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Effects of a hydropower plant on Coleopteran diversity and abundance in the Udzungwa Mountains, Tanzania

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Abstract. The effects of river flow diversion on biodiversity were assessed using Coleoptera as an indicator group in three habitats of the Kihansi Gorge (Udzungwa Mountains, Tanzania), before and after commissioning of a hydropower plant. Data collected using sweep netting and pitfall traps showed that the effect of diversion of the river flow was site-specific, affecting particularly the spray habitat. Rarefaction analysis of both sweep netting and pitfall samples indicated that the expected richness of Coleoptera declined significantly in all habitats after commissioning of the power plant. Sweep netting and pitfall samples showed that the highest Shannon–Wiener diversity index value before the diversion of the river flow was in the spray zone, but the index value decreased after diversion. Changes in the other two habitats were less prominent. Analysis of variance using diversity index values from five pitfall samples in each habitat type before and after commissioning indicated that there were no statistically significant differences in the diversity index between the two sampling periods or among the three habitat types. Renkonen's similarity index between habitats showed that pitfall samples had higher similarity (≥87%) than did samples from sweep netting (≤69%). It is suggested that for mitigation purposes, artificial spray systems, which have been installed in other wetlands of the Kihansi Gorge, also be installed to cover the whole Lower Wetland in which this study was undertaken. In order to maintain overall biodiversity in the Kihansi Gorge, it is suggested that the ecosystem conservation approach be prioritised.

Introduction

The Eastern Arc Mountains (EAM) is a chain of isolated crystalline mountains running from southern Kenya through Tanzania in a crescent or arc shape (Lovett 1990). These mountains are recognised as one of 25 globally important biodiversity 'hot spots' (NEP 1997; Burgess et al. 1998; Iddi 1998; Mittermeier et al. 1998; MNRT 1998; Myers et al. 2000). Although the EAM cover less than 2% of Tanzania's land surface, they have a large variety of flora and fauna (Lovett and Wasser 1993; Burgess et al. 1998), harbouring approximately 18% of all described plant species, 43% of butterflies, 23% of amphibians, 26% of birds, and 24% of mammal species found in the country (Newmark 1999). Furthermore, the forest flora of the EAM has a high degree of endemism and a large number of species of restricted geographic range (Lovett and Wasser 1993; Lovett et al. 1997; Burgess et al. 1998).

Within the EAM, the Udzungwa chain may have the highest biodiversity due to its size and variable topographical characteristics. During recent years the Udzungwa Mountains have received increasing attention from biologists, and many new species have been described from the area (see e.g. Rodgers and Homewood 1982; Scharff 1990, 1992, 1993; Dinesen et al. 1994; Kingdon 1997; Lovett et al. 1997; Poynton et al. 1998; Hochkirch 1999; NORPLAN 2001a). Despite the ecological uniqueness of the EAM, and the Udzungwa chain in particular, its biological diversity is threatened by a variety of human activities including habitat alteration, fragmentation and over-exploitation (Burgess et al. 1998; MNRT 1998; Newmark 1998; Rodgers 1998; Zilihona et al. 1998a; Dinesen et al. 2001).

One of the current threats to the biodiversity of the Udzungwa Mountains is the Lower Kihansi Hydropower Plant (opened in July 2000) on the Kihansi River, a tributary of the Kilombero and Rufiji rivers. The diversion of water away from a 700 m high waterfall system into a power generation plant resulted in a decrease of bypass flow from an average natural flow of 16.3 to 1.5–1.9 $m^3 s^{-1}$ leading to a loss of about 90% of the water that formerly maintained the gorge's habitats. This caused 95% of the spray-dependent habitat to dry up (Doggart and Milledge 2001). For instance, the survival of endemic Kihansi Spray Toad (*Nectophronoides asperginis*), and other biota associated with such habitats is now highly threatened.

The impact of the decreased flow of the Kihansi River on the aquatic and terrestrial habitats raised concern among domestic and international conservation organisations. To remedy the problem, the government, in collaboration with different donor agencies, launched a series of conservation measures entitled Immediate Rescue and Emergency Measures Project (IREMP) (NORPLAN 2002). The main objectives were to study options for, and where possible to implement, measures for biodiversity conservation of the Kihansi Gorge.

The present paper assesses the effects of the diversion of river flow due to construction of the Lower Kihansi Hydropower Plant on Coleopteran diversity. Coleoptera was used as an indicator group since they are known to be sensitive to environmental perturbations, and thus provide early warning on the disturbance effects, hence enabling appropriate measures to be taken sooner rather than later (Nummelin and Hanski 1989; Nummelin and Borowiec 1991; Nummelin and Fürsch 1992; Van Rensburg et al. 1999; Zilihona and Nummelin 2001; Halffter and Arellano 2002; Zilihona 2003).

