



**Responses of Invertebrates to Human-Caused
Disturbances
in East African Tropical Rainforests:
Conservation Implications.**

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Academic dissertation

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This thesis is based on the following articles which are referred to in the text by their Roman numerals:

- I** Zilihona, I., Shangali, C., Mabula, C.K. & Hamisy, C. 1998: Human activities threatening biodiversity of the Udzungwa Scarp Forest Reserve - Tanzania. — *Journal of East African Natural History* 87: 319-326.
- II** Zilihona, I. & Nummelin, M. 1999: A comparison of sampling techniques for insect biodiversity studies in remote areas of Tanzania: A case study of Udzungwa Mountains. — In: Makundi, R.H. (ed.), *Challenges of Entomology in Africa in the 21st century*. Proc. 4th Scientific Conference of the Tanzania Entomological Association 1999, Arusha, Tanzania. Pp. 96-102.
- III** Nummelin, M. & Zilihona, I. Spatial variation of arthropod communities in virgin and managed sites in the Kibale Forest, Western Uganda. — Submitted manuscript.
- IV** Zilihona, I., Heinonen, J. & Nummelin, M. 1998: Arthropod diversity and abundance along the Kihansi Gorge (Kihansi River) in the Southern Udzungwa Mountains. — *Journal of East African Natural History* 87: 233-240.
- V** Zilihona, I. & Nummelin, M. 2001: Coleopteran diversity and abundance in different habitats near Kihansi waterfall, in the Udzungwa Mountains, Tanzania. — *Biodiversity and Conservation* 10: 769-777.
- VI** Zilihona, I., Niemelä, J. & Nummelin, M. Effects of a hydropower plant on Coleopteran diversity and abundance in the Udzungwa Mountains, Tanzania. — Submitted manuscript.

Contributions

The following table shows the major contributions of authors to the original articles or manuscripts.

	I	II	III	IV	V	VI
Original idea	IZ, CH	IZ	MN	IZ, MN	IZ, MN	IZ, MN
Study design	IZ, CS, CH	IZ, MN	MN	IZ, JH, MN	IZ, MN	IZ, MN
Data gathering	IZ, CS, CM, CH	IZ	MN	IZ, JH	IZ	IZ
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CM: Charles Mabula, CS: Chrispine Shangali, CH: Chrispo Hamisy, IZ: Innocent Zilihona, JN: Jari Niemelä, JH: Johanna Heinonen, MN: Matti Nummelin. In addition several people assisted in the field. Their contributions are acknowledged in the relevant parts of the thesis.

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Summary

Introduction

East African rain forest biotope is one of the most diverse habitat types on the planet (Lovett and Wasser 1993, Struhsaker 1997, Burgess *et al.* 1998, Mittermier *et al.* 1998, Myers *et al.* 2000, Newmark 2002). The Eastern Arc Mountains form a large part of rainforest habitats in East Africa. These mountains extend from southeast Kenya through south central Tanzania and are globally known for their high rates of endemism and species richness (Burgess *et al.* 1998, Newmark 2002). Locally, they support the livelihood of millions of people in the mountains and their surroundings.

Despite its importance biological diversity in East African rainforests are currently being lost at an unprecedented rate due to various human-caused disturbances (Nsolomo and Chamshama 1990, Struhsaker 1997, MNRT 1998, Burgess *et al.* 1998, Poynton *et al.* 1998, Wood *et al.* 2000, Fimbel *et al.* 2001). Deforestation is the major threat to the sustainability of biodiversity in East Africa (Nsolomo and Chamshama 1990, Martens 1995, Lulandala 1998, Newmark 1998, Burgess *et al.* 1998). For instance, over 17600 km² or 77 % of the original forests in the Eastern Arc Mountains have been lost (Newmark 1998). Based upon species-area relationships (Whitmore 1997) a loss of 77 % of the original forest in the Eastern Arc Mountains suggests that approximately 31 % of species in the Eastern Arc Mountains have become extinct or are in danger of extinction (Newmark, 2002). However, according to Newmark (1998) the figure could be much higher, if factors like small size of the remaining forest patches, the restricted geographic distribution of many species and the reluctance of many taxa to cross forest gaps are considered. Deforestation has also reduced ecosystem diversity (Newmark 2002) and affected many ecological systems (Lundgren 1980).

