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Research Article

An elevational gradient in litter-dwelling ant communities in Imbak Canyon, Sabah, Malaysia

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ABSTRACT. The predicted effect of climate change across a range of taxa is currently a hotly debated topic. There is a pressing need to learn more about how animals and plants respond to climatic change in their surrounding habitats. A commonly used approach is to link changes in the taxon of interest to elevational gradients, where communities under a range of climatic conditions can be sampled in a small area. We conducted an elevational study of ant communities in the Imbak Canyon Conservation Area. The objective of the study was to investigate changes in ant species richness, abundance and composition along an elevational gradient from 300 m to 1,100 m a.s.l. with sampling points spaced at 100 m elevational intervals. We also measured litter depth to assess whether this factor affected ant communities within each elevational band. Over a total of 1,296 trap-hours, we collected 1,002 individual ants from 41 genera and 116 species. Ant species richness decreased with increasing elevation, as has been found for other invertebrates. However, there were no changes in ant abundance or species composition along the elevational gradient. Our results indicate that the ant communities within this area may be relatively robust to increasing temperatures. Further studies in similar habitats and environments should be carried out in order to reveal the consistency of these results across the region and to investigate changes in ant contribution to ecosystem functions at different elevations.

Keywords: Formicidae, climate change, rainforest, heath forest, pitfall trap, elevational gradients.

INTRODUCTION

Climate change is one of the most pressing threats to biodiversity on Earth, potentially affecting a wide range of taxa across many geographical regions (Bellard *et al.,* 2012; Chown *et al*., 2010). This is especially true in the tropics, where animals and plants are closer to their thermal limits than in temperate zones (Deutsch *et al*., 2008; Ghalambor *et al.,* 2006). The fact that tropical rainforests are highly

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diverse makes it even more urgent to document the effects of changes in climate.

There has been extensive work using latitudinal and elevational gradients in animal and plant composition to predict the effects of climate change on biotic communities (Condamine *et al.,* 2012; Deutsch *et al.,* 2008; Tewksbury *et al.,* 2008). The general conclusion of this research has been that there are more species in lower latitudes than higher latitudes, and that these species are more vulnerable to climate warming, even once other factors such as phylogenetic history and ecological traits have been taken into account (Diamond *et al.*, 2012). Comparably, higher elevations also tend to contain fewer species than lower elevations (Beck & Kitching, 2009; Kumar *et al.,* 2009; Hillebrand, 2004).While the drivers of these diversity patterns are not yet entirely clear, gradients in climate are very likely to play a role, hence the use of latitudinal and elevational gradients as surrogates for climate change through time (Botes *et al.,* 2006; Taylor *et al.,* 1999).

Ants have been among the most successful groups of animals since they began to expand and diversify in the Late Cretaceous and Early Eocene: a period that coincided with the rise of the angiosperms and the major groups of herbivorous insects (Moreau *et al.,* 2006). They occur in nearly all terrestrial habitats, occupy a wide range of ecological niches and consequently play important roles in providing ecosystem services and maintaining ecosystem stability (Wilson, 1987).

Because of their importance to the stability of ecosystems, it is imperative that ant distributions across gradients of latitude and elevation are known. This will allow for the assessment of the vulnerability of ant communities to climate change. In particular, it is vital to discover whether ants are still able to maintain the ecosystem services that they provide in a changing climate. Ants are generally thermophilic (Dunn *et al.,* 2007), with diversity declining further away from the equator (Dunn *et al.,* 2009), and with increasing elevation (e.g. Bruhl *et al.,* 1999). According to a recent study by Diamond *et al.* (2011), ants at lower elevations have a smaller thermal buffer, making them more sensitive to climate warming. Lowland tropical species are therefore likely to be most sensitive to climate change.

To date, there has been relatively little research carried out in Sabah on elevational changes in ant communities, apart from work by Bruhl (1999); Malsch *et al.* (2008) and Mohamed (1998). All these studies have been conducted at a single site: Mount Kinabalu. With increasing elevation, they found a monotonic decrease in species richness. Whether this pattern is consistent across other mountains in the same region or whether the more commonly found mid-elevational peak in species richness seen in many other taxa (Stevens, 1992; Colwell & Lee, 2000; Cardelus *et al.,* 2006) is present, is not currently known.