Material and methods

Description of the study area

The Kihansi Gorge is located along the eastern escarpment of the southern Udzungwa Mountains. The gorge, created by the Kihansi River, is approximately 4 km long and 0.5 km wide. The Kihansi River is unusual among rivers that descend the Udzungwa Scarp because its catchment covers an extensive area of the Upland Uhehe plateau, totalling 688 km^2 (Poynton et al. 1998). Along this gorge the Lower

Kihansi Hydropower Plant (180 MW with the possibility of increasing to 300 MW) was constructed. The scheme incorporates a 25 m high dam, which results in the inundation of about 26 ha when the reservoir is full. The dam diverts water into a tunnel, which leads to the power generation station. The plant takes advantage of the change in elevation through the Kihansi Gorge, which drops nearly 900 m within 3 km. The water is returned to the river about 6 km downstream.

The gorge contains four major vegetation types: (1) miombo woodland (95 ha), (2) montane forest (100 ha), (3) *Filicium* forest (0.25 ha), and (4) wetland spray meadow (3 ha). The vegetation of the wetland spray zone is characterised by a shallow-rooted, low growing herbaceous sward that rarely exceeds 1 m height and is usually only 30 cm high. The cliff and the aerial spray create water logging in the soil, which limits development of deep-rooted species. Constant moisture on leaf surfaces leads to growth of epiphylls that prevent the long-lived leaves from photosynthesising (NORPLAN 2001b). This prevents woody vegetation from colonising the area under the influence of sprays. Under wet conditions the club moss *Selaginella* is abundant. Other plants include broad-leaved hydrophilous species such as *Impatiens* and *Begonia*, ferns and grasses adapted to boggy conditions. The wetland sites are edged with a belt of much taller herbaceous vegetation dominated by plants in the ginger family, Zingiberaceae, such as *Costus afer* and *Aframomum* sp., which in turn is surrounded by closed canopy forest in the gorge.

Miombo woodland is dominated by *Brachystegia* species, while *Aphloia theiformis*, *Olea capensis*, *Allanblackia stuhlmannii*, *Cephalosphaera usambarensis*, *Drypetes usambarensi* and *Garcinia semseii* are found in the montane forest. *Filicium* forest is dominated by a single tree species, *Filicium decipiens*. Vegetation types in the gorge are described in more detail by NORPLAN (1995, 2001c) and Lovett et al. (1997).

Methods

The study area was divided into three sampling sites with different microclimates: (1) Spray zone (Lower Wetland spray meadow), which was influenced by constant sprays generated by the waterfall before commissioning of the hydropower plant but dried up after commissioning of the plant. (2) Forest site, a site representing 'normal' montane forest along the gorge and not affected directly by the sprays. This site was located about 800 m downstream from the spray zone. (3) Riverine site, montane forest along the river bank about 2 km downstream from the spray zone.

The sites were sampled before (in 1997) and after commissioning (in 2002) of the hydropower plant. Sweep netting and pitfall traps were used as sampling methods. Sweep netting was used to collect insects from above-ground vegetation and foliage (Zilihona and Nummelin 1999). One sample comprised 800 sweeps, and four samples from each site were collected before and after commissioning of the power plant, respectively. After commissioning this method was used only on the spray habitat. Fourteen 0.4 l plastic cups with top diameter of 8.5 cm per site were used as pitfall traps. Sampling techniques used were according to Nummelin and Hanski (1989). One sample of pitfall traps comprised beetles from 14 traps per 14 days. From each study site five such samples were collected before (June–August 1997) and after commissioning (June–August 2002).

Expected Coleopteran richness was calculated using the rarefaction technique and diversity was measured using the Shannon–Wiener diversity index (H') (Magurran 1988). The values of both indices increase with community diversity. Coleopteran evenness, that is the extent to which beetle families at each site were equally distributed before and after commissioning, was compared using the evenness index E, calculated as $E = H'/\ln S$ (S is the number of families in the habitat) (Magurran 1988). E ranges from 0.0 to 1.0, with 1.0 representing a situation in which all families were equally abundant. We used the BIODIV software package to perform the analysis (Baev and Penev 1995). We used analysis of variance to test statistical differences in Shannon–Wiener indices before and after commissioning and between habitat sites. To estimate similarity of Coleoptera between habitats, a similarity index (Renkonen index; Wolda 1981) was used (maximum 100% in identically distributed samples). The classification scheme of beetles was according to Scoltz and Holm (1985) and Booth et al. (1990).

