. The substrate comprised small—medium cobbles ($<$ 15 cm longest dimension) and gravel, with fine sand and areas of slack water. Filamentous algae grew on stony substrates, and accumulations of leaf litter (mean $\pm$ S.E. = 20.8 $\pm$ 2.0 g fresh wt 0.25 m^{-2}) were present. Elevation 160 m; gradient 0.012; univ. grid. ref. 55MCP233867; lat. 5°33′S, long. 145°23′E.

Maram Creek drained rain forest and was 95—100% shaded. The stream was approximately 7 m wide, and comprised a number of deep ($>$ 1 m) pools separated by runs and small riffles. Current speeds outside pools ranged from 0.2 to 0.5 m sec^{-1}. The water in runs was generally $<$ 15 cm deep, down to 2 cm in some localities. The substrate comprised small cobbles ($<$ 10 cm longest dimension) of friable, sedimentary rock. Both the bottom sediments and leaf pack accumulations (13.8 $\pm$ 4.3 g fresh wt 0.25 m^{-2}) appeared rather unstable. Water levels rose as a result of heavy rain towards the end of the sampling period. Elevation 80 m; gradient 0.029; univ. grid. ref. 55MBQ765960; lat. 4°33′S, 144°59′E.

Materials and methods

In essence, replicated benthic samples were taken from a single run (approximately 30 m in length) at each site. Two sets of paired drift nets were then positioned so as to fish water entering and leaving the sampled run. Rotenone was applied to the stream immediately downstream of the upper pair of nets, and drift of animals into both nets was monitored. Benthic samples were taken again from the study reach (avoiding areas sampled previously) after the monitoring period, thus allowing comparison of standing stocks before and after rotenone application.

Rotenone was applied to each stream in aqueous suspension on a single occasion, as soon as the drift nets had been positioned. The amount of rotenone used varied between sites, but was administered until mortality of melanotaeniid fishes (which were common in both streams) was observed. This pattern of application probably mimics the use of rotenone by indigenous fishermen. Because rotenone deteriorates with time (LEONARD 1939), especially under warm, damp conditions, it was not possible to obtain a precise estimate of the concentration used.

The drift samplers used were basically the same as those described by FIELD-DODGSON (1985), although the mouthpiece of each of the paired nets was circular (16.6 cm internal diameter) instead of rectangular. Each collecting net was 1.7 m long and constructed of 220 micron mesh. They were set for 2 or 2.5 hours in water velocities of approximately 20 cm sec^{-1}, and emptied at 30-minute intervals.

Benthic collections were made with a 25 × 25 cm Surber sampler (mesh size 220 microns). Sixteen samples were taken before and after rotenone application. For logistical reasons, each set of 16 samples was combined to produce four replicates, each a composite of four samples. CANTON & CHADWICK (1988) point out that collection of replicate samples, each a composite of several samples, can keep down laboratory processing effort while "...providing increased precision in estimates of total density and species richness".

Drift and benthos samples were hand-picked in the laboratory under a dissecting microscope. All aquatic invertebrates were sorted to genus and morphospecies with the exception of Chironomidae which were separated into subfamilies. It is not generally possible to assign Papua New Guinea stream invertebrates to species. Generic names, as used herein, must be interpreted as *sensu lato*, while numbers are used to distinguish species within a genus. Specific identification of certain Trichoptera by association of metamorphotypes and larvae was possible using NEBOISS (1986).

Results

Benthos composition

Both Kojé and Maram Creeks had diverse benthic faunas dominated by insects. A total of 60 morphospecies were collected in benthic samples from unshaded Kojé Creek and 48 species from shaded Maram Creek. An ANOVA carried out on the number of morphospecies per sample (data were transformed to meet the assumptions of parametric methods, so that $X' = \log[X + 1]$) revealed that Kojé Creek (mean ± S.E. = 41 ± 1.0) samples were more species-rich than those from Maram Creek (31 ± 0.6) ($F = 83.25$, $P = 0.0001$).

The ten most numerous families or subfamilies of benthic macroinvertebrates in each stream were all insects, but community composition showed considerable intersite differences (Table 1). Four of the most numerous Kojé Creek taxa (Orthocladiinae: Diptera, Caenidae: Ephemeroptera, Naucoridae: Heteroptera and Nymphulinae: Lepidoptera) were relatively scarce in Maram Creek, while Hydroptilidae, Philopotamidae (Trichoptera) and Simuliidae (Diptera) were significantly more abundant in Maram than in Kojé Creek. Odonata appeared among the ten top-ranked taxa in Maram Creek

Table 1. Population densities and relative abundance of the ten most numerous families or subfamilies of benthic macroinvertebrates in Kojé and Maram Creeks, Papua New Guinea. Significant intersite differences in population densities (as revealed by one-way ANOVA) are also shown.

