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Disturbance of a Kenya Rift Valley stream by the daily activities of local people and their livestock

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Abstract

Human and domestic animal activities and visits to an impacted site in the Njoro River, Kenya, were recorded from 1994 to 1995. The activities of people in the humid and wet zones of the stream included linen washing, water abstraction, excretion, bathing and swimming. Human and animal visits and activities along the Njoro River were on a daily basis and were patterned according to the time of the day, weather and seasons. Women formed the first group to visit the stream at dawn, followed by men and lastly, children. The diurnal pattern of visits was bimodal, with major peaks between 0600 and 1100 h and from 1600 h until dusk. The intensity of all major activities peaked at around midday and donkeys and cattle formed the largest proportion of the domestic animals that visited the stream. Much of the small-scale water abstraction occurred between 0700 and 1100 h, coinciding with the time when most people visited the stream. Water abstraction was most intense during the dry season. A mean discharge of 1.7 litres per second was measured whilst 0.3 litre of water per second was abstracted at the impacted site, implying that about 20% of the flow volume of the Njoro River was abstracted at a single site in one day.

The effects of the human and animal activities on the structure of macrozoobenthos in the wet zone of the Njoro River were studied on the 'impacted site' in relation to an 'upstream reference site' and a 'downstream reference site'. Oligochaetes and chironomids dominated the fauna in all three sites. The impacted site had low patchiness and mean crowding, with the taxa distribution tending toward a randomly dispersed spatial pattern. The mean turnover ($\pm$SD) of the macroinvertebrates was 47$\pm$18, 48$\pm$26 and 36$\pm$22 in the impacted, downstream and upstream sites, respectively. The trampling of the streambed by humans and livestock could, therefore, alter the benthos structure through redistribution and reduction of faunal patchiness. The cumulative effect of small-scale, but widespread and frequent disturbances might have large impacts on whole river systems. This study demonstrated that, in the tropics, quantification of the daily activities of people and domestic animals is important for future management of the Njoro River and consequently, Lake Nakuru.

Introduction

Visits to aquatic systems by people and their domestic animals and the consequent disturbances have taken place since time immemorial. Because of prolonged interactions with streams, it is probable that virtually no pristine streams exist in the world today. The effects of human activities on the structure and function of small and large hydrosystems is a theme running through ecology and pollution biology. Disturbance, defined as "a cause, a physical force, agent or process, either abiotic or biotic, causing perturbation in an ecological component or system" (Rykiel, 1985) may be caused by the activities of people and domestic animals within the stream channels. Physical disturbances in stream wet and humid zones are very common along African streams where water for humans and livestock is scarce. Wet and humid zones are hereafter referred to as that "sediment area wetted by water flow at the time of observation" and "dry area on both sides of the stream bordered by the edge of the flowing water and the highest extent reached by the stream flow in its history", respectively (Mathooko, 1995; Mathooko et al., 2000). It is interesting to note that most studies on disturbance in streams have focussed on the effects of the more recent impacts of point sewage discharges, toxic chemical spills, channelization or damming while ignoring the effects of physical disturbances by humans and domestic animals within stream channels. These disturbances normally displace substrata and thus they may influence the distribution of stream biocoenosis. Humans in densely populated but less developed countries normally exert definitive impacts on streams through linen washing, livestock watering, body washing, swimming and water fetching to satisfy domestic water demands.

Visits to watercourses and the activities of humans and domestic animals in the humid and wet zones of streams occur on a daily basis in tropical countries. Daily water abstractions made directly from streams and activities within and around the lotic hydrosystems in the tropics have not received scientific attention. The effects of large-scale water abstractions on invertebrate communities have, however, been considered in Europe (e.g. Boon, 1988; Castella et al., 1995). In most of Africa, the most common small-scale type of water abstraction is the use of containers to transfer water outside the stream system. Whether the small-scale water abstraction has any effect on stream biocoenosis is not known. Bretschko (1995) suggests that the other activities by people and domestic animals in the humid and wet zones of streams could be more important ecologically than the small-scale water abstraction. The aims of this study were to enumerate visits by both people and domestic animals to a single observation site on the Njoro River, to quantify small-scale water abstractions from the Njoro River at the single observation site and, to describe and record the frequencies of activities in the humid and wet zones of the stream at the observation site. The potential impacts of such activities on stream ecology are shown in Table 1. The effects of human and animal activities on macroinvertebrate communities within the wet zone of the Njoro River were also considered. This study, therefore, gives the first impression of the effects of physical activities on stream macroinvertebrates in the tropics. Such effects could be taken into account and may need to be regulated in stream management plans.