Results

The total number of Coleopteran individuals and families collected was higher before the commissioning of the plant. Pitfall samples taken before commissioning indicated that the forest site had the highest number of individuals, whilst the spray zone had the highest number of families (Appendix 1). Sweep netting samples showed that both numbers of individuals and families were higher in the spray zone before commissioning (Appendix 1). After commissioning, sweep net samples were only taken from the spray zone, and the number of individuals and families was much lower than before commissioning. After commissioning, Coleopteran families such as Hydrophilidae, Meloidae, Cicindellidae, Anobiidae, Cleridae, Mycetophagidae, Languriidae and Nitidulidae were not observed in all habitats, while Buprestidae was sampled only in the spray site by sweep netting after commissioning (Appendix 1).

The rarefaction analysis of both pitfall and sweep netting samples showed that after commissioning Coleopteran expected richness in the spray site declined drastically (Table 1). However, Coleopteran richness in forest and riverine sites was affected less.

Sweep netting and pitfall samples showed that the highest Shannon–Wiener diversity index value before diversion of the river flow was in the spray zone. After diversion it was lower than before diversion (Table 1). Changes in the diversity value in the other two habitat types were less prominent. However, probably due to high variation among samples, an analysis of variance using diversity index values from five pitfall samples in each habitat type before and after commissioning indicated that there were no statistically significant differences in the diversity index between the two sampling periods (before/after commissioning) or among the three habitat types (Table 2).

Table 1. Rarefaction ($E(S)$), Shannon–Wiener index of diversity (H') and evenness index (E) of pitfall and sweep netting samples in different habitats after and before commissioning of the hydropower plant.

Habitat	Method	Pre-commissioning			Post-commissioning		
		$E(S)$	H'	E	$E(S)$	H'	E
Spray	Pitfall trap	7.13	0.64	0.28	4.0	0.28	0.20
	Sweep netting	17.70	2.41	0.77	12.0	2.02	0.77
Forest	Pitfall trap	5.29	0.29	0.14	4.29	0.40	0.23
	Sweep netting	14.10	2.19	0.81			
Riverine	Pitfall trap	4.82	0.27	0.15	4.17	0.22	0.14
	Sweep netting	13.40	1.96	0.71			

Table 2. An analysis of variance using diversity index values from five pitfall samples in each habitat type (spray zone, forest and riverine) before and after commissioning (time).

Source	DF	MS	F	P
Time	1	0.0309	1.05	0.315
Habitat type	2	0.0207	0.71	0.503
Residual	26	0.0293		

Table 3. Renkonen similarity index between different habitats before and after the commissioning, and in the same habitat between pre- and post-commissioning situation. SW and PF indicate similarity index with sweep netting and pitfall samples, respectively. Similarity index in parentheses indicates when dung beetles were excluded from the analysis.

Habitats	Pre-commissioning		Post-commissioning	
	SW	PF	SW	PF
Spray/forest	59	88 (24)	–	92 (23)
Spray/riverine	51	89 (25)	–	97 (23)
Forest/riverine	69	99 (24)	–	92 (23)
Spray/spray	–	–	54	90 (26)
Riverine/riverine	–	–	–	98 (23)
Forest/forest		–	–	92 (22)

In general, Coleopteran evenness showed relatively small changes after commissioning of the power plant (Table 1). Moreover, sweep netting samples indicated a relatively high evenness index compared to pitfall samples, and further showed that there was no change in evenness after commissioning of the power plant in the spray zone. Pitfall samples indicated that the evenness index in all habitats before and after diversion of the river's flow was low, suggesting that Coleopteran families in Kihansi were not equally distributed.

The similarity index between the habitats showed that samples from pitfall traps had higher similarity index values, both before and after commissioning of the power plant, than did samples from sweep netting (Table 3). However, the result could be partly because of the biases of the method, since when Scarabaeidae (dung beetles) were excluded from the analysis, the similarity index decreased, indicating that the abundance of dung beetles dominated the samples and dung beetles were common/wide spread.

The similarity in pitfall samples among habitats both before (88–99%) and after commissioning (92–97%) was at the same level as between the same habitats pre- and post-commissioning (90–98%) (Table 3), indicating that (1) the overall similarities are high, and (2) habitat changes caused by the commissioning of the hydropower plant were not reflected in the similarity patterns.

Discussion

Commissioning of the Lower Kihansi Hydropower Plant had an impact on the Coleopteran fauna. However, changes differed between the parameters studied, as abundance and number of beetle families decreased but diversity and evenness were not affected in a consistent way. Similarities of the pitfall samples from the same habitat pre- and post-commissioning were high, indicating that community structure remains, although the overall abundance may decrease and some taxa disappear.