Kojé Creek			
	No. of Morphospecies	No. 0.25 m^{-2} (Mean ± S.E.)	% of Total
Orthocladiinae[1]	–	410.8 ± 66.6	19.7
Elmidae	4	353.8 ± 89.2	17.0
Leptophlebiidae[2]	2	316.5 ± 45.0	15.2
Hydropsychidae[3]	4	259.3 ± 69.7	12.5
Baetidae	9	254.8 ± 32.1	12.2
Chironominae	–	165.5 ± 42.1	7.9
Tanypodinae[4]	–	117.0 ± 12.7	5.6
Caenidae[5]	1	79.3 ± 14.2	3.8
Naucoridae[6]	5	59.5 ± 13.6	2.9
Nymphulinae[7]	2	58.5 ± 17.7	2.8
			99.6
Total individuals	60	2082.0 ± 83.9	

Maram Creek			
	No. of Morphospecies	No. 0.25 m^{-2} (Mean ± S.E.)	% of Total
Leptophlebiidae[2]	1	1122.0 ± 172.3	59.6
Elmidae	2	232.8 ± 115.9	12.4
Baetidae	5	179.0 ± 22.7	9.5
Chironominae	–	68.8 ± 17.6	3.7
Hydroptilidae[8]	1	49.8 ± 8.3	2.6
Philopotamidae[9]	1	47.5 ± 17.5	2.5
Tanypodinae[4]	–	37.3 ± 13.6	2.0
Hydropsychidae[3]	3	22.3 ± 4.9	1.2
Simuliidae[10]	1	22.0 ± 4.9	1.2
Odonata	4	20.3 ± 8.0	1.1
			95.8
Total individuals	48	1884.0 ± 244.4	

[1] $F = 90.89$, $P = 0.0001$; [2] $F = 28.92$, $P = 0.0017$; [3] $F = 50.59$, $P = 0.0004$; [4] $F = 10.62$, $P = 0.0173$; [5] $F = 22.54$, $P = 0.0032$; [6] $F = 129.94$, $P < 0.0001$; [7] $F = 79.14$, $P = 0.0001$; [8] $F = 11.26$, $P = 0.0153$; [9] $F = 15.19$, $P = 0.0080$; [10] $F = 135.81$, $P < 0.0001$.

only, but did not achieve significantly higher population densities than in Kojé Creek. Densities of Elmidae (Coleoptera), Baetidae (Ephemeroptera) and Chironominae (Diptera) did not differ significantly between streams although Tanypodinae (Diptera), which were numerous at both sites, were significantly more abundant in Kojé Creek. Total macrobenthic population densities in both streams were similar.

Of particular interest is the observation that a single species of leptophlebiid mayfly comprised almost 60 % of benthic standing stocks in Maram Creek (Table 1). By contrast, leptophlebiids (two species) made up only 15 % of the benthic animals in Kojé Creek, and the most numerous taxon (Orthocladiinae) at this site constituted only 20 % of the total standing stock.

Rotenone effects on drift

A dramatic increase in drift densities was recorded in both streams following rotenone application, and the effect was still apparent after two or two-and-one-half hours (Fig. 2). Numbers of macroinvertebrates caught in Kojé Creek increased from 1.38 ± 0.12 individuals 100 m^{-3} (mean ± S.E.) in the un-

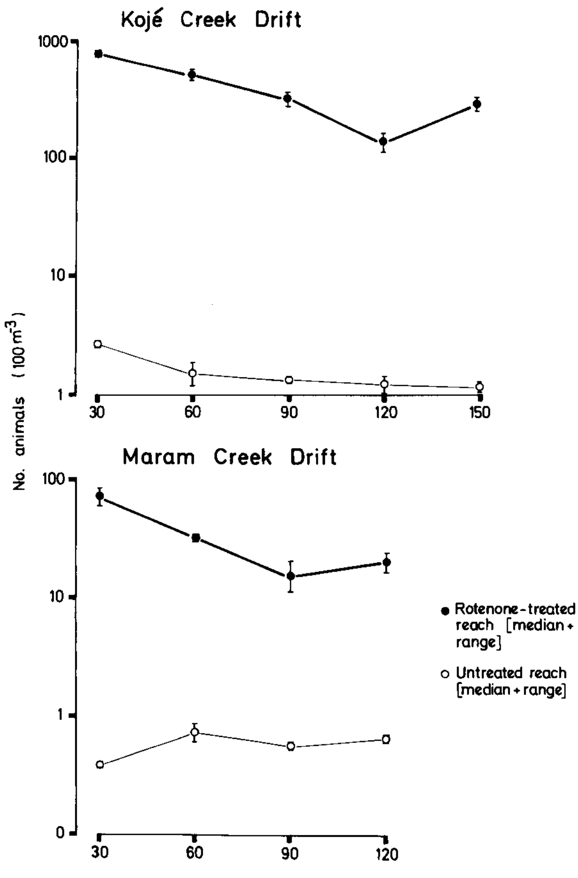

Fig. 2. Total drift densities (median and range) from rotenone-treated and untreated reaches of Kojé and Maram Creeks, Papua New Guinea. Rotenone was applied to treated reaches at time 0 minutes.

treated reach to 404.67 ± 75.83 in the treated reach. A smaller increase from 0.71 ± 0.06 individuals 100 m^{-3} to 35.25 ± 7.88 was recorded in Maram Creek. Drift densities did not vary significantly between the two nets in each pair in either reach of the study streams.

