A comparison of tea plantation and forest soil habitats in the East Usambara Mountains, Amani, Tanzania

Nuhu Daniel, Department of Wildlife Management, Sokoine University of Agriculture, Morogoro, Tanzania.

Colin Minto, Department of Zoology, Trinity College, Dublin, Ireland.

Abstract

An assessment of the effects of tea growing on soil habitat was carried out over a two-week period in the East Usambara Mountains, Amani, Tanzania. The study focuses on the habitat changes that occur in the soil when forest is cleared to make way for tea plantations. Results are given for the comparison of environmental and biological variables between three established tea and primary forest sites. Soils in the forested areas were found to support a greater organic layer depth, lower temperature variability, providing better habitat for microbial and invertebrate fauna. The resulting microbial activity and invertebrate diversity is increased indicating a healthier system. Soil nitrogen content is higher in the tea plantation, owing to continual fertilisation of the tea plantations. In light of the quantifications of the degree of soil habitat alteration that occurs in tea plantations, guidance is given for possible restoration.

Introduction

The East Usambaras are a range of low mountains close to the coast in the northeastern corner of Tanzania (Hamilton, 1989a). The forests cover an area of 45.2km^2 and form part of the Eastern Arc mountains The area has been of considerable interest for more than 100 years, and the first agricultural and biological research station in East Usambaras was established in Amani by the German colonial government in 1902. (Johansson and Sandy, 1996). The East Usambaras, as one of the most important elements of the Eastern Arc forests, are included in one of the global biodiversity hotspots (Myers 1988).

In the early and mid nineteenth century, the East Usambara Mountains were probably regarded primarily as land available for small-scale farming. Following colonisation, the Germans expropriated much of the land from peasants and encouraged the establishment of large plantations and a large proportion of the Usambara Mountains was issued as private concessions (Hamilton and Mwasha, 1989). Coffee was initially planted in many of these estates but was replaced with tea during the British colonial era (Newmark, 2002). Currently tea estates make about 6.6% of all agricultural land (2,363 ha) in East Usambara (Hyytiäinen, 1995).

When the forest is cleared for agriculture, the soil is relatively fertile and can initially give reasonable crop yields, but with time its productivity declines as nutrient reserves are depleted through a harvesting loss of organic matter, leaching and soil erosion (Hamilton, 1989a). Given the effect of agricultural activities on forests and soil in general and based on the length of time the tea plantations have been operating, this project aims at finding the effects caused by tea growing on the soil. Our study compares tea plantation soils, which are located in Derema, East Usambara, with adjacent forest soil. Several variables were measured; including nitrate concentration, pH, conductivity, microbial activity, temperature, and depth of organic matter layer so making possible a broad comparison.

Tea plantations have been operating for more than five decades and it is possible that further areas of forest might be cleared for tea growing. There is a need to assess their effects on soil structure, chemistry and biology. This study provides a critical analysis of the degree of habitat alteration with the expansion of agriculture into previously forested areas. In light of the findings proposals for possible mitigation measures will be discussed.

Materials and Methods

Study Sites

The study sites were all located at “Derema” tea plantation and adjacent forest. Three separate established tea plantations (>50 years old) with adjacent primary forest sites were selected for analyses. Five paired samples of each measurement variable (see below) were obtained from the tea plantation and forest soils at each site.

Environmental variables

The organic layer depth was measured as the depth of the surface soil (dark brown/black) above the underlying oxisol (red brown/yellow). Soil organic layer depth was measured using calibrated ruler. The temperatures, of the soils were all measured to a depth of 5cm using a soil thermometer. Soil ionic content was measured using a Hanna water conductivity meter. To make a readable dilution twenty-five grammes of soil was diluted in 75ml of low conductivity water to produce a 1:3 dilution. Soil nitrogen content was measured with a CHEMets K-6095 Nitrate Test Kit. This test is generally used to analyse water nitrate content but was here adapted to test for nitrate (NO_3^{-2}) content in the soil. Eight grams of soil were diluted in 30ml of water and shaken vigorously. The dilution was then filtered through paper filters and the resulting filtrate was then usable for the nitrate test.

Microbial activity

As soil microbes are generally aerobic and therefore consume oxygen it was decided that the rate of oxygen depletion would give an accurate estimate of microbial activity within the soil. A 50 g soil sample was added to a 150ml of water in a sealed container. Percentage oxygen saturation was measured using a Hanna oxygen meter. After initial observations of the rate of depletion it was decided that a measuring interval of two accurately hours over a 10-hour period was sufficient to measure the rate of depletion.