Here we present data from an expedition to Imbak Canyon, Sabah, Malaysia, on ant species diversity and composition along an elevational gradient. The area surrounding the canyon is newly explored and there have been only two previous expeditions to the area (in 2004 and 2010). Our study was the first to record ant diversity and elevational changes among ant communities within this area.

MATERIALS AND METHODS

Fieldwork was carried out in the forest near Gunung Kuli Research Station, Imbak Canyon, Sabah, Malaysia (5.04N, 117.06E) between 13 and 20 June 2011. The Imbak Canyon Conservation Area covers an area of 30,000 hectares and is a Class I (Protection) Forest Reserve, conserved as a watershed and for the maintenance of stability of essential climatic and other environmental factors. Sampling was carried out along the “Ridge trail” which follows the main ridge to the west of the research station. The trail is approximately 10 km long and passes through a lowland mixed dipterocarp forest before entering the lower montane heath forest above 1,000 m a.s.l. The climate in the interior of Sabah in mainly aseasonal, with an average annual rainfall of 2,669 mm and average annual temperature of 26.7°C recorded at the lowland dipterocarp rainforest at the nearby Danum Valley Field Centre (Walsh & Newbery, 1999).

Pitfall trapping for ants was conducted at intervals of 100 m elevation from 300 m to 1,100 m a.s.l. (nine different elevations). At each point, two pitfall traps were placed at a horizontal distance of 56 m from each other with the trail as the middle point (the total number of pitfall traps per elevation was limited by the length of the expedition). A total of 18 pitfall traps (nine pairs) were put in place for 72 hours (1,296 trap-hours).

The pitfall traps used in this research comprised a 500 ml bottle, a funnel of 19.5 cm diameter, and four wooden sticks of approximately 30 cm in length, to which a plastic cover was tied to shelter the trap from rain (Figure 1). A hole was dug and the bottle, with c. 150 ml of 70% alcohol added, was placed in the hole and the funnel was inserted into it such that the funnel rim was level to the ground. Earth was packed around the gap between the funnel edge and the ground to increase trapping efficiency. The four sticks supporting a plastic cover were then stuck into the ground to cover the funnel. This pitfall trap design is identical to those that are being used in the nearby Stability of Altered Forest Ecosystems project (SAFE), one of the largest forest fragmentation experiments in the world (Ewers *et al.,* 2011).

Litter depth (cm) was measured in three different locations at approximately 30 cm distance from each other, with the pitfall trap as the centre point. An average was taken to represent litter depth for each site.

Changes in species richness and abundance across different elevations and litter depths were tested using General Linear Models. The effects of elevation and litter depth on species composition were measured using Canonical Correspondence Analysis. Analyses were carried out in R Statistical Analysis Packages (R Development Core Team 2010) and CANOCO 4.5.

RESULTS

A total of 1,002 ants from 10 subfamilies (41 genera, 116 species) were collected (Table 1). The sub-family Myrmicinae represented

Figure 1. A pitfall trap showing the funnel, plastic sheet and four wooden sticks. A bottle containing alcohol was placed under the funnel. Note the hole cutter (candak) that was used to dig the pitfall trap.

51.7% of the total species, followed by Ponerinae (18.1%), Dolichoderinae (12.9%) and Formicinae (8.6%). The remaining sub-families accounted for 6.9% of the total species number.

Ant species richness decreased with increasing elevation, but did not change with litter depth (Elevation: T=-2.47, P=0.026; Litter depth: T=-0.025, P=0.803). Ant abundance was not affected by either elevation or litter depth (Elevation: T=-0.57, P=0.575; Litter depth: T=-0.32, P=0.752; Figure 2). There was also no effect of either elevation or litter depth on species composition (Elevation: F=1.164, P=0.185; Litter depth: F=0.964, P=0.446; Figure 3).

DISCUSSION

The number of ant species declined as elevation increased from 300 m to 1,100 m a.s.l. Based on fitted values from the linear regression, mean species richness decreased from 16.4 to 8.9 (-46%) per pitfall trap from the lowest to the highest elevation. This represents a loss of 0.9 species per 100 m increase in elevation. However, there was no change in abundance or species composition. This pattern of negative relationship between species richness and elevation is consistent with that found in many other studies on insects (McCoy, 1990; Beck & Kitching, 2009; Kumar *et al.,* 2009; Machac *et al.,* 2011).