Drift rates in the treated reach of Maram Creek declined over the monitoring period ($r = -0.821$, $n = 8$, $P < 0.01$), despite heavy rain which caused the stream to rise so that sampling had to be terminated after two hours. Tramping of the stream bed in Kojé Creek by local residents (attempting to negotiate a purchase of rotenone) may have contributed to a slight increase in the number of animals caught in nets emptied after 150 min. Nevertheless, a strong tendency for total drift densities to decline with time was observed ($r = -0.858$, $n = 10$, $P < 0.001$).

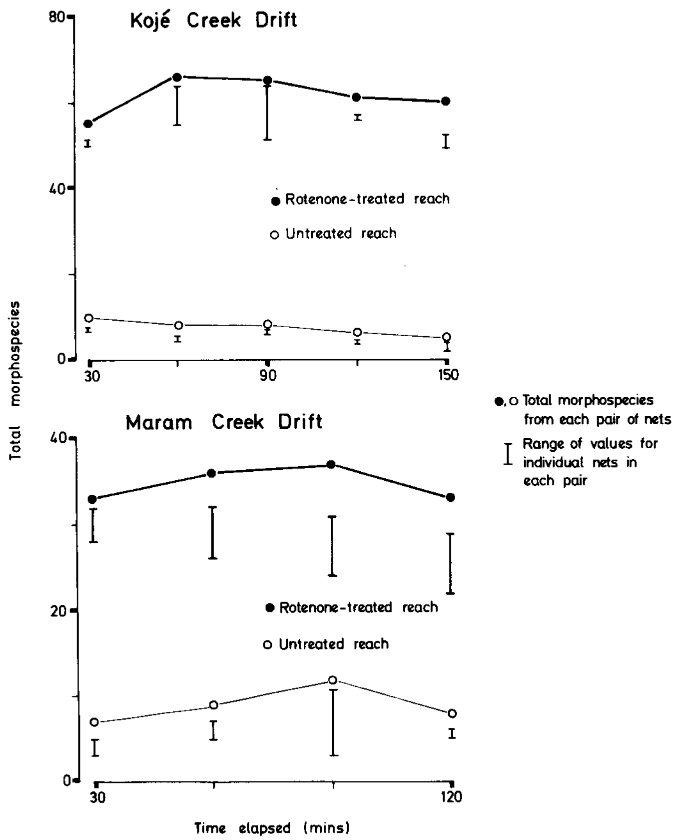

Fig. 3. Total morphospecies drifting from rotenone-treated and untreated reaches of Kojé and Maram Creeks, Papua New Guinea. The total morphospecies from each pair of nets as well as the range of values for individual nets in each pair are shown. Rotenone was applied at time 0 minutes.

The numbers of morphospecies drifting was greater in treated than in untreated reaches, and showed no clear tendency to change over time (Fig. 3). The mean (± S.E.) number of morphospecies in drift nets from the untreated reach of Kojé Creek was 5.1 ± 1.7, compared to 55 ± 1.7 morphospecies per drift net from the rotenone-treated reach. The equivalent values from Maram Creek were 5.6 ± 0.9 and 28 ± 1.3 respectively. Note that the total number of morphospecies collected by each pair of nets in the rotenone-treated reaches was 71 in Kojé Creek and 50 in Maram Creek. Both totals exceed the number of benthic morphospecies recorded in Kojé and Maram Creeks because benthic sampling did not include all of the microhabitats which could have been a

Table 2. The composition of rotenone-induced catastrophic drift in Kojé and Maram Creeks. The total number of the ten most numerous families or subfamilies of benthic macroinvertebrates collected in paired drift nets from each site, as well as their proportionate contribution to total drift, are shown.

Kojé Creek			
	No. of Morphospecies	Total No. Drifting	% of Total
Baetidae	8	24468	47.1
Orthocladiinae	–	6381	12.3
Hydropsychidae	4	3565	6.9
Hydroptilidae	5	2473	4.8
Tanypodinae	–	2375	4.6
Chironominae	–	2055	4.0
Leptophlebiidae	2	1852	3.6
Hydrophilidae	7	1296	2.5
Caenidae	1	1151	2.2
Hydraenidae	2	1116	2.1
			90.1
Total drifting	71	51943	

Maram Creek			
	No. of Morphospecies	Total No. Drifting	% of Total
Baetidae	7	1796	47.6
Leptophlebiidae	1	443	12.2
Atyidae	1	275	7.6
Helodidae	1	156	4.3
Hydraenidae	2	154	4.2
Elmidae	2	137	3.8
Dixidae	1	107	3.0
Orthocladiinae	–	58	1.6
Chironominae	–	56	1.5
Hydropsychidae	3	51	1.4
			89.2
Total drifting	50	3619	

source of drifting animals. Appendix 1 lists the taxa recorded in drift and benthos samples from both streams.

