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Full Length Research Paper

The influence of a semi-arid lowland river with human interferences on benthic macro invertebrate productivity

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The study investigated the constraints in benthic macro invertebrate productivity in semi arid river with human interferences. The effects of benthic macro invertebrates predation and impaired water were studied in a 500□□m mesh net 1 m^3 exclosures situated in the upstream and downstream of a river. The common species of benthic predators include birds, fish, crab and odonata. The control was a cageless open control area, where all predators could feed. The highest mean number of taxa was found in the control exclosure of unpolluted control sites. Number of taxa in exclosures where large fish were absent were two-fold higher than where all predators were present at test sites. The mean density of the benthic macro invertebrate taxa caught in all the sites was not significantly different (t test, p>0.05, df=8) between the control and test sites. The results do not constitute proof of a detrimental impact of pollution. The idea of population regulation in the Runde River is complex; a wet summer may drown them, a hot dry summer may dessicate them, emigration and immigration may exacerbate population changes and predation may be an important force structuring populations.

Keywords: benthic macro invertebrates, predation, impaired water, semi-arid river

INTRODUCTION

Benthic macro invertebrate populations maybe limited in some sites and yet show a high population in other locations of water bodies. The factors explaining presence/absence of a species and abundance have been investigated for years but still without conclusive answers. Benthic productivity assessments provide opportunities to evaluate local conditions for successful fisheries management. In semi-arid areas, it is critical to understand the constraints in benthic production if protein requirements by a growing population are to be met. In most semi-arid areas fish production may be constrained by both in-situ and ex-situ factors but little work has been done to show the relative importance of these factors.

Production is the most comprehensive measure of success of a population because it includes a composite of several features: abundance, biomass, growth, reproduction, survivorship, and generation time. Several workers (Nhapi and Tirivarombo, 2003, Josefson and Rasmussen, 2000) have reported on the impacts agricultural development can have on discharges of nutrients that cause eutrophication and succession of benthic fauna. Stress resulting from the impact of pollutants on the biota may drastically alter community assemblages and structure. Thomson et al. (2003) proposed the harsh-benign model of community dynamics that predicts that the impact of predation will decline as abiotic conditions become more stressful to biota. Exclosure studies may be required to understand the effects of pollution on community structure and assemblage. Macro invertebrates serve as valuable indicators of stream degradation and can provide a useful early warning to changing conditions of the river water quality.

In some aquatic ecosystems that support salmonids it is established that production is limited by benthic production (Wallace and Webster, 1996). As in other types of ecosystems, predators in streams have top-

