

The effect of illegal small-scale gold mining on stream macro-invertebrate assemblages in the East Usambara Mountains

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Abstract

An investigation of the effect of illegal small-scale gold-mining on stream macro-invertebrate assemblages in the East Usambara Mountains was conducted between August 5th and 20th 2013. Macro-invertebrate abundances, species richness and Ephemeroptera, Plecoptera, Trichoptera (EPT) abundances were compared among three river types (semi-natural, restored and active mining) using a Multi Factor ANOVA. We found that macro-invertebrate abundances, overall species richness and EPT (a group susceptible to anthropogenic disturbance) abundances differed among the river types with active mining rivers scoring the lowest results. In addition restored sites showed significantly higher values for these variables than active mining sites, suggesting that restoration (e.g. covering of digging location or afforestation) has a positive effect on stream macro-invertebrate assemblages. Our results also imply that illegal small-scale gold-mining may reduce macro-invertebrate abundance, species richness and EPT abundance, in the East Usambara Mountains.

INTRODUCTION

Background information

The East Usambara Mountains in Tanzania are part of a chain of the ancient Eastern Arc Mountains found in East Africa. Due to their old age (about 200 million years old), they have a unique fauna and flora with a high level of endemism and form part of the world's biodiversity hotspots (Kweyunga & Senzota, 2007). There has been much scientific interest in them and a number of studies have been conducted on the plants and animals inhabiting them (Hamilton & Bensted-Smith, 1989). The forests of the East Usambaras are facing threats such as fire spreading from surrounding farmlands, logging, gold mining and farmland encroachment, especially into ungazetted forests. Alluvial gold mining especially leads to a fast and profound disturbance of the rivers because gold diggers redirect the flow of the rivers and the mining can also lead to the exposure of heavy metals (e.g. mercury) or the release of other harmful substances from deeper within the substrate. Through media the East Usambara Mountains became famous for their gold and to stop the exploitation and nature degradation by foreigners and local people alike, the government declared mining as an illegal activity by 2004 and more than 30,000 people were evicted from the river sites. Some of the mined streams were restored by filling up the holes left by mining and planting trees suitable for the habitat. Nevertheless illegal gold mining is still conducted

in some streams with presumably a negative influence on the river ecosystems. Some of these streams drain into the Sigi River that provides water to the downstream users including subsistence farmers, rural areas as well as the city of Tanga with a growing population of over 250,000.

Macro-invertebrate communities provide considerable information about the ecosystem impairment as well as its health and are hence used as indicators of environmental degradation (Feio *et al.*, 2007). However, their sensitivity varies with different environmental stressors. For example Ephemeroptera, Plecoptera and Trichoptera are sensitive to water pollution and therefore, population changes of such indicator species may reflect environmental changes (Raburu *et al.*, 2009). The sedentary nature of the larval forms of these macro-invertebrates makes them good monitor species of environmental changes as they constantly encounter the changes in the aquatic media that they inhabit (Raburu *et al.*, 2009).

Of regional significance, studies have been conducted on how tea cultivation in the East Usambara Mountains impacts the adjacent stream ecosystems, showing that tea plantations negatively affect water quality by reducing the species richness of aquatic invertebrates (van Biervliet *et al.*, 2009). However, the effect of small scale gold mining on the macro-invertebrate community structure is poorly understood. Understanding the impact of illegal small scale gold mining in this river catchment is important for both the conservation of biodiversity and human welfare. The aim of this study is to examine the effect of small scale gold mining on macro-invertebrate assemblages in the East Usambara Mountains.

Objective

To determine the effect of illegal small-scale gold-mining on stream macro invertebrate assemblages in the East Usambara Mountains.

Hypotheses

- We expect to see lower species richness and abundance of macro-invertebrates in illegal gold mining sites compared to rivers that were not influenced by mining.
- We also postulate that species richness and abundance in restored riverine systems will be higher than in active mining sites.

MATERIALS & METHODS

Study site

The study was conducted during a field course between August 5th and 20th 2013 in the vicinity of Amani Nature Reserve, East Usambara Mountains, Tanzania (5°04-14'S, 38°31-40'E; 250-1,400 m asl; annual rainfall 2,000 mm; Bruen, 1989). A total of nine streams comparable in size and

morphology were selected. Out of these streams, three were attributed as restored, meaning that illegal mining was stopped and restoration measures have been conducted without any gold mining activities after the restoration (further referred to as “restored”). Another three streams were non-restored, meaning that illegal mining is still taking place (further referred to as “active mining”) and the last three rivers were categorised as semi-natural which have never been subject to gold mining activities or restoration (further referred to as “semi-natural”). These three categories will further be referred to as river types. On each stream two sampling locations were identified at a distance of 50 m from each other, where the upstream point was treated as a control of the downstream point.