Soil invertebrate analysis

A 15 x 15cm wide and 3cm deep soil sample was obtained at each of the paired sites. Samples were labelled and stored in zip lock bags for analysis that day. A total of 10 samples was obtained for the tea plantation soils and 10 from the forest soils. The laboratory analysis of soil samples was done using a modified Berlese funnel. The funnel functions in the same manner as a Tullgren funnel; by using a strong light shone on a soil sample to force the invertebrate fauna to remove themselves from the light and heat and drop to the preservative (50% alcohol) below. Invertebrate samples were then identified to family level to estimate family diversity and abundance between the tea plantation soils and forest soils. The Shannon-Wiener species diversity index (equation 1) was adapted to provide an index of family diversity.

$$H' = -\sum pi \ln pi \qquad \text{(Eq. 1)}$$

where $pi = n_i/N$, where n is the number of individual species/family *i* and N is the total number of individuals in the sample.

Data analysis

All data analyses were done using the statistical software package *Minitab*. The statistical analyses used were:

- General linear model for testing between two or more factors.
- T-tests were used for testing between two factors.
- F tests were used to analyse variance.

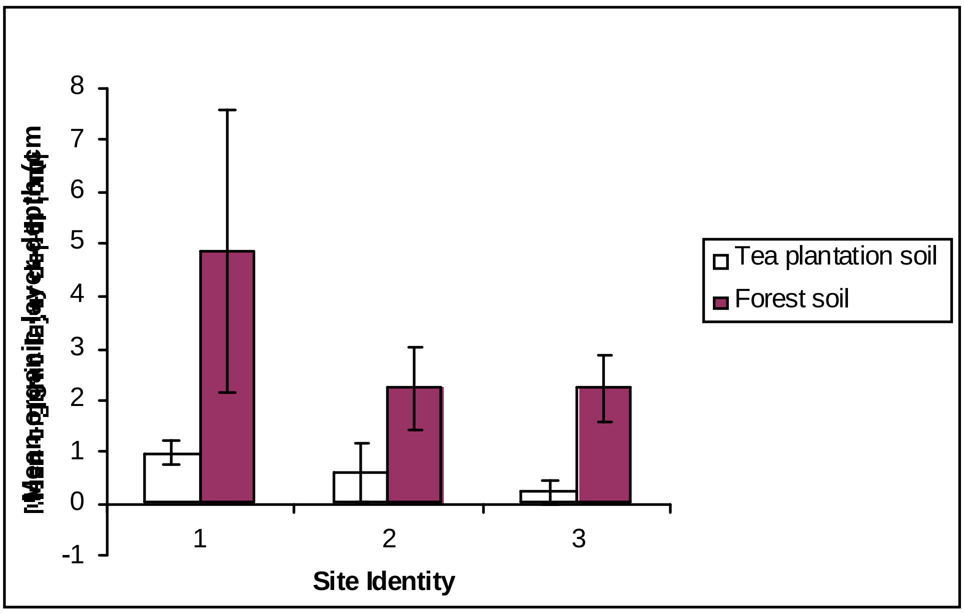
Graphs used to display data were created using *Microsoft Excel*.

Results

Environmental variables

Organic layer depth

The mean organic layer depth in forest soil (3.09 +/- 2.02) was significantly greater than that in the organic layer in areas of tea plantation (0.59 +/- 0.47cm SD), ($F_{1, 22} = 2.74$, $p<0.001$). There was a significant difference in mean soil depth between individual sites ($F_{2, 22} = 5.1$, $p<0.05$; Figure 1). The mean depth of forest soil at site 1 caused the difference. However, there was no significant difference in the interaction of soil type



and site ($F_{2,20}$ = 2.49, $p>0.05$).

Figure 1. A comparison of the mean organic layer depth (cm) for the 3 study sites in forest and tea plantation soils in Amani, East Usambara Mountains, Tanzania. N = 30 samples.

Temperature

Temperature also showed a highly significant difference. Forest soil temperature (mean = 12.23 +/- 0.32ºC SD) was lower than tea plantation soil temperature (mean = 15.53 +/- 2.05ºC SD), ($F_{1,22}$ = 44.6, $p<0.001$). The variation between soil temperature readings is an order of magnitude higher in the tea plantations than the forest soils ($F_{14, 14}$ = 41.0, $p<0.001$).