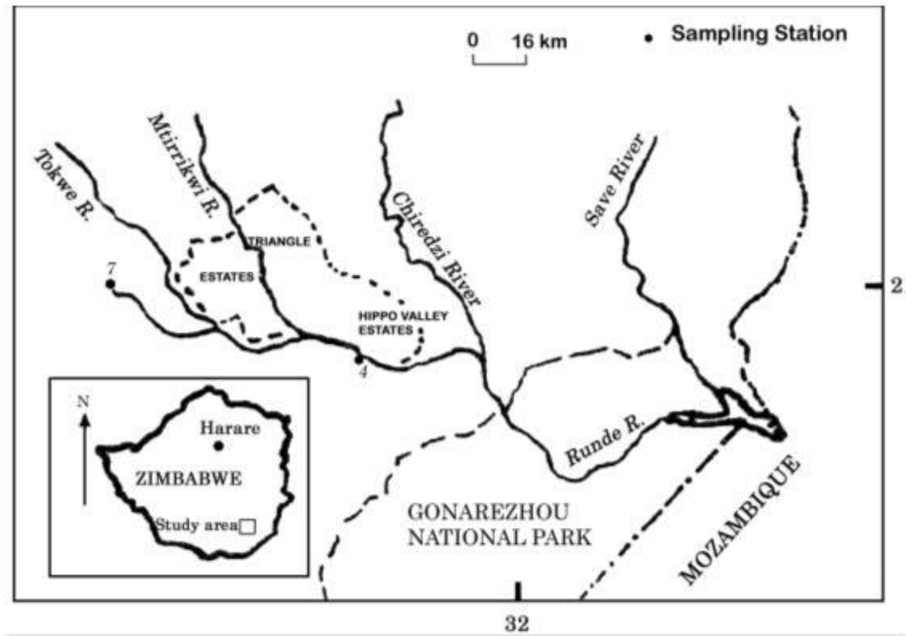

Figure 1. The situation of the study area in the southeast lowveld

down effects on their prey through direct consumption and reduction of prey populations (Machena, 1988). It is postulated in this study that bottom-up effects in the form of water quality may be more important determinants of productivity of aquatic ecosystems by imposing constraints on benthic macro invertebrate production. Many studies show significant results regarding the impact of predators on prey (Gratwicke and Marshall, 2001, Gratwicke, 2000, Sanchez et al., 2004), whereas others have shown little or no impact of predation on prey populations (Wallace Webster, 1996). Studies in isolated stream pools show a greater portion of significant predator impacts than stream studies due to immigration and emigration among substrate patches (Wallace and Webster, 1996). The uncertainty in benthic fauna productivity is seen as critical for fish conservation in the light of unquantified abiotic disturbance, and has raised questions on the future conservation of fishes (Minshull, 1993, Marshall, 1978, 1999, Skelton, 1993).

Waters grossly polluted with organic matter, especially domestic or sewage has a restricted fauna, one capable of thriving in very low concentrations of oxygen and high concentrations of dissolved and particulate organic matter (Pennak, 1978). Mancinelli et al. (2002) noted that some aquatic organisms experience a reduced efficiency of food collection under eutrophic conditions and may consequently be selected against. The hypothesis that predation could be more important than river water conditions was investigated in this study. I have used ‘predation’ to mean that one species reduces the numbers of another by eating it. Several studies (Quammen, 1981, Crowl and Covich, 1990, Dahl, 1998, DeLange et al., 2004, Sanchez et al., 2004) have determined the effects of bird, fish, crab and odonata predation on benthic macro invertebrate prey, but none has combined the effects of benthic predation and pollution. The aims of this study were to document the effects of benthic fauna predation and pollution in the southeast lowveld rivers, determine how this has changed from the reference condition and then to predict changes in response to anthropogenic influences.

Study area

The study area (Figure1) is located between longitude 20°00’S and latitude 32°00’E, approximately 400 km south east of Harare in Zimbabwean south east lowveld. The south east lowveld area covers an area approximately 104 km^2 in extent and slopes gently from outcrops at 500 m a.s.l to perennial river systems at 100 m a.s.l. The landscape dips gently towards the Save and Limpopo rivers (Figure1). The gently undulating landscapes of Zimbabwe are sometimes punctuated by rugged *bornharts* and *kopjes*. Soils vary being principally derived from alluvium, sandstone, paragneiss and basalt. Vegetation types can be crudely classified as riverine, hill miombo, mopane *Colophospermum mopane* (Kirk ex Benth) veld, thorn thicket and open woodland. Rainfall patterns are erratic and the area is prone to drought. Mean annual rainfall is approximately 550 mm, with the wet season occurring November to March. Annual runoff from the Runde/Save hydrological zone is estimated at 5900 x 10^6 m^3 per year (Mitchell, 1977) making this hydrological zone the second most important in terms of runoff yield in Zimbabwe. Not only does the annual runoff vary with mean annual rainfall, but it also varies from year to year in a particular year.

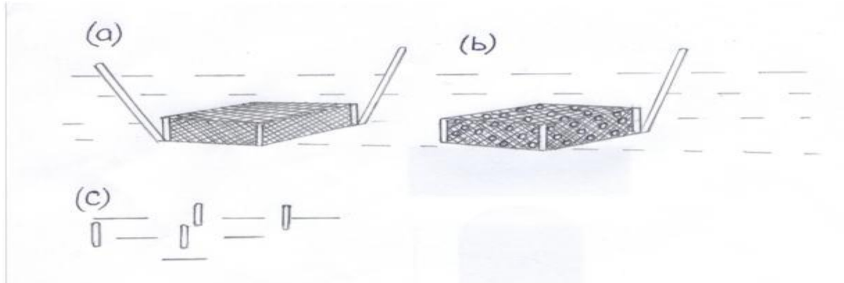

Figure 2. A schematic drawing of the three types of treatments used in the experiment
(a) The submerged exclosure with 500 m mesh net around all four sides,
(b) Rigid exclosure to exclude large fish with 7 mm diameter holes in 500 m plastic mesh size around all four sides,
(c) Control exclosure that is a pegged open area

The study area is drained by the Chiredzi, Mtirikwi, Tokwe and Runde Rivers (Figure1) about 350 km south east of Harare. The three tributaries, the Chiredzi, Mtirikwi and Tokwe Rivers pass through low input peasant agricultural areas before entering the Runde River in the study area (Figure1). The Runde River catchment is approximately 41000 km^2 in area (Mugabe et al., 2003). The Runde River strongly influences the southeast lowveld and the nation's everyday life and longterm economic development. The lowveld predominant landuse is the intensive production of sugarcane under irrigation. Irrigation is facilitated by the use of canals and overnight storage dams that enable flood irrigation of the sugarcane. Chemical fertilizers, floodplain irrigation, canal irrigation and diesel-powered riverbed sand abstraction in the lowveld have enabled the expansion of intensive agriculture into zones with nutrient-limited soils and severe soil moisture deficits, effectively changing the distribution of high potential agricultural lands. The access and manipulation of the region's hydrologic resources has profound environmental consequences and may lead to unforeseen resource degradation. Lands traditionally used for grazing herds are now interrupted by islands of intensive agriculture and agricultural runoff to the rivers may be influencing water quality changes.