The effects of diversion of the river flow were site-specific, affecting particularly the spray habitat. Before commissioning of the hydropower plant this habitat was highly influenced by waterfall sprays that provided a unique microclimate and sustained a unique invertebrate fauna (Zilihona et al. 1998b; NORPLAN 2001b,f; Zilihona and Nummelin 2001). Many taxa probably disappeared entirely from the site as a consequence of its change, as they were not sampled at all after the commissioning of the hydropower plant. However, the absence of such taxa (e.g. Anobiidae, Mycetophagidae, Languriidae, Nilitulidae and Cleridae) after commissioning of the plant needs further investigations to determine if their absence was due to habitat change as a consequence of the hydropower plant or due to other reasons, such as sampling artefact or seasonal variations (Zilihona 2003). It is well documented that there is great variation in arthropod abundance, richness and diversity in African rainforests between both seasons and years (Madoffe and Bakke 1995; Nummelin 1996). The results also indicated that Hydrophilidae, Meloidae and Carabidae provided convincing evidence regarding the effect of the hydropower plant, and therefore could be used as indicator groups for detailed monitoring studies in the Kihansi Gorge.

The slight increase of Coleopteran diversity in the forest site after commissioning of the plant could be due to the fact that for beetles exploiting a wide range of forest resources (generalists), disturbance could increase resources required leading to higher populations (Ghazoul and Hill 2001). Nummelin and Borowiec (1991) and Nummelin and Fürsch (1992) noticed such an increase in generalists after disturbance in the Kibale forest. Also some specialists adapted to the changed conditions could increase. NORPLAN (2001f) also reported increase of relative diversity of Psocoptera, Lepidoptera, and Hymenoptera after commissioning of the plant.

Findings of this study are in line with other studies undertaken in the Kihansi Gorge. For instance, changes in the gut contents of the insect-feeding Kihansi Spray Toad following the diversion of the Kihansi River indicated that the insect fauna had indeed changed, although it was cautioned that this might be due to differences in the area in which they were collected (NORPLAN 2001a). Also NORPLAN (2001f) reported that commissioning of the plant had a dramatic effect on the arthropod community in the spray wetland, with species characteristic of the wetland community, such as *Afrosteles distans* and *Ortheziola* sp., either dying or retreating to areas closer to the falls that continued to receive some spray.

Vegetation studies have shown that the spray wetlands underwent a change in plant composition following diversion of the Kihansi River. For example, loss of three plant species (*Basananthe hanningtoniana*, *Begonia oxyloba*, and *Christella dentate*), and decrease in the relative abundance of some other species such as *Selaginella kraussiana*, *Leersia hexandra* and *Pilea rivularis*, coupled with an increase of colonising species such as *Crassocephalum mannii*, *Vernonia auricurifera*, *Ludwigia abyssinica* and *Helichrysum* sp. have been reported to occur in the wetland (NORPLAN 2001a,b,c, 2002). Considering all these different studies there is no doubt that the hydropower plant has caused significant changes in the biodiversity along the Kihansi Gorge.

Biotic changes in the Kihansi Gorge are common to other hydropower plant operations around the world. In Zambia, construction of the Itzehitezhi Hydroelectric Dam along the Kafue River resulted in a dramatic change in diversity and abundance of ungulates, insects and birds (Sheppe 1985; Happold 1995). Attwell (1970) reported a decrease in insect species along the Zambezi flood plain due to construction of the Kariba dam. According to Runhaar et al. (1996) vegetational changes occurred in The Netherlands due to human intervention on the hydrological systems. Similarly, Miller et al. (1995) discussed the consequence of hydrological changes in the riparian zones at the lower elevations in Western North America. Also White (1969), El Moghraby and El Sammani (1985), Pimm (1991), Alam et al. (1995), Walters (1996), and Berkamp et al. (2000) reported effects of hydropower dams on biodiversity.

According to our results, it is crucial to ensure that selected mitigation measures are effective, otherwise unique biodiversity in the area may continue to be in jeopardy. Encouraging results of the IREMP Project (NORPLAN 2001d, 2002) on the performance of the artificial spray systems in the Kihansi wetlands is a step towards saving the biota in the Gorge. After construction of sprinklers in the upper, lower and mid-gorge wetlands, composition of the insect fauna has regained some of its former characteristics (NORPLAN 2001f). It would, therefore, be useful to install sprinklers to cover the remaining parts of the lower Kihansi wetland in which the former spray zone of this study was located. This would assist in restoring the condition of the zone. Moreover, the artificial sprinkler systems should not only be durable but also their maintenance should be economically feasible. This is very important for a developing country like Tanzania. It is crucial to ensure that in the long term their operations will not depend on donor financial assistance.