Conductivity

There was no significant difference in soil conductivity as a measure of ionic content between forest (mean = 77 +/- 20.17µS) and tea plantation soils (mean = 73 +/- 14.52µS), ($F_{2, 22}$ = 0.37, $p>0.05$). There was a significant difference in mean conductivity between sites ($F_{2, 22}$ = 2.74, $p<0.001$). There was no significant difference in the interaction between soil type and site ID ($F_{2, 20}$ = 1.59, $p>0.05$).

pH

Soils from the tea plantations and forest were both acidic. There was no significant difference between the pH of the tea plantation soil (mean = 5.27 +/- 0.26 log units) and the forest soil (mean = 5.21 +/- 0.39 log units), ($F_{1, 22}$ = 0.23, p=0.245).

Nitrogen

Soil nitrogen content was an order of magnitude higher in the tea plantation soil (mean N=1.73 +/- 1.44 mg/l) than in the forest soil (mean N= 0.48 +/- 0.30 mg/l). There was a difference in the mean nitrate concentration between the sites ($F_{2,9}$ = 15.69, $p<0.001$). The interaction between soil type and site shows that there is a highly significant difference in the interactions between the 3 sites ($F_{2,9}$ = 19.93, $p<0.001$) as shown in Figure 2.

Soil biological analysis

Microbial activity

Figure 3 shows the mean rate of oxygen consumption in tea plantation and forest soils. Oxygen consumption is a result of microbial activity. There was a greater microbial activity observed in the forest soil (mean rate of O_2 consumption = 0.0016 Log (%O_2) min^{-1} +/- 0.0015 SD) **than** in the tea plantation soil (mean rate of O_2 consumption = 0.00047 +/- 0.00021 min^{-1}), ($F_{1, 22}$ = 7.43, $p<0.05$).

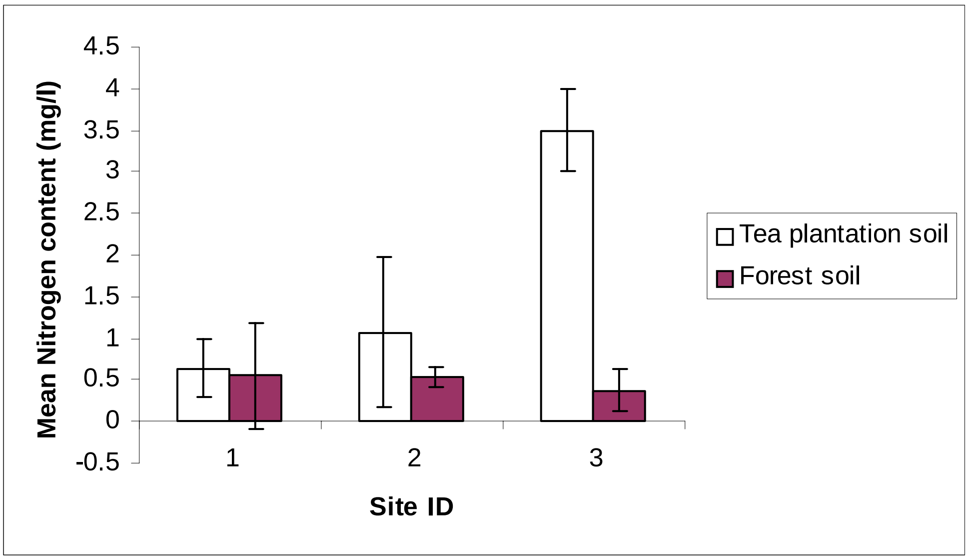


Figure 2. A comparison of the mean nitrogen concentration (mg/l) for tea plantation and forest soils in 3 study sites in Amani, East Usambara Mountains, Tanzania. N = 30 samples.