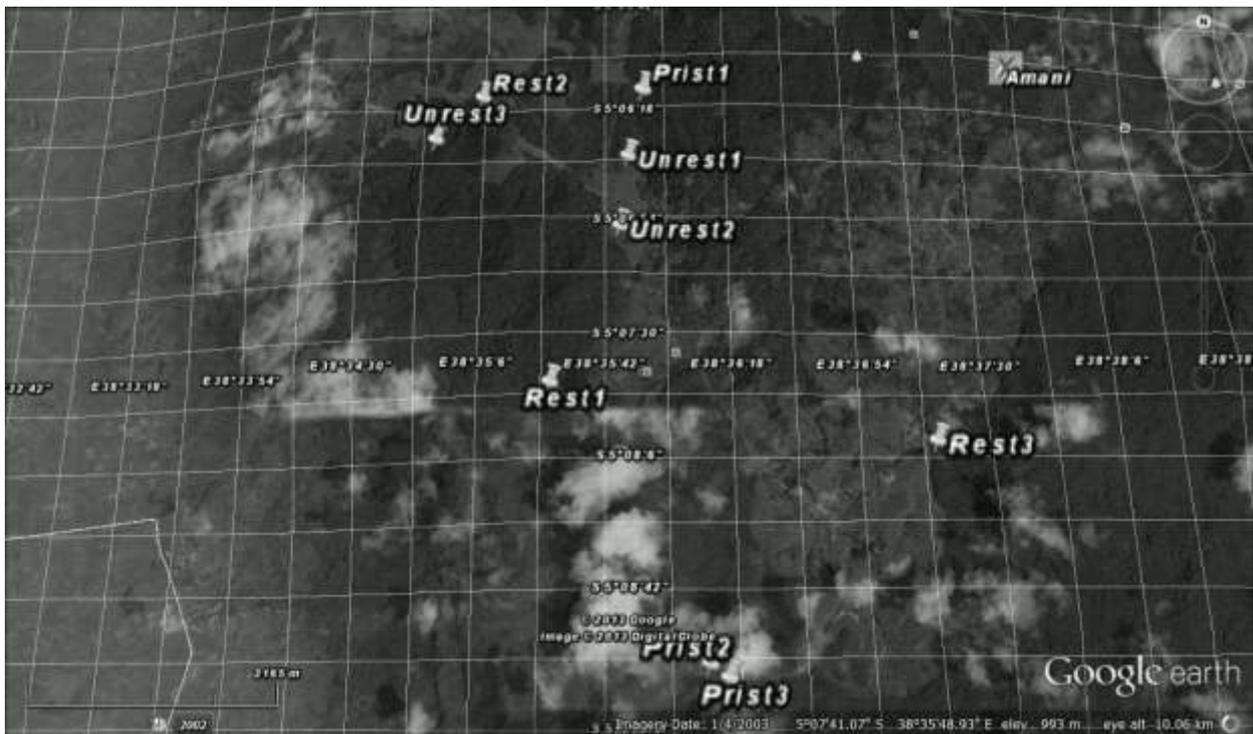


Figure 1. Study sites: Semi-natural (no mining activities: Prist 1, 2, & 3), Restored rivers (Rest 1, 2 & 3) and Active mining river (Unrest 1, 2 & 3) in the 5°07'35.61' S, 38°35'21.23' E; elevation 1,065 m asl.

Table 1. Types of rivers which were sampled and their current state (i.e. either Semi-natural, active mining or restored)

River name	State of the river	Initials used on the map	Latitude	Longitude
Turaco River	Semi-natural	Prist1	5° 6'15.13"S	38°35'52.45"E
Mvuleni River	Semi-natural	Prist2	5° 9'4.97"S	38°36'8.76"E
Kiganga River	Semi-natural	Prist3	5° 9'8.55"S	38°36'13.69"E
Mikwinini River	Restored	Rest1	5° 7'47.66"S	38°35'25.43"E
Ndola 8A plot River	Restored	Rest2	5° 6'17.52"S	5°6'17.52"S
Kihuhwi River	Restored	Rest3	5° 8'4.47"S	38°37'14.49"E
Ndola Falls River	Active mining	Unrest1	5° 6'36.79"S	38°35'47.95"E
Sangarawe water pump River	Active mining	Unrest2	5° 6'59.75"S	38°35'45.31"E
Ndola water pump River	Active mining	Unrest3	5° 6'32.42"S	38°34'50.55"E