Materials and methods

The Njoro River and the study area

This study was conducted in the Njoro River (Fig. 1) in Nakuru District, Kenya, from 1994 to 1995. The Njoro River, with Little Shuru as its main tributary, is a second-order stream with a catchment of approximately 200 km^2, stretching between latitude 0° 15′ S, 0° 25′ S and longitude 35° 50′ E, 36° 05′ E. It originates from the Mau Hills (ca. 2700 metres above sea level) and discharges into Lake Nakuru (ca. 1700 m a.s.l.), a total length of about 50 km. The stream is structured in a typical pool-riffle sequence, with a predominance of soft substrata and bedrock in the pool and riffle sections, respectively. The mean discharge was about 150 $\times$ 10^3 litres per day.

Two main vegetation groups, with a total of six types, form the riparian vegetation of the Njoro River. The two groups include the montane *Juniperus procera-Olea europapaea* sub. sp. *africana* and submontane *Acacia abyssinica* forests (Mathooko & Kariuki, 2000). Sections of the riparian vegetation have been completely cleared for access to stream water for domestic use and watering animals, amongst other uses. Canopy cover over this hydrosystem ranges from 0% to about 90%. Retardation of vegetation growth due to anthropogenic disturbances is conspicuous over a wide area.

The study area was situated in a steep gorge section of the mid-reach of the Njoro River at the border of Egerton University Campus and the Njokerio settlement on the left and right orographic banks, respectively. The steep sides of the gorge are vegetated densely with trees and undergrowth. Three sites were chosen and named ‘impacted site’, the ‘downstream’ and the ‘upstream reference sites’. The reference sites were of similar morphological and hydraulic characteristics to those of the impacted site. This was necessary especially when comparing the effects of human and animal activities on the benthos structure. The population of the Njokerio settlement is not supplied with piped water and, therefore, depends on the Njoro River for its water requirements and those for its domestic animals.

Characteristics of the study sites

The impacted site is a large 22-m long pool, with a small concrete sill on the riffle head. The right bank is less steep above the water line and its riparian vegetation has been cleared. The pool is used mainly for

Table 1. Categorization of human and domestic animal activities in the wet zone of the Njoro River, Kenya. (*) – effect not certain. POM–particulate organic matter, PIM–particulate inorganic matter

Category of activities	Observed and potential effects
I. Human beings	
Bathing/swimming/children playing in the water	Displacement of substrata, fauna, POM, PIM, nutrients
Drawing water	(*)
Washing linen	Increase in water turbidity, increase of phosphorus and other nutrients
Crossing/stepping on the streambed	Displacement of substrata, fauna; release of trapped POM, reduction of algal cover and biofilm
Excretion	Increase in nutrients and POM
Sand harvesting within the streambed	Disruption of the physical structure and function of the stream
II. Domestic animals (e.g. cows, goats, donkeys, sheep)	
Drinking water	(*)
Crossing/trampling on the streambed	Displacement of substrata, fauna, death of fauna, release of nutrients and trapped POM, reduction of biofilm and algal cover
Excretion	Increase in nutrients and POM
III. Others	
Car washing	Increase in water turbidity, oils/grease, heavy metals, killing and displacement of fauna, displacement of the substrata
Tractor compaction of streambed	Displacement of substrata, POM and fauna, death of fauna, compaction of substrata

the provision of water for livestock and domestic use. Other human activities are concentrated on the riffle head and on the left vegetated bank. The concrete sill is also used heavily as a bridge during low water discharge. In addition to the very few bedrock outcrops, the stream bottom consists of 15–20 cm deep fine sediments. The riparian vegetation shades about 60% of the pool area.