Forest fragmentation and degradation are also significant threats to the perpetuity of biodiversity in the region. The Eastern Arc Mountains are highly fragmented, where the median patch size of natural forest is 11.5 km² while the mean patch size is 56.6 km² (Newmark 2002). Forest fragmentation has adversely affected biodiversity by changing the relative size and isolation of the forest and altering the microclimates and rates of predation, pollination, seed dispersal and parasitism (Newmark 2002). Logging has been the primary cause of forest degradation. It has been noted that tree species richness, density, equitability and diversity declined roughly in proportion to the intensity of logging. Struhsaker (1997) reported that in heavily logged sites, tree species richness and density declined by 30-90 % and 24-84 % respectively in comparison to unlogged sites in Kibale Forest. Furthermore, Chapman and Chapman (1997) noted that tree growth rates were slower in heavily logged than moderately or unlogged sites.

Other threats to biodiversity include over-exploitation and bushfires. There is a long tradition for burning, and large areas on mountain slopes and high ridges are burned annually for various purposes such as honey collection, hunting, land preparation for agricultural activities and sometimes by arson. Fires limit the extent of the forests and lead to stunted growth (Struhsaker 1997), hence pose a remarkable problem for maintaining forest cover and quality (Decker 1994). Nevertheless, it is the increase in human population growth and the resulting activities to meet their various needs that have placed an immense pressure on natural resources, and has, as Martens (1995) and Lulandala (1998) have indicated, led to their misuse or abuse. Indeed, more research is needed to identify long-term and practical solutions to reverse the effects of humans on their environment in this vulnerable region.

Invertebrates, which comprise over 90% of the animal biomass of tropical rain forest (Wilson 1987, Samways 1993, 1994, Ghazoul and Hill 2001) are no exception from suffering the consequence of human caused perturbations. The problem is aggravated by the fact that most invertebrates in the region are undescribed, hence many taxa have been extinct or are in danger of extinction while not known to science. Therefore, calls have been made to place more emphasis on the conservation of invertebrates (Pyle *et al.* 1981, Wilson 1987, Samways 1993, 1994, Kremen *et al.* 1993, Wheeler and Cracraft 1997, Niemelä and Baur 1998, Niemelä *et al.* 2000) not only in light of the important functional roles invertebrates play in ecological processes, but also because of their early response to the impact resulted from different human activities, hence providing an early warning on the state of the environment and biodiversity in general. Because of this, invertebrates are currently widely used as tools in various studies, such as environmental impact assessment and assessment of disturbance levels for different forestry management practices (Niemelä *et al.* 1996, Niemelä 1997, Niemelä *et al.* 2000, NORPLAN 1995, 2001a, 2001b, 2001c, 2002, Nummelin 1989, 1992, 1996, 2001, Koivula 2001, Ghazoul and Hill 2001, Fimbel *et al.* 2001).

However, use of invertebrates as a study tool for determining the impact of anthropogenic activities and how such information can assist in attaining sustainable management of biological diversity is still lagging behind, especially in Eastern Africa. Some of the limitations include difficulties associated with sampling methods and taxonomic impediment (Gadagkar *et al.* 1990, Samways 1993, 1994, Ruokonen *et al.* 1997, Nipperes and Beattie 2001). Public perception impediment (Samways 1993) also contributed to the low utility of invertebrates in the design of various natural resource conservation strategies. Serious efforts are needed in East Africa to reverse this trend so that the success which have been attained in other regions through the use of invertebrates in conservation programs be realized also in East Africa. International initiatives and collaboration are vital in these efforts (MNRT 1999, Niemelä *et al.* 2000).