Rotenone-induced drift composition was markedly different from benthic community structure, and was dominated by baetid mayflies which comprised 47% of total drift in both streams (Table 2). This is despite the fact that Baetidae made up only 9.5—12.2% of benthic standing stocks (Table 1). The ten top-ranked drifting taxa constituted approximately 90% of the drift at both sites, and the second-ranked taxon comprised 12% of the total. However, the identity of this taxon, as well as the ranking of other taxa, varied between the two streams (Table 2): Hydroptilidae, Tanypodinae, Hydrophilidae (Coleoptera) and Caenidae were among top-ranked taxa in Kojé Creek drift but not in Maram samples; atyid shrimps (*Caridina*), Dixidae (Diptera), Elmidae and Helodidae (Coleoptera) were included in the Maram Creek rankings only. Nevertheless, the two lists did have six taxa in common and five of these (Elmidae, Leptophlebiidae, Hydropsychidae, Baetidae, Chironominae and Tanypodinae) were among the top-ranked benthic taxa in both streams (Table 1).

One-way ANOVA, using transformed proportionate data (where $X' = \arcsin[\text{sqrt}\,X]$) to meet the assumptions of parametric methods, showed that certain top-ranked taxa were over-represented in the drift by comparison with their proportionate abundance in benthic samples (Table 3). Baetidae as

Table 3. Within-stream comparisons of the relative abundance (mean % ± S.E.) of the ten top-ranked taxa (as listed in Tables 1 and 2) in drift and benthos samples from Kojé and Maram Creeks. Only those taxa exhibiting significant differences (as revealed by one-way ANOVA) between their representation in benthos and drift are included. Significant differences in the relative abundance of top-ranked taxa in Kojé Creek drift samples versus Maram Creek drift samples are also indicated (***$F > 27.70$, $P < 0.001$).

Kojé Creek			
	Benthos	Drift	
Baetidae	12.3±1.6	40.9±6.3	F = 19.37, P = 0.0032
Leptophlebiidae	15.1±1.7	4.8±1.2	F = 17.05, P = 0.0044
Hydrophilidae***	1.1±0.3	2.5±0.3	F = 9.12, P = 0.0194
Hydraenidae	0.2±0.1	1.8±0.5	F = 23.69, P = 0.0018
Naucoridae***	2.9±0.7	0.8±0.2	F = 13.56, P = 0.0078
Orthocladiinae***	19.5±2.4	12.2±1.3	F = 8.06, P = 0.0251
Elmidae	16.6±3.8	3.2±1.2	F = 14.81, P = 0.0063
Maram Creek			
	Benthos	Drift	
Baetidae	9.9±1.6	42.7±9.3	F = 14.99, P = 0.0083
Leptophlebiidae	59.1±4.8	17.8±7.3	F = 18.27, P = 0.0052
Hydrophilidae***	0.0	0.3±0.1	F = 61.99, P = 0.0002
Hydraenidae	0.2±0.1	5.3±1.8	F = 18.10, P = 0.0054
Helodidae***	0.5±0.3	5.7±1.9	F = 15.02, P = 0.0082
Simuliidae***	1.1±0.1	0.3±0.1	F = 14.23, P = 0.0093

well as hydrophilid and hydraenid beetles were more common in the drift than in benthic samples in both streams; Helodidae were likewise over-represented in Maram Creek drift. Leptophlebiidae were significantly under-represented in the drift in both streams, while drifting Naucoridae, Orthocladiinae (Kojé Creek) and Simuliidae (Maram Creek) were relatively scarce. Orthocladiinae, Hydrophilidae and Naucoridae comprised a significantly greater percentage of drifting animals in Kojé Creek than in Maram, while Helodidae and Simuliidae were numerous in Maram drift samples but were rare in Kojé Creek drift (Table 3). Philopotamidae, Dixidae, and Atyidae, which were rare in Kojé Creek drift samples, were also relatively abundant in Maram drift ($F > 96.52$, $P < 0.0001$). Dixids and atyids were proportionately more numerous in Maram drift when compared to their representation in benthic samples.

Taxon-specific responses to rotenone were noticeable from temporal changes in the numbers of drifting animals. Patterns of response did not vary between streams, and consequently data are presented only for the stream with the greater drift densities for each taxon. Drift of baetid mayflies was highest during the first 30 minutes following rotenone application (Fig. 4); the num-