The Lowveld sugar industry is the major user of water in the Runde catchment. The main estates are Triangle, Hippo Valley (Figure1), which obtain their irrigation water from dams. Six major municipal areas obtain raw water from Runde catchment. It is therefore apparent that rainfall and runoff has an impact on the ecology of the benthic macro invertebrates.

MATERIALS AND METHODS

This study examined effects of birds, fish, crabs and odonata predation on benthic macro invertebrates at sites suspected to be impaired. Among the common bird predators in the area are Giant kingfisher (*Ceryle maxima*), Secretary bird (*Sagittarius serpentarius*), Three banded plover (*Charadrius tricollaris*), Marsh owl (*Asio capensis*), Black flycatcher (*Melaenornis pammelaina*) and Maccoa duck (*Oxyura maccoa*) (Maclean, 1985). Other common bird predator species and fish species are given in Appendix I. Detailed information about food is lacking for most bird species in Southern Africa, although the usual type of food is known in general terms for nearly all of them (Maclean, 1985). The diet of fish species has been shown in several studies (e.g. Mhlanga, 2000, Minshull, 1993, Skelton, 1993) to include benthic macro invertebrates. Nearly all freshwater fish species include benthic fauna in their diet (Minshull, 1993, Skelton, 1993). If fish and dragonfly predators could be removed, would the invertebrate population change?

Stratified sampling in which the rivers were subdivided according to land use zones was undertaken. Benthic macro invertebrates were monitored at two sites (Figure1), in both control and test sites using exclosures effective against fish and against all predators that include fish, crabs, odonata and birds. Predator exclosures were used to examine the effects of predation on benthic macro invertebrates in the upstream (control) and downstream (test) sites for periods of 15 weeks during summer. The sampling stations represent a wide range of water quality conditions in the study area (Figure1). Studies below the outfall represent the worst case, reflecting conditions downstream of agricultural runoff. On the Runde River benthic predation exclosure cage treatments were conducted near a discharge point and this was aimed at measuring the impact of agriculture. The site above the outfall was situated in peasant agricultural areas and was expected to measure river water conditions in the absence of irrigated agriculture. The objective was to test whether the impact of predation affect densities of macro invertebrates on impaired and unimpaired sites.

The common species of benthic predators include birds, fish, crab and odonata. To test for benthic macro invertebrate predation and pollution, an experiment using exclosures (Figure 2) was performed. Benthic macro invertebrate predation manipulation was carried