In order to address the broad issues presented above, the aim of this thesis is fourfold. First, to study different human activities threatening biodiversity perpetuity in an East African tropical rain forest (**I**). Secondly, to compare and test various insect sampling methods for biodiversity studies (**II, III**). Thirdly, to document invertebrate diversity and abundance in a case study, the Kihansi Gorge before and after commissioning of the hydropower plant (**IV, V, VI**). Finally, to study how invertebrates responded to different forestry management practices (**III**).

Results and discussion

In the following sections, I present and discuss the main findings of this thesis:

(1) Human activities were identified as being the major threat to biodiversity in an East African rain forest. Provision of alternative sources of livelihood and poverty eradication among people could ensure sustainability of natural resources (I, III, VI).

The livelihoods of the local communities surrounding the Udzungwa Scarp Forest Reserve depend on the diverse products accrued from it (**I**). Wood (mainly building poles, withies, fuelwood and tool handles), medicines, food (i.e. fruits, vegetables, edible stems and roots), and wildlife as well as honey are the important necessities sought from the forest almost on a daily basis by the local communities (**I**). Other minor products include rope, barks or leaves for making various items, roofing materials like grass, and a multitude of other utilities. There is also exploitation for commercial products such as sawn timber (**I, III**). Usually the seekers of commercial products come from outside of the local communities. In many cases the means of harvesting of the resources are unsustainable leading to uncertainty in the perpetuity of biodiversity. These forests are also main source for various rivers, which have often been dammed to generate hydroelectric power (**I, IV, V, VI**).

It is obvious that depletive losses to biodiversity in East African tropical forests are likely to escalate as the natural-resource-dependent human population continues to grow (Lulandala 1998). Moreover, poverty coupled with a lack of alternative sources of livelihood put in dilemma the efforts to reverse the trend. In order to conserve biodiversity, it is necessary to focus on poverty alleviation and meeting human basic needs through provision of various alternatives for survival. Diversification of local livelihood options could reduce human pressure on these biodiversity centres, leading to its improved conservation.

However, despite the different consequences of human activities on biodiversity (**I, III, VI**), the use of natural resources is necessary for improving

living standards of the people and for the development of the country in general. Now the question is: How can conservation and development be integrated? It is crucial that a balance between development and environmental conservation is sought. In this context what is required is sustainable development. This means achieving a quality of life that can be maintained for many generations and which is socially desirable, economically viable and environmentally sustainable (UNCED 1992, NEP 1997, Biodiversity in Development Projects 2001, WSSD 2002).

(2) Sampling efficiency of insects varied with sampling method, type of insect group sampled and habitat type sampled. Despite their limitations, sweep netting and pitfall traps provided useful information regarding the insect communities and their use are recommended especially in remote areas (II-VI).

Result showed that sampling efficiency varied with the type of insect group, sampling method, and habitat type sampled. Sweep netting collected 91%, 84%, and 82% of all sampled insect orders in the Kihansi Gorge's spray zone habitat, montane forest and riverine forest habitats respectively. Sticky and pitfall traps collected more or less the same numbers of insects (II). Sweep net samples of 800 sweeps gave consistent replicable results, separating different forest types from each other in terms of order richness (II, III).

Among the sampling methods used, light traps were the most expensive, followed by malaise traps. Cost, availability and ease in application of pitfall traps were among the merits of the method. Some disadvantages of sweep netting include time needed to sort through the specimens collected and the destruction of small and soft-bodied insect specimens. Despite these limitations, sweep netting was the most efficient method. This was in line with Wolda and Wong (1988) who found that sweepnetting produced 20% more species than other insect sampling methods.