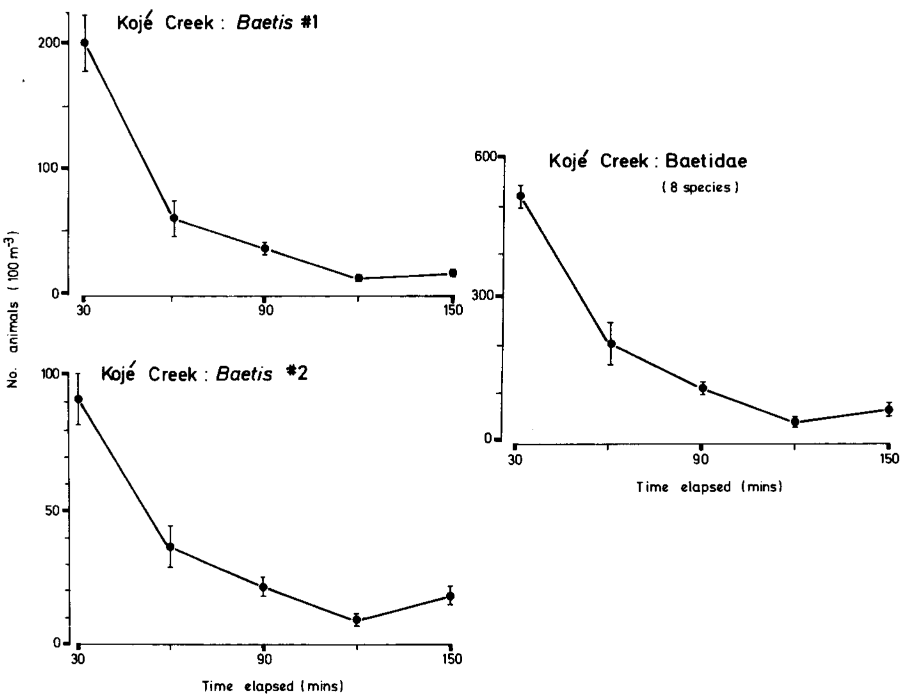

Fig. 4. Drift densities (median and range) of baetid mayflies (*Baetis* # 1, *Baetis* # 2 and total Baetidae) from a rotenone-treated reach of Kojé Creek, Papua New Guinea. Rotenone was applied at time 0 minutes. Total baetid drift from an untreated reach of the same stream was < 1 individual 100 m^{-3}.

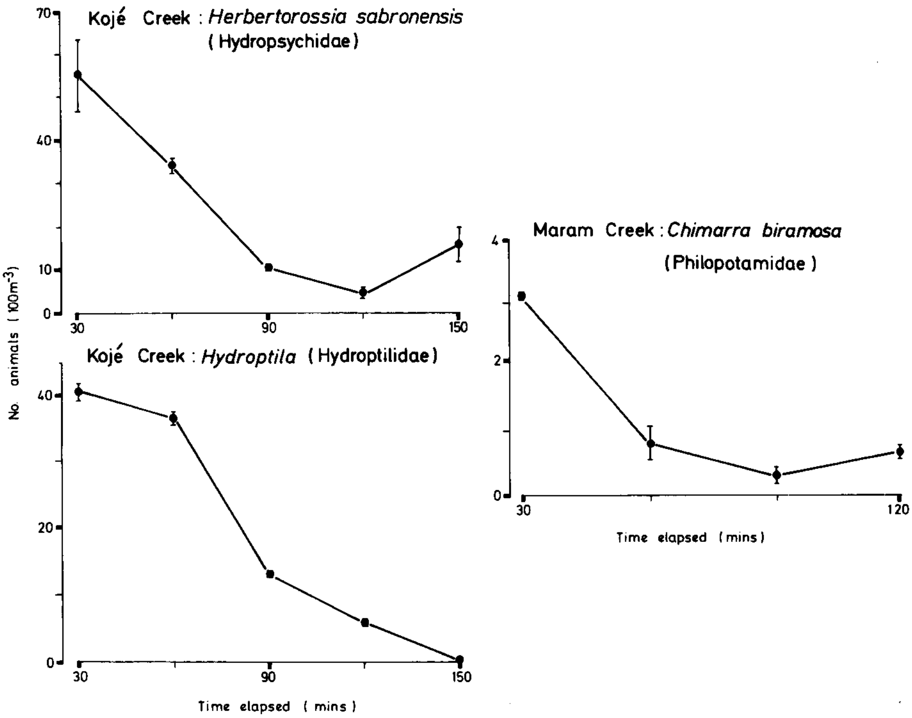

Fig. 5. Drift densities (median and range) of Trichoptera from rotenone-treated reaches of Kojé and Maram Creeks, Papua New Guinea. Rotenone was applied at time 0 minutes. Trichoptera did not occur in drift samples from untreated reaches.

bers drifting declined subsequently. This pattern applied to individual *Baetis* species ($r = -0.818$ and -0.820 for *Baetis* # 1 and # 2 respectively, $P < 0.01$) as well as to the family as a whole ($r = -0.851$, $P < 0.001$). Drift of Trichoptera also peaked within 30 minutes of rotenone application (Fig. 5). The subsequent decline was rapid in the case of *Chimarra biramosa* KIMMINS and somewhat slower for *Herbertorossia sabronensis* KIMMINS and *Hydroptila* # 2, but a significant decrease in drift densities with time was observed for all three species ($r = -0.722$, -0.809 and -0.964 respectively, $P < 0.05$). Among the Coleoptera (Fig. 6), elmid drift increased steadily during the monitoring period ($r = 0.844$, $P < 0.01$), while drift of adult hydrophilidae and *Hydraena* # 1 exhibited the converse pattern ($r = -0.885$ and -0.812 respectively, $P < 0.01$). Drift among other orders of aquatic insects (Fig. 7) showed clear temporal trends in the case of Naucoridae ($r = -0.704$, $P < 0.02$), but not Libellaginidae or Nymphulinae ($r = -0.014$ and -0.372 respectively, $P > 0.05$). Nevertheless, drift of these taxa in rotenone-treated reaches was very much greater than that in untreated reaches.