Although the current conservation priority in the Kihansi Gorge is directed towards the Kihansi Spray Toad, the importance of insect conservation in the area cannot be neglected. This is due to their major roles in the ecological functioning of the natural ecosystem through their diverse activities (Samways 1994; Picker and Samways 1996; Andersen 1997; NORPLAN 2001f; Fimbel et al. 2001; Ghazoul and Hill 2001). For instance, insects form the main part of the diet of the Kihansi Spray Toad, as it was noted that more than 80% of food items identified from their guts were insects (NORPLAN 2001a). Therefore, conservation efforts should be directed towards habitats and ecosystems in addition to addressing individual species. Since it is evident that the survival of this 'flag-ship' species depends on the survival of their food species and suitable abiotic conditions, there is a need for an ecosystem approach that moves away from a single species focus to take a broader view that includes interactions between species, ecosystems and the non-living environment (Biodiversity in Development Project 2001). This approach is also important when implementing the Convention on Biological Diversity, which Tanzania has ratified and is thus bound to fulfil its obligations.

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Appendix 1 Number of individuals in the different Coleopteran families in different habitats as recorded before and after commissioning of the Lower Kihansi Hydropower Plant. Catches of all study areas have been pooled. The families are ordered according to their abundance rank in the pooled data. SW indicates individuals that were collected by sweep netting (four samples × 800 sweeps) while PF are those collected using baited pitfall traps (14 traps/60 days). Classification according to Scoltz and Holm (1985) and Booth et al. (1990).

Taxon	Habitats									
	Pre-commissioning						Post-commissioning			
	Spray		Forest		Riverine		Ex-spray		Forest	Riverine
	SW	PF	SW	PF	SW	PF	SW	PF	PF	PF
Scarabaeidae	–	1028	13	1988	6	999	–	246	587	1006
Chrysomelidae	82	4	39	17	67	–	33	–	2	–
Staphylinidae	6	36	14	47	4	25	–	8	64	36
Curculionidae	63	–	62	–	66	1	10	–	–	3

Appendix 1 (continued).

Taxon	Habitats									
	Pre-commissioning						Post-commissioning			
	Spray		Forest		Riverine		Ex-spray		Forest	Riverine
	SW	PF	SW	PF	SW	PF	SW	PF	PF	PF
Carabidae	–	127	–	26	5	21	–	7	3	2
Coccinellidae	77	2	24	–	24	–	25	–	–	–
Hydrophilidae	119	6	–	–	12	–	–	–	–	–
Attelabidae	39	–	12	–	7	–	3	–	–	–
Trogidae	–	16	–	21	–	6	–	1	4	–
Apionidae	10	–	3	–	10	–	11	–	–	–
Tenebrionidae	18	–	7	–	–	–	3	–	–	–
Cerambycidae	6	2	2	1	8	–	4	–	–	3
Lycidae	15	–	7	–	–	–	1	–	–	–
Bostrychidae	5	–	4	–	3	–	9	–	–	–
Elateridae	8	–	–	–	10	–	2	–	–	–
Meloidae	19	–	–	–	–	–	–	–	–	–
Platypodidae	–	–	18	–	–	–	–	–	–	–
Geotrupidae	–	4	–	2	–	–	–	–	–	–
Bruchidae	8	–	–	–	–	–	4	–	–	–
Cicindelidae	6	–	–	–	–	5	–	–	–	–
Anobiidae	9	–	–	–	1	–	–	–	–	–
Mycetophagidae	6	–	2	–	–	–	–	–	–	–
Cleridae	8	–	–	–	–	–	–	–	–	–
Mordellidae	6	–	–	–	–	–	1	–	–	–
Rhipiphoridae	–	2	–	1	–	–	–	–	3	–
Anthicidae	–	–	–	–	6	–	–	–	–	–
Anthribidae	2	–	–	–	1	–	4	–	–	–
Languriidae	3	–	2	–	–	–	–	–	–	–
Rhipiceridae	1	–	–	–	2	–	–	–	–	–
Scolytidae	–	–	3	–	–	–	–	–	–	–
Nitidulidae	2	–	–	–	–	–	–	–	–	–
Buprestidae	–	–	–	–	–	–	2	–	–	–
Coleoptera, individuals	507	1227	212	2103	232	1057	112	262	663	1050
Coleoptera, families	23	10	15	8	16	6	14	4	6	5
Total number of families/site	28		19		18		18		6	5

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