There is no evidence of a mid-elevational peak in species richness in this study. The same results are shown by Bruhl (1999) and Malsch *et al.* (2008) who conducted studies in Mount Kinabalu from elevations of 560 m to 2,600 m a.s.l. (Bruhl, 1999) and 580 m to 1,520 m a.s.l. (Malsch *et al.,* 2008) despite the existence of a mid-elevational peak in diversity of vascular plants within the same sampling area (Grytnes & Beaman, 2006). In an elevational study carried out by Samson *et al.* (1997), a mid-elevational peak of ant species richness was found at 400 m a.s.l. However, this result may have been due to the lower elevation site (200 m) being in a different location to the rest of the sampling points. Mid-elevational peaks of insect diversity are often associated with short-term, and therefore incomplete, sampling with one proposed explanation being that

Table 1. Species of ants collected from Imbak Canyon at nine different elevations (300m a.s.l to 1100 m a.s.l). Numbers in brackets denote species richness for the specified genera.

Subfamilies	Genus
Aenictinae	*Aenictus (1)*
Amblyoponinae	*Prionopelta (1)*
Cerapachynae	*Cerapachys (2)*
Dolichoderinae	*Dolichoderus (6), Euprenolepis (2), Loweriella (2), Nylanderia (5)*
Ectatomminae	*Gnamptogenys (3)*
Formicinae	*Acropyga (1), Camponotus (3), Oecophylla (1), Prenolepis (1), Pseudolasius (4)*
Leptanillinae	*Leptanilla (1)*
Myrmicinae	*Cardiocondyla (1), Carebara (4), Cataulacus (1), Crematogaster (3), Lophomyrmex (2), Monomorium (2), Myrmecina (1), Myrmicaria (1), Pheidole (18), Pheidologeton (2), Proatta (1), Pyramica (3), Rhopalomastix (1), Solenopsis (1), Strumigenys (6), Technomyrmex (2), Tetramorium (7),*
Ponerinae	*Cryptopone (1), Diacamma (1), Harpegnathos (1), Hypoponera (2), Leptogenys (7), Odontoponera (1), Pachycondyla (4), Ponera (4)*
Proceratiinae	*Discothyrea (2)*

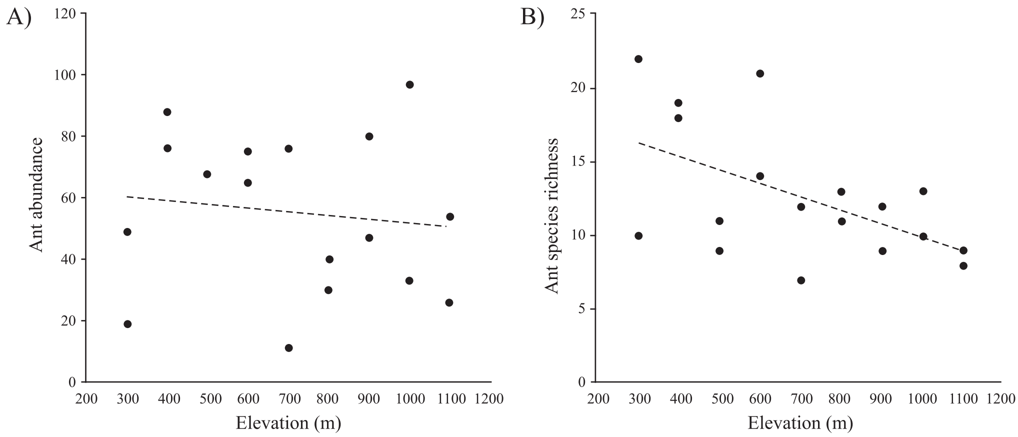

Figure 2. Ant abundance did not change with elevation (A), whereas ant species richness decreased (B). Neither abundance or species richness changed with litter depth (data not plotted).