Sample collection and processing

Determination of the physical and chemical variables

Prior to the collection of macro invertebrate samples, pH and water temperature were measured for each site (and recorded in situ) (Hanna water quality meter). Surface water flow was also determined by recording the time taken for a float to cover a known distance and multiplied by cross-sectional area (depth*width) to obtain flow rate (Moss, 1988). Canopy cover was measured by using a spherical densiometer (by Paul E. Lemmon).

Macro invertebrate sampling and sorting

Macro invertebrate samples were then collected using a dipnet frame (effective area: 0.0686 m²) for exactly 2 minutes per sampling site. The samples were put in plastic containers and transferred to the laboratory for further processing.

In the laboratory, all macro invertebrate samples were washed through a series of sieves (2 mm, 0.5 mm and 63 µm) to separate organic and inorganic materials from macro invertebrates. Macro invertebrates were sorted under a dissecting microscope, identified and counted. The identification was done using keys which were developed for South African inland waters (Davies, Day & King 1986) for family level identification and morphospecies were established for certain groups known to be good indicators of water quality (Ephemeroptera, Plecoptera, Trichoptera).

Data analysis

The data were analysed using a Multi Factor ANOVA (Statgraphics Centurion v.12 and R v.2.11.1) and all significant differences for all inference tests were accepted at 95% confidence level. Post hoc multiple range tests were used to test for differences among the river types. Variances were homoscedastic as tested with Levene's test.

RESULTS

Macro-invertebrate abundance in relation to different river types

The mean macro invertebrate abundance collected in the river types ranged between 65.67 – 176.33 individuals/sampling period (Figure 2). The highest mean abundance was recorded for the semi-natural rivers (176.33 ± 17.16 ind./sampling period, $n = 3$) with the lowest recorded for the active mining rivers (65.67 ± 16.00 ind./sampling period, $n = 3$). The river types differed significantly (Multi Factor ANOVA; $F_{(2,17)} = 8.87$; $p < 0.05$). Post hoc analysis indicated significant differences in abundance between semi-natural and active mining rivers (LSD test, $p < 0.01$) as well as restored with active mining rivers (LSD test, $p < 0.05$).

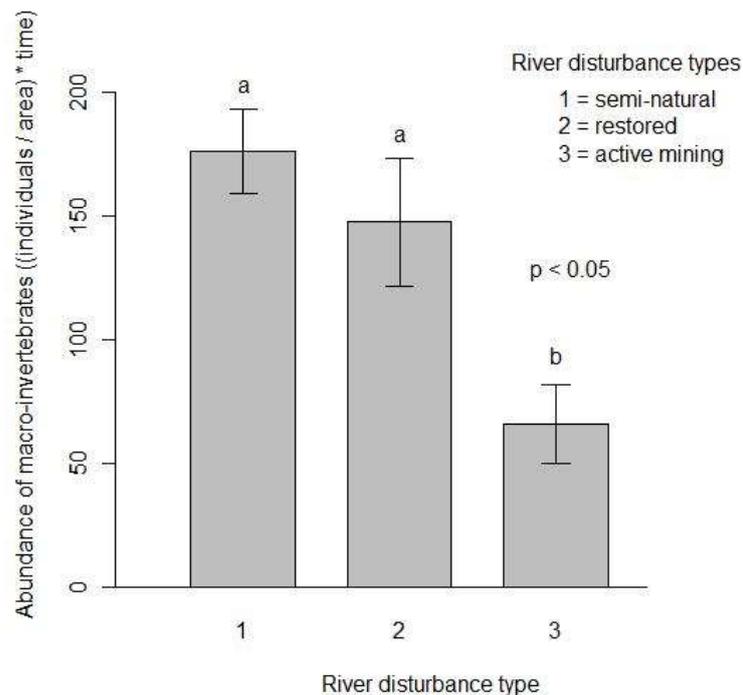


Figure 2. Abundance of micro-invertebrates in the different river types; means \pm SE, $n = 3$. Bars sharing the same letter notations are not significantly different from each other, $\alpha = 0.05$.