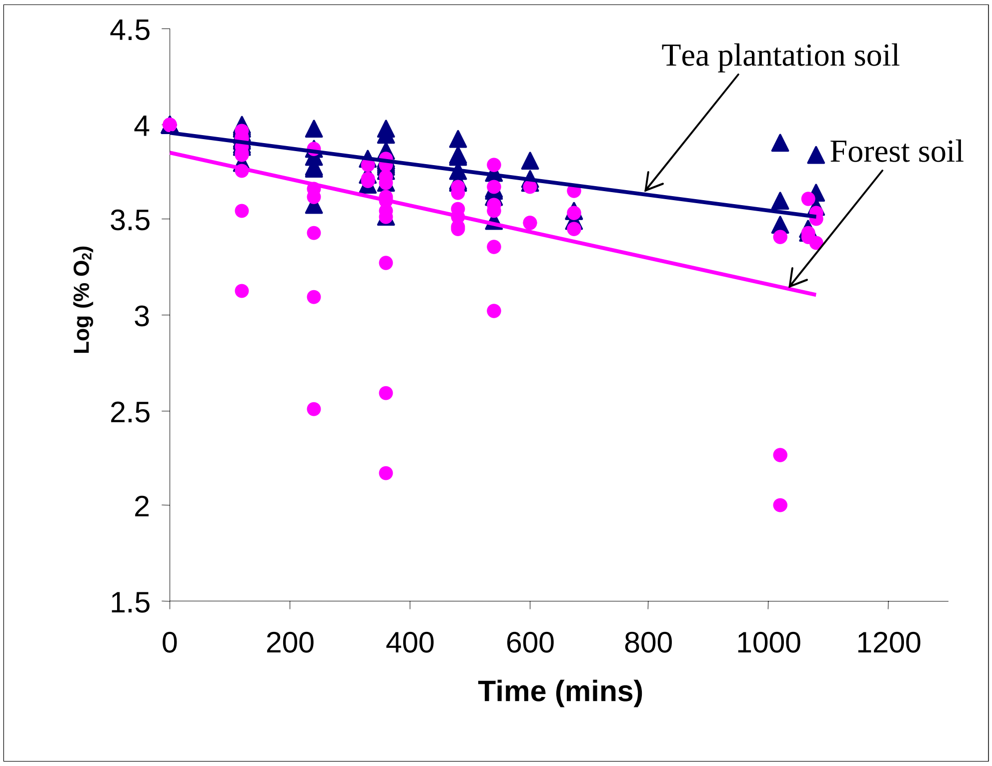


Figure 3. The relationship between oxygen consumption and soil type over time. N = 30 soil samples from East Usambara forest and tea plantation soils.

<u>Invertebrate composition</u>

A comparison of the invertebrate family fauna between tea plantation soil and forest soil is shown in Figure 4. Nine families of invertebrate were found in the soil samples from the tea plantation whereas there were 15 families present in the forest soil samples. Collembola were present in 70% of soil samples from the forest but were absent from the tea plantation soils. Also noticeable in their absence from the tea plantation soils were the Diplopoda, Isopoda, Aranae, Ponerinae and Lepidoptera larvae.