The downstream reference site is a small, 8-m long and absolutely undisturbed pool. It is situated about 100 m downstream of the impacted site in a very steep narrow gorge section with extremely dense riparian vegetation. Fine sediments are 5–15 cm deep, but most of the pool bottom is bedrock. Maximum water depth was about 46 cm and the riparian vegetation shades approximately 70% of the pool.

The upstream reference site is a pool with a more complex shape and a maximum length of 12 m. It is about 50 m upstream the impacted site. Fine sediments (ca. 20 cm deep) are predominant. Maximum water depth was about 1 m and about 80% of the pool area is shaded.

Visits and activities: the impacted site

Visits and the activities of humans and domestic animals were determined by direct counts and visual observations on twelve separate days spread from January 1994 to September 1995. All the counts and observations were carried out from 0600 h to 1800 h at 15-min intervals during each of the 12 sampling occasions. The volume of water abstracted from the stream

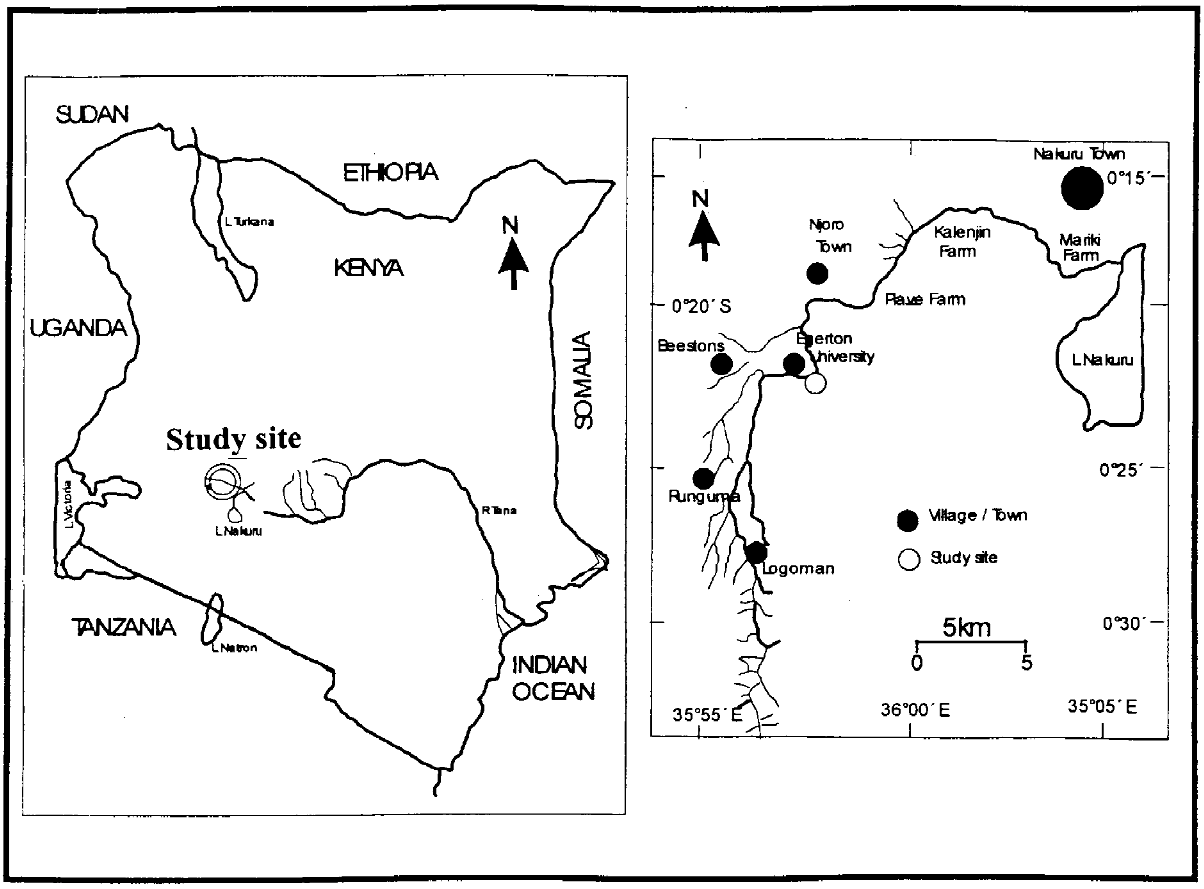

Figure 1. Location of the Njoro River and of the study site.