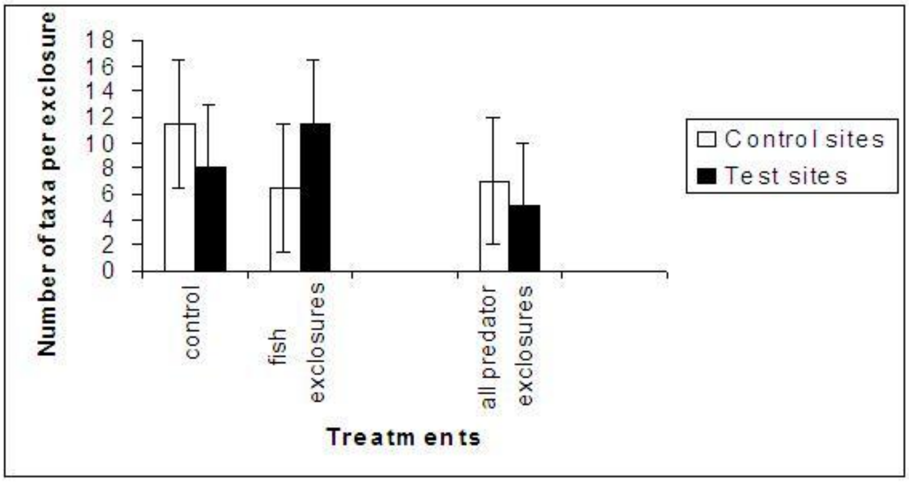

Figure 3. Mean number of taxa caught in exclosures at control and test sites

out using cages with 500□□m mesh net all around the four sides. They consisted of square plastic frames 1 m high covered with 500□□m plastic mesh. Benthic macro invertebrate predators access to exclosure cages (Figure 2) was manipulated in three exclosure cage treatments: (a) cageless open control area, where all predators could feed; (b) a rigid exclosure cage, with extra 7-mm diameter holes excluded large fish from feeding on benthic macro invertebrates, this techniques has advantages over the traditional benthic macro invertebrate cages e.g. the emigration and immigration of macro invertebrates can be regulated without resorting to total exclosure with excessively small mesh size, and (c) a rigid exclosure, which excluded birds, fish, crab and odonata from feeding on benthic macro invertebrates.

All exclosures were 1 m^3 in size and were stapled onto stakes so the tops remained approximately 25 cm above the water. Sedimentation was reduced by selecting areas where current movement, and therefore sediment movement was low. The effects of shading and sedimentation in the exclosures were not important factors affecting prey density. The exclosures were checked during October after three months. Three replicate sets of the two treatments were spread 1.5 m apart over a 40 m transect set parallel to the water so all exclosures would be at a similar tide level. Upon retrieval of the specimens, these were sieved on a 0.5 mm mesh sieve, and what remained on the screen was preserved in a 5% formaldehyde solution. Samples were stained in a rose Bengal/ethanol solution and sorted by species under a light microscope. A One-way analysis of variance using species as variables was used to determine significance.

The limitations of exclosure experiments have been highlighted by Wallace and Webster (1996): a) Exclosures were usually deployed at specific times of the year and were of a short duration, b) they failed to consider indirect effects that require several generations to detect, c) laboratory exclosures uses unnatural densities of primary and secondary consumers, d) exclosures or exclosures do not allow sufficient exchange with the stream environment, and e) no replication with ecosystem level studies. Compared to exclosures, exclosures represent an almost unavoidable choice when investigating the effects of fish whose behaviour and feeding habits can be strongly altered by confinement. The biomass, diversity, faunal composition and relative abundance of individual taxa within exclosures were compared between polluted and unpolluted sites and predation by fish and all predators.

In the laboratory, benthic macro invertebrates were identified under dissection microscope to the family level and enumerated. The biomass (mass loss after ignition at 60 ^{o}C for 48 hours) was assessed cumulatively for specimens sampled on the same treatment and determined to the nearest 0.01 mg. While drying at 60 ^{o}C will not remove all of the bound water, the seriousness of this is not as great as the volatilization of fats that will occur at higher temperatures (Edmondson and Winberg, 1971).

RESULTS

The numbers of bottom fauna taxa per square metre of stream bottom during the experimental periods are summarized in a histogram (Figure 3). The highest mean number of taxa was found in the control exclosure of unpolluted control sites and, fish exclosures on test sites where both had a mean of 11.5 genera (Figure3). The control exclosure at the control site had a high of 7 genera compared to 5 genera for the all predator exclosures at test sites. Number of taxa in exclosures

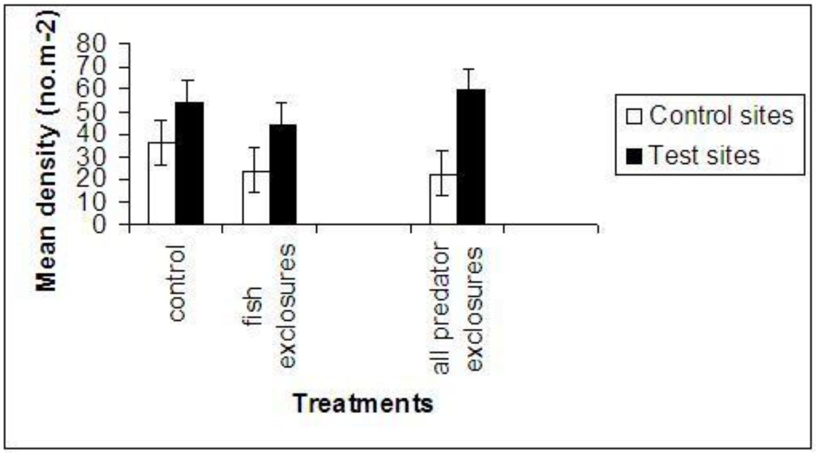

Figure 4. Mean density of benthic macro invertebrates collected in control and test sites in the study area

Table 1. Estimated density (no.m2) of benthic macro invertebrates in unpolluted and polluted sites using a variety of exclosures

Sites	Treatments	n	Mean Density (no./m2)	s.d	s.e
Unpolluted	Control	2	36	16.971	12
	Fish exclosures	2	24	1.414	1
	All predator exclosure	2	22.5	2.121	1.5
Polluted	Control	2	54	16.971	12
	Fish exclosures	2	44	7.071	5
	All predator exclosure	2	59	16.971	12
ANOVA: F-ratio=2.250 P=0.06 n.s					

n=number of sites (each with 3 exclosures)
X=mean
s.e.=standard error

n.s=not significant

where large fish were absent were two-fold higher than where all predators were present at test sites. The changes in the number of taxa were lower in the control at test sites and, all predator exclosures.