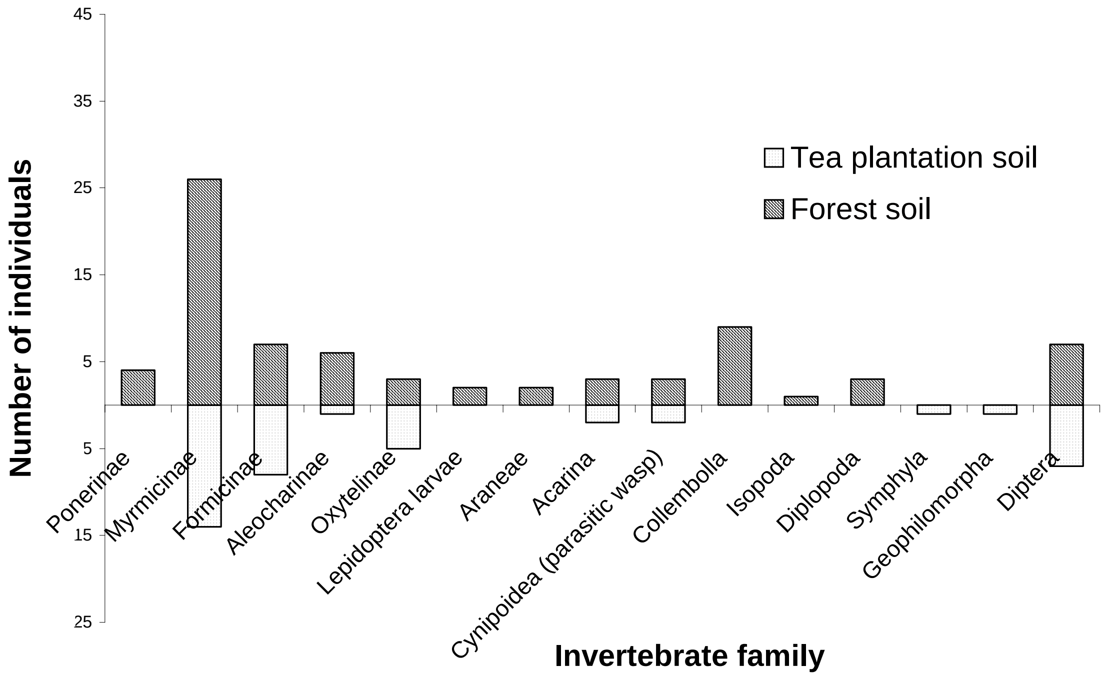


Figure 4. Invertebrate family distribution between forest soils and tea plantation soils. N = 20 samples from 3 sites in the East Usambara Mountains, Tanzania.

Calculations of the Shannon-Weiner species diversity index showed that the forest soils had a richer species diversity (*H'* = 2.17 +/- 0.11) than the tea plantation soils (*H'* = 1.81 +/- 0.18) ($t = 2.113$, d.f. = 18, $p<0.05$).

Discussion

Environmental variables

Organic layer depth

The organic layer depth was found to be deeper in the forest soil than in tea plantations soils. This difference could be owing to the amount of litter fall in the two sites. It is interesting to note that site three was on a steep slope, which may induce increased loss of organic matter with run off. This may reduce the amount of nutrients in the system and habitat heterogeneity. The organic layer is important for the protection of the underlying inorganic soil layer, reduces the chances of soil erosion and helps to conserve the soil moisture (Ewel *et al.*, 1981)

Temperature

Temperature was lower in the forest than in the tea plantations. This might be due to the effect of canopy which acts much in the same way as cloud cover in blocking sunlight. Another reason for the lower temperature in the forest might be due to the larger amount of organic matter present in the forest bed acting as a blanket against excessive heating by sunlight which is not the case with tea plantation soils. Tea plantation soils had high temperature that in turn may have several detrimental effects such as loss of the soil moisture that is important for soil plants and animals. Sharp increases and decreases in temperature occurred in the tea plantations which had a standard deviation of +/- 2.05°C compared with a forest soil temperature standard deviation of +/- 0.32°C. This may affect organisms' metabolic ability.

Conductivity

In analysis of soil ionic content no difference was observed. The soils are derived from very ancient Precambrian rocks that are poorly weathered. Therefore the soil ionic content is a consequence of ionic content of rainwater which is dominated by H^+, Na^+, Mg^{2+}, SO_3^{2-}, Cl^- ions. The same rain falls on the tea plantation and forest soils this is why a difference in ionic content is not observed.

pH

No difference was observed between the pH of the two sites and the pH was found to range from 4.82 to 5.53 which is approximately the same to the range stated by Anderson, 1963 who found that the soil pH in the East Usambara Mountains ranged from 4.95 to 5.25. This acidic range might be due to the fact that the wetter climate of higher altitudes results in greater leaching and a tendency for the ecosystems to accumulate more acidic humus (Hamilton, 1989b)

Nitrogen

Nitrogen analysis results showed that the amount of nitrogen is higher in tea plantation than in forest soils. This seems to be counter-intuitive to our knowledge of increased nutrient leaching with the removal of vegetation. N was expected to be higher in the forest than in tea plantations. The forest soil has low N because of withdrawal of minerals before abscission and according to Edwards (Undated) N concentrations in falling leaves were 15% lower than in healthy leaves and it seems they are withdrawn from senescing leaves. The high N in tea plantations might be due to slight accumulation of N from the rain and by microbial fixation (Edwards, Undated) or more likely it might be due to continual fertilizer input to support tea production. As there is continual human alteration we do not have baseline data of how agriculture removes N. It would have been interesting to have an area without fertilization to monitor how soil Nitrate is altered.

Soil biological analysis

Microbial activity

The difference in the rate of oxygen depletion over time may tell us a number of things about differential microbial activity between the two soils. Higher microbial density would contribute to a greater rate of depletion. It is therefore inferred that the forest plantation soils have a higher number of microorganisms per unit weight than the tea plantation soils. Facultive or obligate anaerobes that might occupy micro niches within the soil are not accounted for in our analysis. However, owing to the pervasiveness of gaseous oxygen in the surface soil they may only occur in waterlogged areas that were not encountered during this study.

From Figure 2 it is clear that oxygen is being consumed but without agar plates and staining it is impossible to infer what microorganisms are present and their importance in soil ecology. From previous research on soil microorganisms there are five groups of important soil microorganisms each with habitat requirements, as shown in Table 1.