was estimated by counting the water-filled containers, classified as small 10-l and large 20-l containers.

Macroinvertebrate sampling at the study sites

Five samples were collected from the sediment surface of each of the three study sites during four of the twelve sampling occasions using a Kajak sampler fitted with a 5 cm-diameter corer. After collection of the samples, they were preserved in 5% formaldehyde solution and then washed through a 0.1-mm mesh sieve. The macroinvertebrates were sorted under a stereo microscope, identified to the lowest taxonomic level and enumerated. The data obtained were then used to relate the effects of the activities observed on the distribution of the macrozoobenthos at the sediment surface, with the following assumptions:

(i) the water physicochemical conditions were not changing significantly during the observation times,

(ii) macrozoobenthos dispersal/migration from the study sites was due solely to trampling and the other physical activities measured in this study, and

(iii) the seasonality of the macrozoobenthos did not influence its densities between the observation times.

The distribution of the macrozoobenthos on the sediment surface was assessed using Lloyd's (1967) index of mean crowding. The mean crowding statistic normally estimates the degree of crowding and incorporates information on both density and aggregation and is calculated as follows:

$$\overset{*}{m} = m + \left(\frac{\sigma^2}{m} - 1\right),$$

where $\overset{*}{m}$ is mean crowding, σ^2 is the variance, and m is the mean density. Patchiness, defined as the ratio of mean crowding to mean density $\left(\frac{\overset{*}{m}}{m}\right)$ was also calculated. A randomly dispersed spatial pattern would generate a patchiness value of unity whereas regular patterns would produce patchiness values of <1. There is no theoretical upper limit to patchiness values for aggregated patterns. Species turnover (TO) was determined according to Hövemeyer (1999):

$$\mathrm{TO}\ (\%) = [100 * (E_i + E_j)]/(E_i + E_j + C_{ij}),$$

where E_i and E_j denote the number of species exclusive to samples *i* and *j*, respectively, and C_{ij} is the number of species common to both samples.

Results

Visits and activities: the impacted site

Visits and activities started shortly after 0600 h and continued to the late evening. Adult females, adult males and children comprised 48.1%, 18.2% and 33.7%, respectively, of the people that visited the stream. A sequential pattern of visits to the stream in the morning hours was very evident (Fig. 2a). Women formed the first group to visit the stream at dawn, followed by men and, lastly, children. The diurnal pattern at the impacted site was bimodal, with two major peaks between 0600 and 1100 h and from 1600 h until dusk.

Human activities were very diverse, including linen washing, swimming, body washing and excretion. All but linen washing were popular with children. The intensity of all the major activities peaked at around midday (Table 2). Small-scale water abstraction occurred bimodally (Fig. 2b), in a pattern that was similar to the pattern for visits. Much of the water was abstracted between 0700 h and 1100 h, coinciding with the period of most frequent visits. Increased water abstraction also occurred after 1600 h, a time when water was drawn with small containers of about 10 l. This was in accord with the high number of children visiting the stream at this time. This was normally the time when children were free after the afternoon school classes. The increased number of children visiting the stream between 1100 h and 1500 h did not result in increased water abstraction. A total of 2.3 $m^3\ d^{-1}$ of water were abstracted from the Njoro River during the twelve sampling occasions that spread over more than $1\frac{1}{2}$ years. There was a steady increase in the linen washing activity from morning, peaking between 1200 and 1300 h, and thereafter declining steadily toward the evening hours (Fig. 3). After small-scale water abstractions, linen washing was the next major activity at the impacted site.