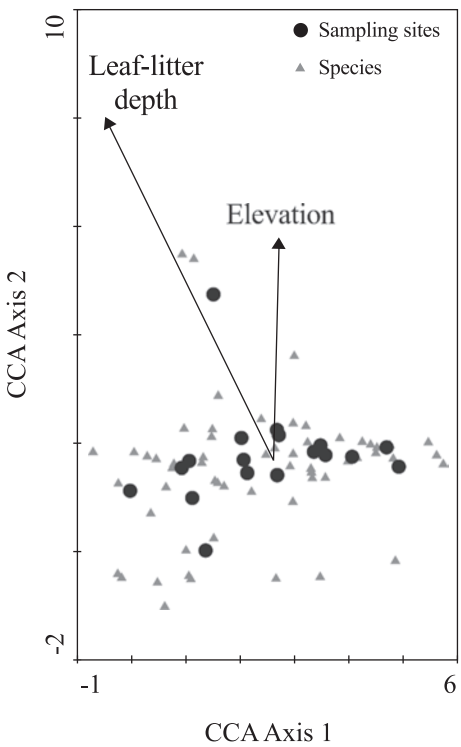

Figure 3. There was no effect of elevation or leaf litter depth on species composition, (CCA, 1000 permutations for environmental variables).

turnover in space or time is higher at lower elevations. This could result in species pools being incompletely sampled at lower elevations (McCoy, 1990). If this is the case, it would indicate that our sampling was sufficiently intensive for a representative species assemblage to be collected at each elevation.

One reason for the decline of species richness in this study is probably the change in vegetation from a lowland mixed dipterocarp forest to a heath forest. A study previously conducted by Andersen (1986), although not carried out along an elevational gradient, showed that there were twice as many ant species in a *Eucalyptus* forest than in a heath forest. This is probably due to lack of nesting sites and food resources in the heath forest (Malsch *et al.,* 2008). Another factor that may influence changes in species richness we observed was the microclimate, in this case mainly lower temperature and higher humidity at higher elevations (Bruhl, 1999). The same patterns of species richness declining with elevation caused by changes in temperature has been shown by Machac *et al.* (2011) in three different mountainous areas in North America with elevation ranging from 379 m to 2,600 m a.s.l.

Despite changes in species richness, there was no change in abundance of ants from low to high elevations within our study area. This indicates that the colony size is larger at higher elevations (Machac *et al.,* 2011). Such a result is in accordance with Bergman's rule, which states that at higher latitudes or elevations, animals evolve larger body sizes in order to be able to more closely thermoregulate their body temperature (Blackburn *et al.,* 1999). A study carried out by Kaspari &Vargo (1995) showed that colony size (being the measure of "body size" for a whole ant colony) follows Bergmann's rule. They found that ant colony sizes increase by an order of magnitude from the tropics to temperate areas. However, Geraghty *et al.* (2007) found that although ant species with higher latitudinal ranges can tolerate higher elevations, there was no evidence for Bergmann's rule. An alternative explanation might be that climate limits the number of species able to survive at higher elevations, and therefore the remaining species are released from competition and are able to produce more workers.

There was no significant change in species composition with elevation, meaning that very few species are unique to particular elevations, indicating that the ant communities at this site will cope reasonably well with any changes in climate. This is despite the prediction that ants in tropical forests are at the highest risk of going extinct compared to those in colder regions (Diamond *et al.,* 2011). This might also be the case if lower elevations become uninhabitable from clear cutting, logging and the expansion of oil palm plantations (Achard *et al*., 2002; Sodhi *et al.,* 2010; Turner *et al.,* 2009, Fayle *et al.,* 2010). However, more subtle differences in community composition with elevation might not have been detected using our sampling protocol, since only two pitfall traps were used at every elevation. Furthermore, because a shift of climatic bands up the side of the canyon would result in smaller population sizes for the ant species present (since there is a lower density of species at higher elevations), it is possible that there are longer term extinction risks for some of the rarer species.

In conclusion, ant species richness decreases monotonically with increasing elevation, although there is no change in abundance and species composition. This result suggests that ant communities within this area will be relatively robust to increasing temperatures, although possibly will become more vulnerable due to smaller population sizes in the future, either from climate change or from habitat alteration and degradation. There is a need to sample across wider geographical and elevational ranges in order to reveal the generality of these patterns. Moreover, there is also a pressing need to determine changes in ant contribution to ecosystem functions in relation to changes in community structure with elevation.

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