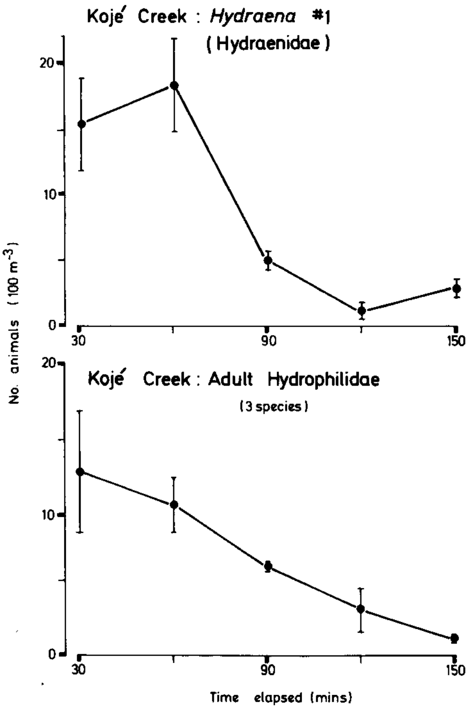

Fig. 6. Drift densities (median and range) of aquatic Coleoptera from a rotenone-treated reach of Kojé Creek, Papua New Guinea. Rotenone was applied at time 0 minutes. There were no Coleoptera in drift samples from an untreated reach of the same stream.

Rotenone effects on benthic standing stocks

Despite high drift rates from the rotenone-treated reaches of Kojé and Maram Creeks, the abundance of most benthic taxa was unaffected in the short term. Standing stocks of *Baetis* # 1 declined significantly in Kojé Creek (ANOVA: $F = 6.26$, $P = 0.045$) and Maram Creek ($F = 7.85$, $P = 0.03$); numbers of *Baetis* # 2 in Kojé Creek also decreased somewhat ($F = 4.82$, $0.10 > P > 0.05$). Significant declines in the abundance of the hydropsychid caddisfly *Herbertorossia sabronensis* ($F = 11.74$, $P = 0.014$) and Dixidae ($F = 7.42$, $P = 0.034$) were recorded in Maram Creek. Nevertheless, total benthos abundance and mean number of morphospecies per sample did not change significantly in either stream as a result of rotenone application.

Discussion

Despite generalizations concerning the poverty of freshwater fauna in Papua New Guinea (Gressitt 1982), both Kojé and Maram Creeks yielded diverse collections of benthic macroinvertebrates. In terms of morphospecies

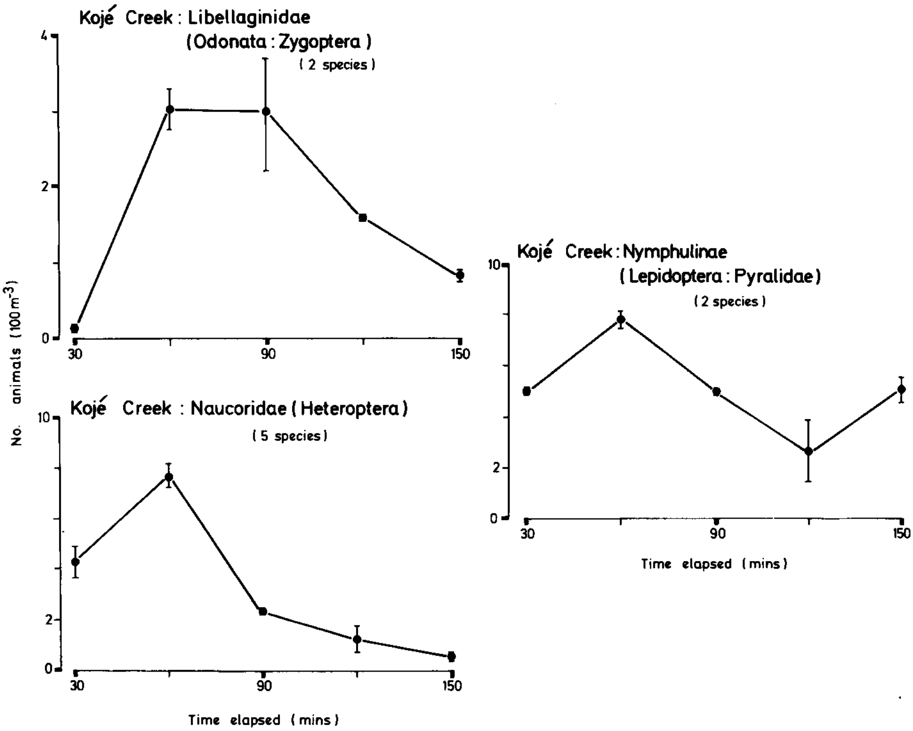

Fig. 7. Drift densities (median and range) of Libellaginidae, Naucoridae and Nymphulinae from a rotenone-treated reach of Kojé Creek, Papua New Guinea. Rotenone was applied at time 0 minutes. Naucorid and nymphuline drift from an untreated reach of the same stream was <0.2 individuals 100 m^{-3} (combined total); libellaginids did not occur in such samples.