The mean densities (no.m^{-2}) of individuals found in each exclosure were found to be different between sites (**Figure** 4). The highest densities, ranging from 44 to 59 individuals per m^{2} were consistently found in exclosures (control, fish and all predators) at test sites (Table 1). Differences were greatest between all predator exclosures in control and test sites. Benthic macro invertebrate densities were low when large fish predators and other predators were excluded (Figure 4). The results do not constitute proof of a detrimental impact of agricultural development.

The results in Table 1 show that benthic macro invertebrate densities were significantly different in all 6 exclosures, whether control or test. Variances of densities for catches in the polluted and unpolluted sites were higher, but there was no evidence to suggest that pollution had any adverse impact on the densities of active benthic macro invertebrates in the area. Certainly other environmental variables are more important than pollution in determining the abundance and diversity of active benthic macro invertebrates, as neither the total number of benthic macro invertebrates showed real differences between control and test sites within the whole study area. Benthic macro invertebrate abundance was high when all predators were present.

The results obtained in this study agree with the findings of other workers. Makoni et al. (2005) showed the impact of fishes on snail densities using fish exclosure experiment. Snail species included *Bulinus globosus, B. tropicus, Biomphalaria pfeifferi*, *Lymnaea natalensis* and *Melanoides tuberculata*. The fish species present in the pond prior to the start of the experiment

Table 2. Estimated biomass (mg) of benthic macro invertebrates in the control and test sites using a variety of exclosures

Sites	Treatment	n	Biomasss.d (mg)	s.e
Unpolluted	Control	2	412.1	0.071 0.05
	Fish exclosures	2	474.5	5.445 3.85
	All predator exclosure	2	516.3	4.526 3.2
Polluted	Control	2	481.7	2.1921.55
	Fish exclosures	2	479.2	8.7 6. 15
	All predator exclosure	2	452.8	62.65 44.3

included *Tilapia rendalli*, *Oreochromis mossambicus, O. macrochir, Clarias gariepinus, Kineria auriculata* and *Labeo* species. At the beginning of the experiment 85 *Sargochromis codringtonii* were introduced into the pond. All the fish species were periodically monitored by seine netting and the stomach contents of a sample of these were analysed. At the end of the experiment, the density of *B. globosus* was 150.5 snails' m^{-2} in the exclosures and 4.7 snail's m^{-2} in the control areas. The other snail species showed the same trend. *Sargochromis codringtonii* was the only fish species that was successfully established and found to feed on the snails (Makoni et al., 2005).

Chakona et al. (2007) investigated the cumulative impact of the entire fish assemblage on benthic macro invertebrate assemblages over four months in a removal experiment in isolated pools that persist through the dry season in an intermittent stream in northwestern Zimbabwe. Macro invertebrate taxonomic richness did not differ significantly between sampling dates, indicating that fish removal had no effect on the zoobenthos taxa richness but led instead to large increases in the densities of certain macro invertebrates (Chakona et al., 2007). Chakona et al. (2007) further showed a progressive increase in the body size of Odonata in fishless pools 34 and 55 days after treatment and, by 78 days post-treatment, the proportion of large-sized odonates was significantly higher in fishless than in control pools.

Chimbari et al. (2004) investigated the impact of *Sargochromis codringtonii* on pulmonate snails, including those that transmit schistosomiasis over 29 months in 2800m-2 irrigation ponds. After 10 months 85 *S. codringtonii* were introduced into each of three ponds and the molluscide niclosamide was applied at a dose of 1 ppm to another three ponds. Although *Sargochromis codringtonii* populations increased to 85-400 per pond, they did not have a significant effect on snail populations, whereas niclosamide had a significant and sustained negative effect on them (Chimbari et al., 2007). Low fish population density may fail to impact negatively on snail populations (Chimbari et al., 2007).