Macro-invertebrate species richness

Species richness differed among the river types (Multi Factor ANOVA; $F_{(2,17)} = 14.41$; $p < 0.05$). On average the restored streams had the highest species richness followed by semi-natural with the active mining sites following far behind (19.33 ± 2.47 , $n = 3$; 17.5 ± 3.44 , $n = 3$ and 9.17 ± 2.47 , $n = 3$ respectively). Post hoc analysis indicated significant differences in species richness between the restored and the active mining rivers (LSD test, $p < 0.05$), as well as the semi-natural and the active mining (LSD test, $p < 0.05$) (Figure 3).

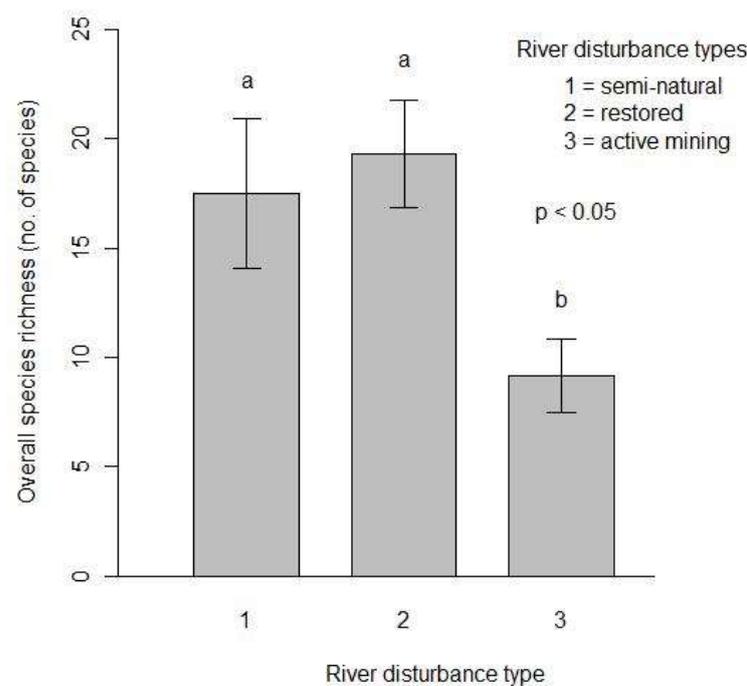


Figure 3. Macro invertebrate species richness among different treatments; means \pm SE, $n = 3$. Bars sharing the same letter notation are not significantly different from each other $\alpha = 0.05$.

Ephemeroptera, Plecoptera and Trichoptera abundance according to rivers

Ephemeroptera, Plecoptera and Trichoptera (EPT) are sensitive to water pollution and therefore, population changes of such indicator species may be reflective of environmental changes. From the results, high EPT abundance was recorded at the semi-natural rivers (65.67 ± 23.44 , $n = 3$) while the active mining rivers recorded the least EPT abundance (5.67 ± 2.43 , $n = 3$). There was a significant difference in EPT abundance between semi-natural and active mining rivers (Multi Factor ANOVA, $F_{(2,17)} = 4.73$ $p < 0.05$) (Figure 4).