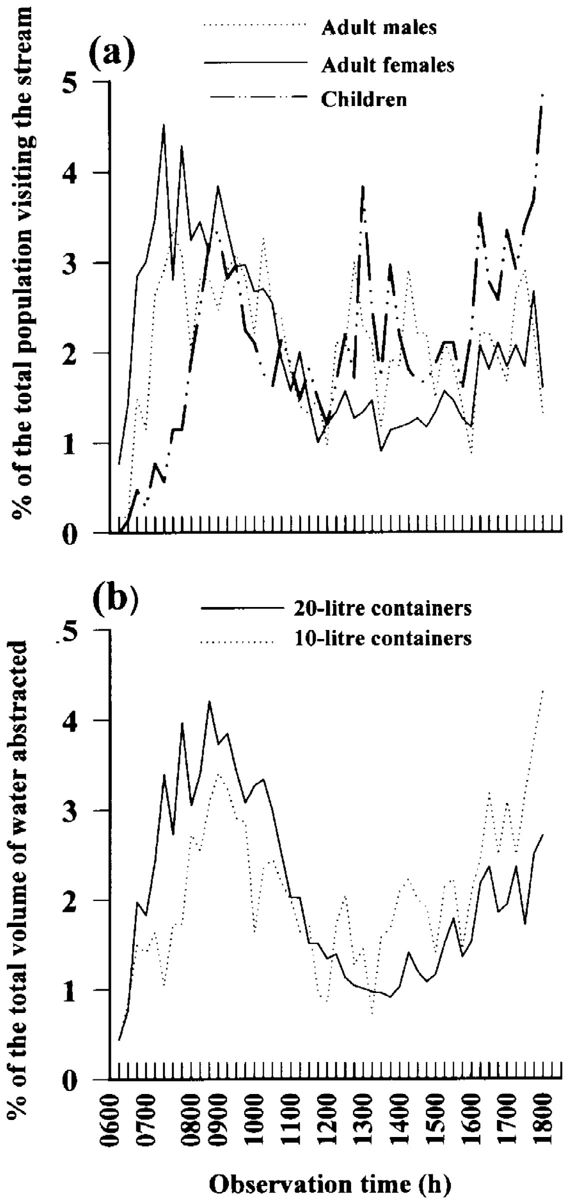

Figure 2. Diurnal fluctuations of visits and water abstractions from the Njoro River, Kenya. (a) Diurnal fluctuations of adult males, adult females and children (relative percentage of the total population of 6209 people) visiting the Njoro River. (b) Diurnal fluctuations of the volume of water abstracted (expressed as % of the total volume of 2.3 $m^3\ d^{-1}$ water abstracted) from the Njoro River.

Donkeys and cattle were the main animals to visit the Njoro River at the impacted site. An average of 47 donkeys per day were counted over the 12 sampling occasions. Donkeys were used to carry water contain-

Table 2. Human activities in the humid and wet zones of the Njoro River, Kenya, at an impacted site from January 1994 to September 1995. *Percentage of the total water abstracted, - water abstracted by humans and used by domestic animals

Activity	Peak time of activity (h)	% of total population involved in activity at peak time	% of total population visiting the stream
Linen washing	1200–1300	14.9	23.4
Swimming	1400–1500	62.5	0.1
Body washing	1200–1300	27.9	1.0
Urinating	1200–1300	47.7	1.0
Water drinking	1300–1400	57.1	0.2
Defaecating	1300–1400	45.7	0.6
Other activities	1500–1600	40.0	0.8
10-l water abstractions	1700–1800	13.8*	-
20-l water abstractions	0800–0900	14.4*	-
Total water abstraction	0800–0900	14.0*	-