In order to collect data that would yield meaningful information on the target invertebrate group, the proper use of sampling methods in appropriate habitats is very important. Moreover, topography, climate, human resources, cost of equipment, applicability and time constraints are important factors to be considered (II, Gadagkar *et al.* 1990, Finnamore *et al.* 1998). It is, therefore, important to ensure that the selected method will adequately collect appropriate data, which will answer the target question. For instance, one has to keep in mind that different sampling methods sample insects differently. Pitfall trapping is dependent on the activity of insects while sweep netting is a passive method from the insect's point of view. Collection of data 'for the sake of it' or 'just in case it proves useful' is unlikely to be either helpful or cost effective.

(3) Arthropod diversity and abundance was higher in the spray zone habitat before diversion of the Kihansi River flow for power generation. The effect of diversion of the river flow affected the spray zone considerably. Changes in Coleopteran diversity, abundance, and similarity were evident after commissioning of the hydropower plant (IV, V, VI)

It is well documented that in most cases loss of biodiversity is a major outcome of activities associated with damming of rivers for any purpose (Happold 1995, Alam *et al.* 1995, Berkamp *et al.* 2000). In order to predict possible impacts of the Lower Kihansi Hydropower Plant along the Kihansi Gorge, a checklist of environmental characteristics (NEMC 1997) was used. The spray zone habitat along the Kihansi waterfall in the Kihansi Gorge had higher arthropod diversity and abundance before diversion of the Kihansi river flow for power generation (IV, V, VI). The reason for this was that before commissioning the habitat was highly influenced by waterfall sprays that provided special microclimate, which apparently was conducive for the survival of highly specialized biota (IV, V, NORPLAN 1995, 2001a, 2001b, 2001c, Lovett *et al.* 1997).

Due to diversion of water away from the more than 700 metres high waterfall system into power generation plant, the mean discharge of water through the gorge declined from approximately 16 to 1.9 m³/s. This caused 95 % of the spray-dependent habitat not receiving natural water spray (Dorggat and Millege 2001). The consequence of this was a significant decline of Coleopteran species richness and diversity (VI). Some Coleopteran families such as Hydrophilidae, Languriidae, Meloidae and Mycetophagidae were not recorded at all after commissioning. However, this observation needs further research to examine, if their absence was due to environmental stress of the habitat as a consequence of the hydropower plant or due to other reasons such as a short sampling period or seasonal variation. Moreover, the results showed that different habitats in the Kihansi Gorge were not equally affected by commissioning of the power plant. The spray zone was the most affected (VI). This was apparently due to the environmental stress experienced after commissioning of the hydropower plant caused by change in the spray climatic regime and resource availability. The continuous water spray generated by the waterfall was responsible for maintaining special habitats with high biodiversity.

In general, the adverse effect of the diversion of the Kihansi river flow could have been averted if the concerned parties had taken serious measures early enough. This is because it is well known and documented that unless serious measures are taken, hydropower plants result in adverse impacts on biodiversity (Bergkamp *et al.* 2000, Sadler *et al.* 2000). Therefore, the proper and timely implementation of environmental impact assessment (EIA) is a prerequisite for the identification and implementation of effective mitigation measures. However, in the case of Kihansi the EIA studies were conducted concurrently with the plant construction activities. Therefore, it was difficult to integrate

research findings into the project design. Moreover, the problem was aggravated by short time scale provided for the studies and the failure of timely investigation on the spray zone during the main EIA (NORPLAN 1995), which was the most prone habitat to the effect of diversion of the river flow. This suggests that more efforts have to be focussed on ensuring that EIA plays its proper role in balancing development and biodiversity conservation.

(4) There was a difference in the structure of arthropod communities in four differently managed forest sites in the Kibale Forest, Western Uganda. A percentage similarity index showed lower variation of arthropod communities within habitat than between habitats. The differences of arthropod communities in managed habitats seem to grow greater when succession proceeded 15-25 years after management practices compared to adjacent unlogged forest (III).