Other studies (James and Cothran, 1982) on causal relationships between animal and sediment distribution, concluded that "the complexity of soft-sediment communities may defy any simple paradigm relating to any single factor". Particularly valuable are experiments that test interactions between a number of processes or variables, especially when such studies are developed within the framework of a predictive model.

Estimated biomass of benthic macro invertebrates at the control sites and test sites using a variety of exclosures are shown in Table 2. The results in Table 2 show that benthic macro invertebrate biomass was significantly different in all 6 exclosures, whether control or test. Variances of densities for catches in the control and test sites were higher, but there was no evidence to suggest that agricultural development had any adverse impact on the densities of active benthic macro invertebrates in the area.

A total of 351 benthic macroivertebrates covering 39 taxa were collected during the survey. The most numerous species, each constituting > 10% of the total, were mollusca with Sphaeriidae being the most abundant. Relative abundance of individual taxa of the most numerous taxa collected was compared between control sites and test sites and within the exclosures. There were significant differences detected between control and test sites for many taxa, but few showed a consistent change in relative abundance, which could be, attributed to predation/pollution. The fauna represent a wide range of trophic levels including primary consumers, detrivores, scavengers and predators.

Species richness of the most common macro inveretebrates collected in the exclosures showed important trends (Table 3). Psephenidae declined from a mean density of 3 to 2, Sphaeriidae from 16.5 to 15, and Mellanidae from 5 to 3. Lymnaeidae increased from mean density of 4 to 16.67, Planorbidae from 2 to 4. Few of the benthic macro invertebrates show consistent evidence of an adverse impact of pollution on their relative abundance. None of the 87 taxa showed any differences in relative abundance between the control and test sites.

The occurrences of benthic macroinvertebrtae taxa in all the exclosure treatment are summarized in Figures 5-7. There is no clear pattern in the occurrences of benthic macro invertebrate taxa by exclosure treatment and

Table 3. Mean density (no.m2) of benthic macroinvertebrate taxa collected in the control and test sites. Densities not significantly different (t test, p>0.05, df=8)

Taxon	Control sites	Test sites
Lymnaedae	4	16.7
Mellanidae	5	3
Planorbidae	2	4
Psephenidae	3	1.5
Sphaeriidae	16.5	15

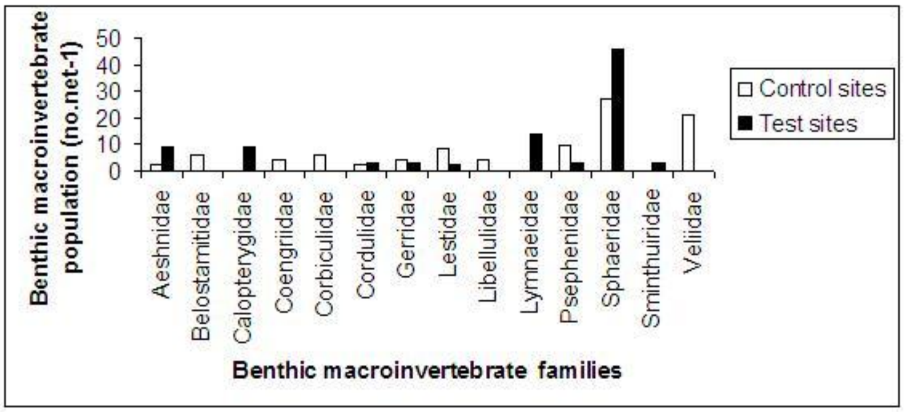

Figure 5. Relative abundance of benthic macroinvertebrates collected in the cageless open water of the control and test sites

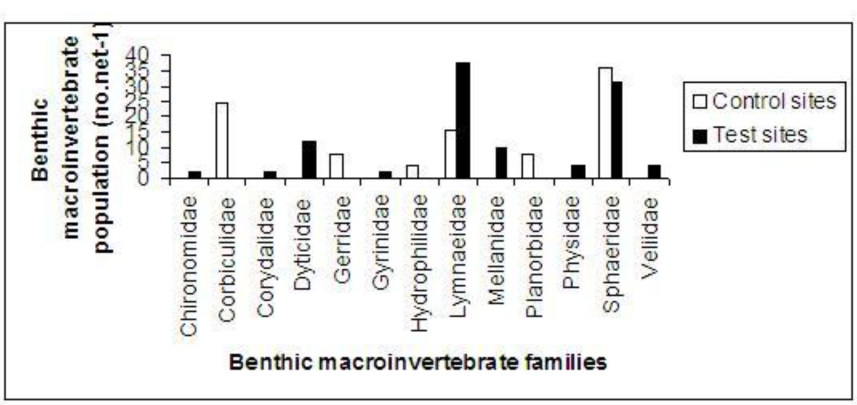

Figure 6. Relative abundance of benthic macroinvertebrates collected in fish exclosures in the control and test sites

control and test sites (Figs 5-7). Among all the cageless open water sites, Sphaeridae was the most abundant taxa in the test sites than in the control sites (Figure 5). Molluscs especially the Corbiculidae, Lymnaedae and Sphaeridae were most abundant in both the control and test sites of the fish exclosures (Figure 6). Molluscs again dominate in abundance between the control and test sites of the all predator exclosures (Figure**7**).