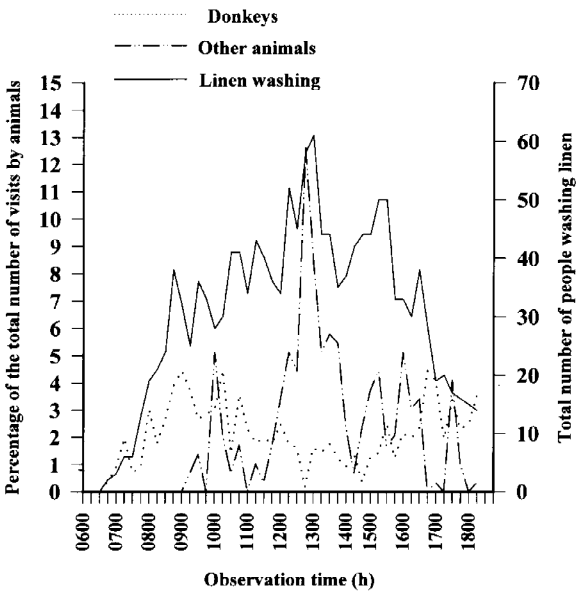

Figure 3. Percentage fluctuation of the number of donkeys and other domestic animals visiting the Njoro River and the total number of people involved in linen washing between 0600 and 1800 h.

ers although most of the people fetching water were carrying the containers themselves. The temporal pattern of the number of donkeys visiting the stream (see Fig. 3) was similar to that of visits by people and the volume of water abstracted from the stream. Cattle, sheep and goats were watered between 1130 h and 1430 h, corresponding with the increase in the number of children visiting the stream. Children did not, therefore, visit the stream specifically to fetch water (see low water volumes fetched) but also to bathe and lead animals for watering. Peak visits to the stream by cattle, sheep and goats occurred at about 1245 h. Thus, intensified physical disturbances on the streambed were observed between 0900 h and 1100 h and from 1600 h until dark.

Seasonal water abstraction and visits to the stream by people and domestic animals are shown in Table 3. With the exception of the rates indicated for children, all the others showed high rates in the dry season (Fig. 4a, b). However, water abstraction using small containers showed a steady seasonal trend (Fig. 4b). The general pattern of water abstraction using 20-l containers reflected the human and donkey trends irrespective of season.

Macroinvertebrate crowding, patchiness and turnover on the streambed of the impacted and reference sites

The fauna in the three study sites was dominated by oligochaetes and chironomids (% of the total fauna range: 65.9–75.4% and 12.5–24.5%, respectively). The number of oligochaetes and chironomids was highest in the downstream and upstream reference sites, respectively. However, the average mean crowding for oligochaetes was 59, 69 and 62 for the upstream, downstream and impacted sites, respectively. Generally, the intensity of potential interaction between individual taxa was low in the downstream and impacted sites compared with the upstream site. Although the distribution of all the taxa in the three sites was of the aggregated type (patchiness indices >

Table 3. Visit rates (VR) and water abstraction from the Njoro River, Kenya, at an impacted site during dry and wet seasons. Means are based upon six observation days

	Mean ± SD VR h^{-1}		Mean ± SD VR sampling occasion^{-1}	
	Dry season	Wet Season	Dry season	Wet Season
Adult females	25 ± 5	16 ± 2	304 ± 59	194 ± 25
Adult males	10 ± 2	6 ± 1	116 ± 28	73 ± 13
Children	14 ± 4	16 ± 3	162 ± 52	187 ± 31
Donkeys	6 ± 1	2 ± 1	67 ± 15	27 ± 5
Other animals	3 ± 1	1 ± 1	35 ± 13	14 ± 6
	Volume (l h^{-1})		Volume (l sampling occasion^{-1})	
10-l water abstraction				
	200 ± 0	100 ± 0	1900 ± 400	1700 ± 200
20-l water abstraction				
	1000 ± 200	600 ± 0	11900 ± 2200	7300 ± 900

Table 4. Ranges of mean crowding for the major taxa based upon four random samples of 0.01 m^2 streambed