The most common arthropod groups in the Kibale forest were Hymenoptera, Heteroptera, Coleoptera, Orthoptera, Lepidoptera, Araneae, Homoptera and caterpillars (mainly of Lepidoptera and some Symphyta larvae). These formed 95% of all arthropod fauna sampled from the forest floor vegetation. The forest management practices in Kibale had both a spatial and a temporal effect. Heavily selectively logged and exotic pine plantation sites contained different arthropod community, while lightly selectively logged and virgin forest sites, to some extent, shared the arthropod community structure. However, during ten years of succession, communities in managed forest sites seem to develop more distinct groups. Thus, as a result of heavy selective logging as well as clear-cutting and the planting of pines, the arthropod community in these habitats is apparently not returning towards the virgin forest community in Kibale Forest. This suggests that new types of communities are developing in all managed sites differing from that of the adjacent virgin forest.

It is argued that long-term assessments of ecosystem recovery from human caused disturbance and assessment of community resilience are needed for conservation planning and sustainable utilisation of resources. According to Mason and Putz (2001) natural resource harvesting techniques that aim at reducing harvest damage are among the most profitable for natural resource managers and the most beneficial for biodiversity conservation. Therefore, this kind of knowledge is urgently needed for putting in place harvesting systems, which would be in harmony with biodiversity conservation.

(5) The use of higher taxonomic levels of arthropods served the purpose for circumventing taxonomic impediments (II-V).

The efficiency of various sampling methods and effects of human activities on biodiversity were studied using higher taxonomic level than species (**II, III, IV, V, VI**). Use of higher taxonomic levels which is known as taxonomic sufficiency approach (Ellis 1985, Beattie and Oliver 1994, Pik *et al.* 1999, Nipperess and Beattie 2001, Wilkie *et al.* 2003) is the pragmatic concept of identifying specimens only to a level of taxonomic resolution necessary for achieving study objectives. Moreover, this approach is less labour intensive and low expensive than species-level sorting, and is also less demanding on available taxonomic resources (CBD 1996, Nipperess and Beattie 2001). Indeed, the approach is more suitable for developing countries like Tanzania where resources, expertise and knowledge of biodiversity are limited.

Several studies have been undertaken using this approach and some have shown that patterns in biodiversity at the species level are also evident at higher taxonomic ranks. For instance, Andersen (1995) and Pik *et al.* (1999) showed that patterns in assemblages of ants were essentially the same when species or genera were used. Nielsen *et al.* (1998) found the same to be true for families and species of rotifers, while William & Gaston (1994) reported that family richness was a good predictor of species richness for ferns, butterflies, passerine birds and bats. Also according to Kitching *et al.* (1993), Australian forest types can be distinguished based on the order-level diversity of canopy arthropods. Furthermore, Balmford *et al.* (1996a, 1996b) and Reid (1998) provided useful results through the use of higher taxa. In my studies, structure of insect communities in differently managed forest sites and efficiency of insect sampling methods could be distinguished by arthropods at the level of order (**II, III**). Also the effects of diversion of river flow could be detected both at order level of arthropods (**IV**) and family level of Coleopterans (**V, VI**). Therefore, results obtained by use of higher taxon serve and provide necessary information, which satisfy and answer question in mind.

Conclusions

There is no doubt that different human activities pose a major threat on biodiversity perpetuity. With present experience at hand, conservation efforts would not succeed, if there were no measures to ensure that human needs are met in one way or the other (**I**). Provision of alternative sources of income and poverty eradication would significantly reduce human pressures that threaten biodiversity, hence promote biodiversity conservation in global biodiversity hotspots.

The present study shows that most invertebrate taxa are affected to some degree by habitat disturbances, although not all taxa are adversely affected (III, VI). In order to acquire a better understanding on how invertebrate taxa are affected by different disturbances and to estimate the magnitude of biodiversity change (May 1986, Myers 1988) long-term studies on population trends and community dynamics are necessary. However, in a situation where such information is limited, short-term studies provide a clue on the impact of anthropogenic disturbances on invertebrates and biodiversity in general (III, VI) enabling appropriate measures to be taken sooner rather than later.