The mean density of the benthic macro invertebrate taxa caught in all the sites is not significantly different (t test, p>0.05, df=8) between the control and test sites (Table 4). The benthic macro invertebrate taxa caught in the study sites were assigned feeding groups and these included grazers, predators and detrivores (Table 4) but as Pennak (1978) and Thirion et al. (1995) note most benthic fauna may be associated with more than one feeding group. Table 5 shows the benthic macro invertebrate densities above and below the outfall. The only significant differences in densities were noted in the all predator exclosures (Table 5).

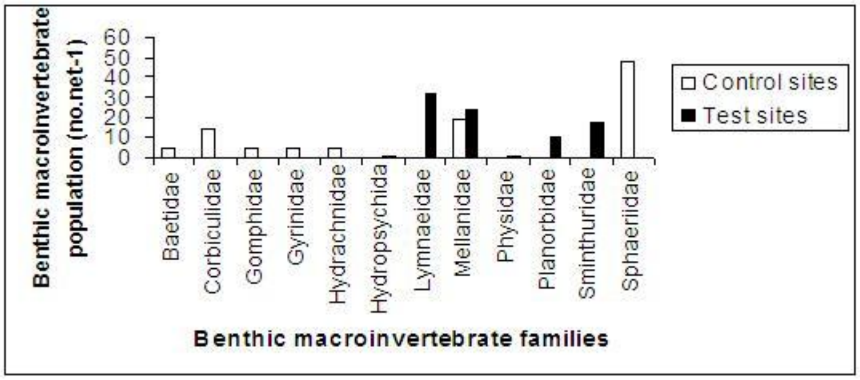

Figure 7. Relative abundance of benthic macro invertebrates collected in all predator exclosures in the control and test sites

Table 4. Benthic macro inveretbrates feeding groups identified in the manipulative exclosure experiment

Taxon	Common name	Feeding Group
Aeshnidae	Dragonfly	Predator
Baetidae	Mayfly	Grazer
Belostamitadae	Giant waterbug	Predator
Calopterygidae	Dragonfly	Predator
Chironomidae	Midge	Grazer
Chlorocyphidae	Dragonfly	Predator
Coengriidae	Dragonfly	Predator
Corbiculidae	Bivalves	Detrivore
Cordulidae	Dragonflly	Predator
Corydalidae	Dobsonfly	Predator
Dyticidae	Beetle	Predator
Gerridae	Water strider	Predator
Gomphidae	Dragonfly	Predator
Gyrinidae	Beetle	Detrivore
Hydrachnidae	Water mite	Predator
Hydrophilidae	Beetle	Grazer
Hydropsychidae	Caddisfly?	Grazer
Lestidae	Dragonfly	Predator
Libellulidae	Dragonfly	Predator
Lymnaeidae	Snail	Grazer
Mellanidae	Snail	Grazer
Physidae	Snail	Grazer
Planorbidae	Snail	Grazer
Psephenidae	Riffle beetle	Grazer
Sminthuridae	Springtail	Grazer
Sphaeriidae	Bivalve	Detrivore
Veliidae	Water strider	Predator

DISCUSSION

Removal of large fish predators in exclosures resulted in a dramatic increase in benthic macro invertebrate taxa although there was no corresponding increase in densities (Figure 3). Number of taxa in exclosures where large fish were absent were two-fold higher than where all predators were present at test sites. The changes in the number of taxa were lower in the control at test sites and, all predator exclosures. There were significant

Table 5. T-Test of different treatments on benthic macro invertebrate density above Effluent outfall and below effluent outfall (NS=not significant; *=P<0.05)

Levene's Test for Equality of Variances	F	Sig. (2-tailed)
TREAT 1	1.043891	
TREAT 2	3.325344	
TREAT 3	5.830654 *	

differences detected between the control and test sites for many taxa, but few showed a consistent change in relative abundance, which could be, attributed predation/pollution. The changes in the number of taxa were lower in the control at test sites and, all predator exclosures but were even with the control at unpolluted control sites and fish exclosures. Sensitive fauna suffer from the direct effects effects of pollution. Mean densities in the exclosures of test sites were greater than in the controls of open water, fish and all predator exclosures (Figure 4). Presumably in a waterbody one of the main requirements for success is ability to avoid predators, especially in the juvenile stages when the macro invertebrates are most vulnerable. Densities of macro invertebrates (Figure 4) in all control cageless open water were very high. It can be presumed that the stones and rocks on the substrate were of a size range suitable to provide protective cover considering the size of the macro invertebrates.