richness, they did not differ greatly from stream communities in the Oriental tropics (e.g. Bishop 1973; Dudgeon 1988). The composition of the fauna was, however, rather different from that of Oriental streams. This was not a consequence of the inclusion of Australian elements in the stream fauna, but instead reflected an lack of certain Oriental groups and a radiation of others. For example, Heptageniidae, Ephemerellidae and Ephemeridae among the mayflies, Psephenidae among the aquatic beetles, and all Plecoptera were absent from the Papua New Guinea collections although these animals are abundant in topographically-similar streams on the Asian mainland. Naucorid bugs, by contrast, were well-represented and may have occupied the vacant stonefly-predator niche in these streams. A wide array of baetid mayfly species was also present although the extent to which they may have diversified to occupy ephemerellid and heptageniid niches is a matter for speculation. The reasons for differences in community composition between the study streams is also unclear, but may be related to the influence of riparian vegetation on allochthonous and autochthonous food sources in both habitats (DUDGEON 1988). Ongoing work in the Sepik-Ramu River system (DUDGEON, in prep.) will provide additional data on the structure of macrobenthic communities and indicate the extent to which Kojé and Maram Creeks are typical of Papua New Guinea streams.

The main effect of rotenone application in the study streams was to induce catastrophic drift (sensu BRITTAIN & EIKELAND 1988). Taxa differed in their tendency to enter the drift: drift densities of some morphospecies decreased after a peak early in the monitoring period, while others showed an increase in drift densities with time. Taxa such as baetid mayflies were particularly sensitive to rotenone and were over-represented in the drift relative to their abundance in benthic samples. Leptophlebiid mayflies, by contrast, seemed less sensitive and were under-represented in drift samples. These comparisons must be tempered by the observation that animals in drift nets originated not only from runs but also from microhabitats such as marginal areas, with a result that drift composition might have been expected to differ from that of the benthic samples. Nevertheless, the differences in relative responses of Leptophlebiidae and Baetidae to rotenone seem genuine.

The present results accord with investigations indicating that there is considerable variability in the effects of rotenone on terrestrial insect populations (HALEY 1978). Such differences are in agreement with studies of aquatic insects exposed to rotenone for 48 hours in laboratory tanks. Under these conditions, odonate larvae were the most tolerant taxon and trichoptera larvae the least (ZISCHKALE 1952; CLAFFEY & RUCK 1967). Other laboratory studies have indicated that tolerances vary greatly within single orders or families (ENGSTROM-HEG et al. 1978): for example, among ephemeropterans (where Baetidae were sensitive and Heptageniidae were relatively unaffected by rotenone) and between hydropsychid caddisfly genera (where *Cheumatopsyche* was more tolerant than *Hydropsyche*).

Laboratory studies of the effects of rotenone on aquatic insects are unsatisfactory in that the exposure to rotenone does not mimic the way in which these animals experience or respond to the poison in running waters. Field studies have shown that catastrophic drift is the immediate consequence of application of insecticides (EIDT & WEAVER 1983; BRITTAIN & EIKELAND 1988) or piscicides (DERMOTT & SPENCE 1984) to streams. This drift seems to involve living animals unless high concentrations of taxon-specific insecticide are employed (EIDT & WEAVER 1983; DERMOTT & SPENCE 1984). Catastrophic drift in the Papua New Guinea streams comprised mainly living animals plus a few moribund individuals. Evidently, the initial response to the rotenone is behavioural but whether the insects are drifting in response to their detection of rotenone, or as a result of some toxic effect of the compound causing them to release their hold on the bottom sediments, is unclear. Rotenone dust can have an acute paralytic effect on terrestrial insects (HALEY 1978), and a delayed effect of the poison would account for increases in the drift densities of certain taxa (e.g. Elmidae) even after the rotenone had been washed downstream. An immediate increase in drift following rotenone application, followed by a rapid decline (e.g. Baetidae and Trichoptera) might imply a behavioural response to the toxin. Significantly, taxa showing the latter pattern are those which laboratory studies have identified as rotenone-sensitive (see above).