Taxa	Upstream Site	Impacted Site	Downstream Site
(a)			
Oligochaeta	11.6–137.1	19.8–114.8	19.8–121.4
Tanypodinae	5.0–30.1	9.6–15.5	14.0–14.9
Chironomini	10.4–23.7	8.2–26.1	8.3–15.1
Tanytarsini	0.0–13.6	0.0–24.2	1.0–9.1
Caenidae	7.9–17.3	9.0–26.3	0.0–25.1
Mean (±SD) patchiness for the major taxa based upon four random samples of 0.01 m^2 streambed			
(b)			
Oligochaeta	1.28±0.10	1.45±0.24	1.58±0.62
Chironomini	1.90±0.91	1.28±0.92	1.90±1.01
Tanypodinae	2.23±1.95	1.80±2.50	3.38±3.90
Tanytarsini	2.00±4.00	1.78±3.55	2.00±3.37

1), the impacted site had low mean crowding (Table 4a) as well as low patchiness, with the taxa distribution tending toward a randomly dispersed spatial pattern (patchiness indices ≈1) (Table 4b). However, there were no significant differences in mean crowding, patchiness and turnover among the three sites (one-way ANOVA, $p>0.05$). Nevertheless, the mean turnover of the macroinvertebrates was high in both the impacted and downstream reference sites whilst it was comparatively low in the upstream reference site (Fig. 5).

Discussion

Human and domestic animal activities in the humid and wet zones of streams take place daily at selected sites depending on bank gradients, quantity and quality of water available and also on the nearness to human settlement. The intensity of the activities assumes definite diurnal patterns. Scrutiny of the current dataset showed that daylight hours were well apportioned to the activities and visits of the various human and animal categories. These activities are influenced by time of the day, seasons and the nature of the human community living along the streams. Observations at a single site in the Njoro River indicated that close to human settlements, the stream was disturbed constantly during the daytime period. The bimodal water abstraction and visit patterns observed in this study could probably represent most tropical African streams.

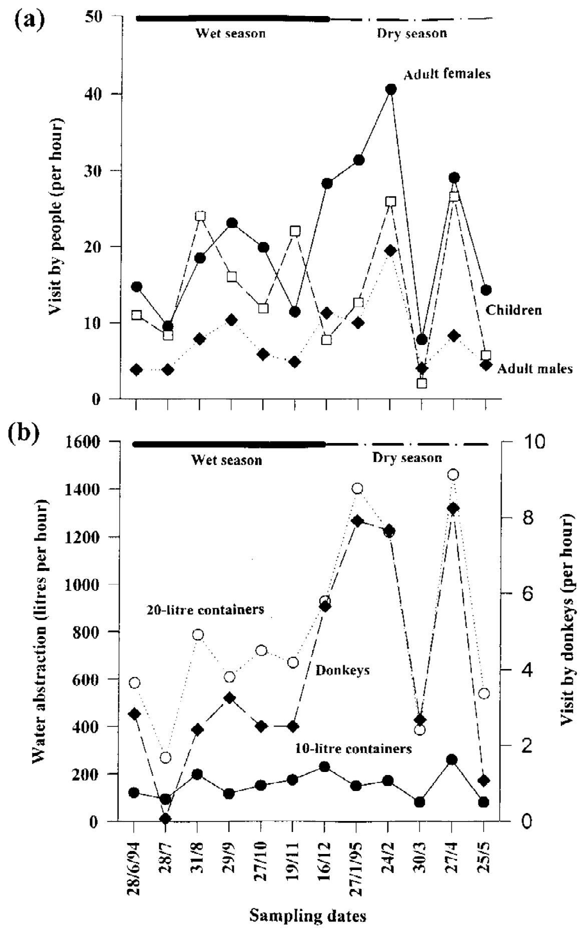

Figure 4. Seasonal fluctuations of visits by people (a) to the Njoro River, Kenya, and (b) water abstraction rates and visits by donkeys.