The highest densities, ranging from 44 to 59 individuals per square metre were consistently found in exclosures (control, fish and all predators) at test sites (Table 1). Differences were greatest between all predator exclosures in the test and control sites. Benthic macro invertebrate densities were low when large fish predators and other predators were absent. Benthic macro invertebrates may be considerably exposed to large fish predators at sites below the outfall. Large fish predators may have a controlling effect on densities and dominant forms of benthic macro invertebrates. These effects may cascade throughout the food web, but this possibility has not been investigated in tropical rivers. These findings suggest that predation may be an important force in checking the densities of benthic macro invertebrates. There were significant differences detected between test and control sites for many taxa, but few showed a consistent change in relative abundance, which could be attributed to predation/nutrient loading. Predator-driven interactions have been demonstrated in benthic systems using exclosures by Mancinelli et al. (2002).

Mean densities of benthic macro invertebrates were consistently lower in exclosures at control sites than polluted sites suggesting that the lack of suitable food may constrain population growth. The chemical environment of streams places many constraints on organisms as well as on type and form of food that is available. The faunal composition represents a wide range of trophic levels including primary consumers, detrivores, scavengers and predators (Table 5). Using exclosures to study the effect of predation by fish and birds on macro invertebrates DeLange et al., (2004) noted that benthic macro invertebrate species richness was negatively affected by sediment contamination. Production of gastropods was negatively correlated with contamination (DeLange, 2004). Sedimentation or erosion, shading of the substrate, the use of the exclosures as refuge sites by some predatory species, and the possible use of common resource by several groups of predators are factors that have to be considered as limitations of exclosures.

Species richness of the most common macro inveretebrates collected in the exclosures showed a few patterns (Table **4**). Psephenidae declined from a mean density of 3 to 2, Sphaeriidae from 16.5 to 15, and Mellanidae from 5 to 3. Lymnaedae increased from mean density of 4 to 16.67, Planorbidae from 2 to 4. The lack of significant differences

(t test, $p>0.05$) in densities of taxa between the control and test sites suggest that the Runde River is characterised by low nutrients that do not seem to have a controlling effect on taxa distribution. This is further confirmed by the lack of significant differences in benthic densities in the exclosure experiments between the control sites and test sites.

Estimated biomass of benthic macro invertebrates at control and test sites using a variety of exclosures are shown in Table 2. The results in Table 2 show that benthic macro invertebrate biomass was significantly different in all 6 exclosures, whether control or test. Biomass was very variable within test sites and there were no significant differences detected between test sites and control (Table 2). There is thus no evidence that predation affected the biomass. Changes in the total amount of biomass of benthic fauna with enrichment have been demonstrated in fertilization experiments (Wetzel, 2001, Ricklefs, 2001, Lee and Lee, 2001). High phosphate and nitrogen fertilization resulted in a 42% greater yield of benthic invertebrates and 3.3 times greater yield of zooplankton.

A total of 351 benthic macro invertebrates from 6 test sites and exclosures (trapping effort of 75 trap days) were sorted, counted and identified. Sphaeriidae were the most abundant within the catch but insects were caught in large numbers, made up the highest proportion of the density. The faunal composition shows characteristics of aquatic environments. The fauna represent a wide range of trophic levels including primary consumers, detrivores, scavengers and predators, all-important in the functioning of an aquatic ecosystem. In turn, they provide the major food source for a variety of aquatic and terrestrial insects, reptiles, amphibians, birds and mammals. As with cageless open water on a reference site, the mollusca was numerically dominant, comprising 50% of the catch.

Whilst there was an overall decline in species richness as the study ended this was most marked in the test sites. The results do not constitute proof of a detrimental impact of pollution, although this seems likely. Certainly, other environmental variables are more important than pollution in determining abundance and diversity, as neither the total number of invertebrates nor the number of taxa caught in the exclosures showed differences between the control and test sites within the whole study area. The idea of population regulation in the Runde River is complex; a wet summer may drown them, a hot dry summer may dessicate them, emigration and immigration may exacerbate population changes and predation may be an important force structuring populations.

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