Table 1. A summary of microorganisms present in soil, their requirements and subsequent importance in soil ecology. Table adapted from (Wild, 1994)

Microorganism	**Requirements**	**Importance in soil ecology**

Bacteria	Organic substrates (except Cyanobacteria)	Decomposition of most organic substances (enzymatic diversity)
Actinomycetes	Organic substrates & aerobic environment	Decomposition of organic material (especially in warm soils)
Fungi	Heterotrophic (mainly saprophytic on dead material)	Active decomposers of lignin & cellulose.
Algae	Phototrophic	Produce polysaccharide aggregation of soil particles.
Protozoa	Autotrophic and heterotrophic	Control of bacterial numbers

Using the above table it is possible to infer why the rate of oxygen depletion is different between tea and forest soils. Bacteria and other heterotrophs require organic substrates. In forested areas leaf litter fall has been measured as 30 tonnes per hectare per annum (Swift *et al.* 1979). Removal of leaves is the primary activity in tea plantations. This drop of input of leaf litter to the soil may reduce heterotroph populations. The fungi may also be affected in a similar way. Algae if present require moist conditions to prevent desiccation. In forest soils the organic layer and tree canopy serves as buffers against moisture loss. In the tea plantation this buffering capacity is removed (shown by the great variance in temperature) making the habitat unsuitable for algal growth. Protozoan populations within the soil require moist conditions also. Some are autotrophic but most are heterotrophic, feeding on bacteria. Both moistness and bacteria can be adversely affected in the tea plantation therefore populations of protozoa may decrease.

Soil organic matter decomposition is a successive process comprising complex interactions of groups of microorganisms. A change in any one of the components may alter the whole process. Although proven that tea growing does reduce the rate of microbial activity the explanations given above are speculative.

Soil invertebrate composition

The difference observed in family richness and abundance between the tea plantation and the forest soils is interesting. The effects of tea plantations on soil invertebrates are listed below;

Habitat heterogeneity

As the tea plantation is a monoculture, which is highly controlled, the habitat heterogeneity is reduced. Habitat heterogeneity provides many niches for greater species diversity. From Figure 4 it can be seen that some families are absent from the tea plantation soils whereas they are abundant in the forest soil. Collembola are regarded as important meso-fauna (0.1-10mm) in the decomposition of litter. As shown above, the litter input into the tea plantations is much lower than that of the forest soil. This may explain the absence of Collembola from the soil samples. There may be another explanation in that Collembola were not identified to species level and therefore we cannot distinguish between leaf litter and interstitial soil species. It might be that when identified to a species level, all Collembola from the forest come from the surface litter rather than interstitially in the soil.

Temperature regimes

Variance in the tea plantation was high. Any invertebrates that are sensitive to changes in temperature may find it difficult to survive in the tea plantation. This inference could be analysed in a laboratory experiment testing the optimum and maximum temperatures that the families tolerate and comparing the results with the observed family richness.

Food web alteration

The loss of invertebrates and microorganisms may also disrupt food chains that exist within the soil. By altering the availability of food, families that depend on the resource would be diminished. For example it can be seen in Figure 4 that families, which depend on leaf litter, are noticeable in their absence from the tea plantation (Diplopoda, Collembola, Isopoda).

Further inference on the patterns and differences between invertebrate species abundance in the tea and forest plantation would require identification to a species level accompanied by a detailed analysis of their requirements and importance in soil ecology.

Conclusion

With the alteration of forest to tea plantation large changes occur in the nature of the habitat. Temperature becomes variable, reducing moisture content and organic layer depth decreases, reducing food availability. Soil microbial activity is slowed and invertebrate richness decreases. Habitat heterogeneity is lost. The data presented here attempt to quantify these habitat alterations. If it is known how altered a habitat is, guidance can it can be given on what is needed to restore it.

Under the hypothetical situation of the restoration of a tea plantation to forest what would be required? Most of our results can be summarised as the loss of habitat heterogeneity. Native vegetation must therefore be planted in these areas. As the nitrate levels are generally low (Fig. 2, site 1 & 2) native leguminous trees would be beneficial to provide nitrogen. It is doubtful that the tea plantations support a native seed bank owing to their longevity and controlled nature but most of these tea plantations are bordered by native forest, which given time would return to a natural state. Leaf litter would accumulate in an organic layer and gradually restore the forest microbial and invertebrate activity.

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