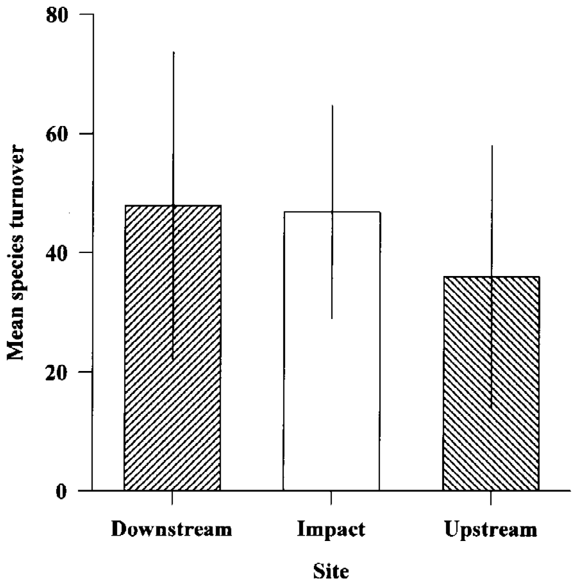

Figure 5. Mean species turnover in the impacted site and the downstream and upstream sites. Means are based upon four random samples collected between January 1994 and September 1995 and the vertical bars represent ±standard deviation.

Anthropogenic disturbances along streams can be very diverse as shown in the present study. The phasing of visits and activities on daily basis showed that women formed the foremost visitors to the Njoro River. Culturally, women are supposed to cater for water needs for the whole family and this explains why they were the first to visit the stream at dawn. Water for the midday and evening meals is normally fetched in the morning and late afternoon hours, respectively. This, together with other activities, could explain the observed water abstraction trends. The number of children visiting the stream between 1100 and 1500 h increased without a corresponding increase in the volume of water abstracted. Children generally came to the stream to bathe rather than to fetch water, since water and air temperatures were high (20 and 27 °C, respectively) at this time and, at the same time, lead animals for watering. Weather conditions could therefore have regulated all the activities that disturbed the stream.

Some of the activities in the streambed could have immediate or long term effects on stream biocoenosis and hydrology. About 20% of the flow volume of the Njoro River was abstracted in 1 day at a single site. This abstraction is most probably not dramatic in the short term but cumulative effects of a chain of settlements along a stream might influence its hydrologic conditions. With an increasing human population along the stream and the consequent disturbance of the riparian vegetation, it would be important to implement long-term observations of the effects of both the mild and strong disturbances on the water quantity/quality and on the aquatic biota.

Macrozoobenthos reacts very rapidly to physical disturbances (Bretschko, 1990; Mathooko, 1996). It was, therefore, assumed that the macrozoobenthos at the impacted site could be influenced by the constant human and animal activities in the wet zone of the stream. Although not significant, mean crowding and patchiness were generally low on the impacted site, emphasizing that prolonged trampling of the streambed by people as well as domestic animals could result to redistribution of the benthos through dispersal/migration. This could also explain why the distribution of taxa was tending toward a randomly dispersed spatial pattern. The distribution of the various taxa in the downstream and upstream reference sites was patchy. It was speculated that this could have been due to patchy food distribution on the sediment surface including the presence of competitive exclusion where strong competitors outcompeted the weak ones. Further research is, however, needed to establish this assertion. As a result of the human and animal activities within the wet zone of the impacted site 100 m upstream, the downstream site appeared also to be impacted. The downstream site had characteristics close to those of the impacted site. Taxa turnover was high in the impacted and downstream sites probably due to the high instability, especially in the impacted site. The traits of organisms found could therefore have been '*r*-selected' rather than '*K*-selected'. The upstream site was relatively stable with a low turnover. Human and animal activities in the streambed could also have the following effects:

1. Compaction of sediments leading to a reduction in interstitial spaces which provide habitat, refuge and avenues for the colonization process.
2. Constant disturbance of the sediments through swimming, trampling by animals and humans could probably lead to benthic community change to '*r*-selected species'.
3. Increased energy transfer from the disturbed reach to the lower reaches through increased dislodgement of nutrients, particulate organic matter, particulate inorganic matter and macrozoobenthos drift pulses.
4. Retardation of the growth of biofilm on the surfaces of the sediments in the impacted site due to the frequent physical disturbances.

In order to understand the impacts of physical disturbance on the ecology of tropical streams, short- and long-term research on the above issues is needed. This could also assist us in understanding the effects of recreational, touristic and other leisure-type interactions and pressures on tropical stream ecosystems.

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