Although the present poor understanding of invertebrate responses to different human-caused disturbances makes it difficult to propose sound biodiversity conservation strategies, strong efforts must be made to ensure that economic development does not proceed at the expense of biodiversity, which is vital for all life on earth. Urgent improvement in our knowledge is needed in order to provide useful information for enhancing both better management of the environment and scientific oriented decision-making. Paragraph 103f of the Plan of Implementation of the Johannesburg Summit (WSSD 2002) calls for states to promote and improve science-based decision-making and reaffirm the precautionary approach in development projects as set out in principle 15 of the Rio Declaration on Environment and Development (UNCED 1992), which states: '... where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.' Therefore, actions have to be taken, and time for taking up the challenges is now.

Taking into consideration the commitment of governments of East Africa to the implementation of the Convention on Biological Diversity, long-term studies are required to enhance our understanding on how invertebrates respond to different human caused disturbances. International collaboration is a way to improve such understanding. The knowledge gained could be effectively integrated for the formulation of sustainable conservation strategies. Also development activities could be harmonized with nature conservation through the better conduct of EIAs. However, lack of legislative backing for various policies that recognize explicitly the need of EIA is a major limitation for enhancing effective environmentally sustainable development in the region. For example, the institute responsible for managing EIA in Tanzania (The National Environment Management Council - NEMC) fulfills only an advisory role, since it lacks legal power for enforcement.

It is strongly argued that efforts have to be made to ensure that EIAs are not used just as a rubber stamp for a project to be approved by a higher authority. Therefore, sealing of all environmental legislative loopholes leading to ineffective EIA are necessary. Treweek (1996, 1999) identified four most common legislative barriers to good practice in environmental impact assessment: (1) lack of requirement for strategic environmental assessment, (2)

lack of requirement for independent review, (3) lack of requirement for follow-up or monitoring, and (4) failure to include ecological considerations in indicative thresholds for environmental impact assessment. Moreover, Mwalyosi and Sosovele (2001) reported that proponents have rarely implemented findings of EIA studies and at the same time processes to conduct EIA studies were initiated too late. Therefore, it is important that the East African governments and Tanzania in particular ensure integration of EIA and project designs. They should also ensure that an independent authority according to the agreed terms of reference, reviews environmental impact statements. In addition, conduct of environmental impact assessments and the adherence to their recommendations should carry legal weight. Therefore, tighter wording of East African legislation to remove potential environmental loopholes is an urgent task. Unless these aspects are rectified, loss of biodiversity will continue despite the conduct of environmental impact assessments.

Since studies with invertebrates in the Kihansi Gorge have been concentrating on the Kihansi wetlands (IV, V, VI, NORPLAN 2001, 2002), it is strongly recommended that detailed studies on invertebrates' distribution and patterns be undertaken to cover the whole gorge. This is very important if ecosystem conservation is to be achieved (VI). However, due to high species richness, there is a need that epigaeic invertebrates be selected as bioindicators to enable effective monitoring studies. This is due to the fact that ground invertebrates are better habitat predictors than underground or aerial invertebrates (Koen and Crowe 1987, Kotze and Samways 1999). Selected indicator taxa should comply with properties of bioindicators and their selection criteria should not carry any personal influences. The Indicator Value (IndVal) method by Dufrene and Legendre (1997) and the Step-wise procedure according to McGeoch (1998) are strongly recommended for use since these methods minimize to a large extent personal influences on the selection process (Rainio and Niemelä 2003). Furthermore, it is not advisable to select just one indicator taxon, but several taxa reflecting different aspects of the monitored environment (Niemelä and Baur 1998, Dale and Beyeler 2001)

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