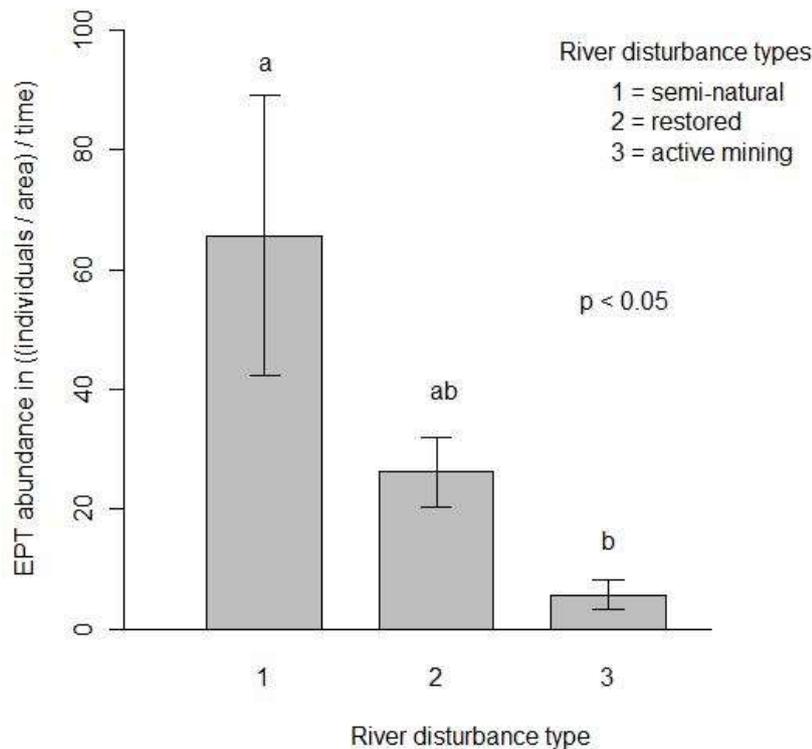


Figure 4. EPT abundance among different river types; means \pm SE, $n = 3$. Bars sharing the same letter notation are not significantly different from each other $\alpha = 0.05$.

DISCUSSION

Macro-invertebrate abundance in relation to different river types

According to Rosenberg & Resh (1993), human perturbations change community structure in watercourses because species are adapted to certain environmental conditions. Modifying species' distribution and abundance can change ecological processes in the ecosystems (Sharma & Rawat, 2009). For example, macro-invertebrate abundance differed significantly among the river types with the active mining streams having average abundances over 60% lower than the semi-natural rivers. This supports our first hypothesis that active mining sites support lower densities of macro-invertebrates. This could be attributed to the loss of habitat diversity such as ecological niche, food quality and protection from predators as a result of disturbance. Increased disturbance can lead to more severe drift events, thus reducing the local pool of potential colonists (Matthaei *et al.*, 1997).

Macro-invertebrate species richness

Macro-invertebrate species' richness often gives important clues of the functional status or health of aquatic ecosystems. The results indicate that macro-invertebrate species richness differed significantly among the river types. The highest species richness was observed at the restored streams and the lowest in the active mining streams (50% fewer species compared to restored

streams). This finding concurs with our hypothesis that macro-invertebrate species richness in restored riverine systems should be higher than in the active mining streams. According to the Intermediate Disturbance Hypothesis (IDH) high diversity occurs at sites experiencing moderate levels of disturbance due to competition hierarchy of species. At low levels of disturbance, more competitive organisms will push subordinate species to extinction and dominate the ecosystem (Dial & Roughgarden, 1988). At high levels of disturbance, all species are at risk of going extinct. This could explain why species richness is higher in restored than in non-mining sites. This conclusion has to be treated with care because we do not know if the IDH has been proven in stream ecosystems, as rivers are very dynamic ecosystems themselves.

Ephemeroptera, Plecoptera and Trichoptera abundance according to rivers

The EPT taxa have been treated as indicators for good water quality for a long time (Raburu *et al.*, 2009). Despite the difficulty to attribute ecological parameters (such as pollution, dissolved oxygen, pH) to whole orders of insects in terrestrial systems this approach is widely accepted for lotic freshwater systems. Some families such as the Caenidae (Ephemeroptera) or Hydropsychidae (Trichoptera) are known to be more tolerant to pollution but the vast majority needs high water-quality standards and therefore the EPT richness and abundance can be used as an overall measure of water quality. The results showed that EPT abundance was higher in semi-natural compared to active mining sites. This, as pointed out earlier, leads to the conclusion that water and habitat quality are higher in semi-natural rivers.

Conclusions

With the limited amount of time spent on this study and the few rivers compared it is already apparent that gold mining has a very high impact on river ecosystems in the East Usambara Mountains. Active gold mining reduces species abundances and richness and therefore it can be assumed that water quality suffers affecting both clean water supply for humans as well as suitable habitat for stream inhabitants as well as animals dependent on riverine ecosystems. Due to the high degree of endemism and the status as a nature reserve it is very important to protect these rivers from further degradation. Mitigating measures such as the restoration of main river channels, covering of the digging locations and afforestation with suitable tree species show very promising results and should be considered as preservation acts for a wider range of active mining sites.

ACKNOWLEDGEMENTS

First and foremost we wish to acknowledge the TBA for giving us the opportunity to be part of the students of 2013 in Amani Nature Reserve. Also our sincere thanks to the entire TBA team who were part of us. Special thanks to Prof Caroline Gross for supervision and proof reading. Last but

not least we want to thank Mr Sesiwa for valuable information concerning river locations, history of the area and assisting us in the field together with Paul.

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