The effects of rotenone on benthic standing stocks in the study streams were minor. The abundance of certain Baetidae were reduced in both streams, but leptophlebiid mayflies were unaffected. Numbers of Dixidae and *Herbertorossia sabronensis* declined in Maram Creek, but overall benthic standing stocks were unaffected in both streams. These results parallel the findings of DERMOTT & SPENCE (1984) who report that increased drift rates, rather than mortality, appear to be the major impact of lampricide (used to control sea lamprey populations) on stream invertebrate communities. ENGSTROM-HEG et al. (1978) implied that there was no appreciable effect of rotenone on the abundance of stream invertebrates in the Delaware River (N.Y., U.S.A.), but did not present any statistical analysis of their results.

This brief study has shown that the numbers of those taxa comprising the bulk of the catastrophic drift (Baetidae, Hyroptilidae, Hydropsychidae, Hydrophilidae and Hydraenidae) had declined to a fraction of the initial peak levels by the end of the monitoring period. Thus, while long-term chronic effects of rotenone on benthic standing stocks cannot be ruled out, there is good reason to suppose that the major effect of the toxin on the benthic community was to cause catastrophic drift rather than causing mortality leading to a significant decline in total benthic standing stocks.

Summary

Standing stocks and drift of benthic macroinvertebrates from reaches treated with rotenone (*Derris* root) piscicide were compared with untreated reaches of two low-altitude (< 200 m a.s.l.) streams within the Sepik-Ramu River drainage, Papua New Guinea. Maram Creek drained primary rain forest, while the original riparian vegetation around Kojé Creek had been cleared. Both streams supported diverse benthic communities, although Kojé Creek was significantly more species-rich than Maram Creek. Total macrobenthic population densities were similar in both streams. Community composition showed significant intersite differences, but nevertheless paralleled that of streams on the Asian mainland although certain characteristic taxa were lacking and others had diversified in their absence.

Rotenone induced immediate catastrophic drift in both streams. Total drift densities peaked after 30 minutes and declined subsequently. Taxa varied with respect to both the degree and timing of their response to rotenone, but Baetidae (Ephemeroptera) were rapidly affected and were the most numerous drifting taxon. Drift densities were higher in Kojé Creek although changes in drift densities after rotenone application followed simmilar trends in both streams. Certain baetid mayflies declined in abundance in ro-

tenone-treated reaches, although not all morphospecies were affected equally. Standing stocks of leptophlebiid mayflies, which dominated the benthos of Maram Creek, were unaffected by rotenone application. Among other orders, significant declines in densities of Dixidae (Diptera) and *Herbertorossia sabronensis* (Trichoptera : Hydropsychidae) occurred in Maram Creek, but total standing stocks in both streams were unchanged. Overall, rotenone induced catastrophic drift but did not cause large-scale mortality and declines in benthic invertebrate abundance.

Acknowledgements

Paul van Zwieten and David Coates provided logistic support of all kinds during the field work upon which this study was based. Without their help, the research could not have been undertaken. Additional assistance was provided by Walain Ulaiwi. Funding from FAO/UNDP for associated fisheries-related studies is also acknowledged. I am grateful for the use of facilities at the Christensen Research Institute, Madang, Papua New Guinea. Graham T. Reels provided indispensable laboratory support in Hong Kong, and David Coates commented on a draft mansucript.

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Submitted: 21 July 1989; accepted: 20 February 1990.

Appendix 1

The number of morphospecies in benthos and drift samples from Kojé and Maram Creeks, Papua New Guinea.

	Kojé Creek		Maram Creek	
	Benthos	Drift	Benthos	Drift
Decapoda				
Atyidae	1	1	1	1
Sundathelphusidae	1	0	1	0
Ephemeroptera				
Baetidae	8	8	5	6
Leptophlebiidae	2	2	1	1
Caenidae	1	1	1	1
Palingeniidae	0	0	0	1
Odonata				
Libellaginidae	1	2	1	1
Libellulidae	2	2	2	1
Macromiidae	1	1	1	0
Heteroptera				
Naucoridae	5	5	1	0
Lepidoptera				
Pyralidae : Nymphulinae	2	2	2	1
Trichoptera				
Hydroptilidae	1	4	1	1
Glossosomatidae	1	2	1	2
Philopotamidae	1	1	1	1
Psychomyiidae	0	1	0	0
Polycentropodidae	0	1	1	1
Ecnomidae	0	1	0	1
Hydropsychidae	4	4	3	3
Calamoceratidae	1	1	1	1
Leptoceridae	2	2	1	1
Coleoptera				
Dytiscidae	2	2	0	1
Hydrophilidae	4	7	0	3
Hydraenidae	1	2	1	2
Helodidae	0	1	1	1
Ptilodactylidae	1	0	1	0
Dryopidae	3	2	2	1
Elmidae	4	4	2	2
Diptera				
Chironomidae[1]	3	3	3	3
Dixidae	1	1	1	1
Ceratopogonidae	3	4	2	2
Simuliidae	0	0	1	1
Psychodidae	0	0	1	1
Tipulidae	3	3	4	4
Stratiomyidae	0	1	1	1
Empididae	0	0	1	1
Athericidae	1	0	2	2
Total morphospecies	60	71	48	50

[1] Each chironomid subfamily was treated as a single morphospecies.