Correlation between higher altitudes and endemic plant species

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Abstract

Plant species do not have an even distribution or species richness over the earth. This can be influenced by many factors, like topography. Especially tropical areas have a high species diversity presumably correlating with the high temperatures and high humidity. Some species are widespread (non-endemics) others only occur very locally (endemics). Could there be a correlation with altitude? This was done by comparing the altitudes of non-endemic and endemic plant species of the islands New Guinea and Borneo. On both islands a trend between altitude and non-endemic or endemic species was found. The number of non-endemic species decreases with increasing altitude. The endemic species of New Guinea have a positive correlation with the altitude; they are relatively more abundant on higher altitudes. The endemic species of Borneo have a negative correlation with the altitude, but compared with the non-endemic species they are more present on higher altitudes, their decrease is far less with increasing altitude. If endemic species are the result of recent speciation, then mountains, by whatever mechanism, catalyse speciation.

Introduction

Species are not evenly distributed on the surface of the earth. Many aspects influence the species richness and distribution. This has led to more than 30 different evolutionary and ecological hypotheses for the account of species richness and diversity gradients have been proposed over the last decades (Hawkins *et al*., 2003; Aliabadian *et al*., 2007). Habitat heterogeneity is one of them. It describes areas that do not have an uniform composition. These environments usually can support more complex and diverse biological assemblages (McClain and Barry, 2010).

Many factors may account for the heterogeneous nature of an environment, e.g. sediment type, topography, temperature, moisture and vegetative complexity. All these factors can create multiple niches (McClain and Barry, 2010) which may lead to differentiation, within taxa, like local, phenotypically different populations that may develop into endemic taxa (Walters, 1976; Triponez *et al*., 2013). These endemic species are narrative to and restricted to a single area. And by this specialisation, the essence of evolution, the production of new forms of life, species that differ from their ancestral populations (Kricher, 2011).

"Endemism tends to follow biogeographic boundaries determined by geographic factors and evolutionary history" (Sekhran and Miller, 1994). Biogeographic distribution studies usually compare the occupancy of an area. They try to show a relation between areas. And it can be very useful to demonstrate an interrelationship between endemism and areas (Henderson, 1991).

Yuan *et al.* (2005) described the connection of the paleotropic regions around the Indian Ocean Basin as an outstanding area as a key topic in the biogeography of plants and animals of the world. Basically this is due to the firmly established and well-documented geological history of this region. Because the Malayan Archipelago is part of the ring of fire. This is still a tectonic active region and it hosts the largest group of islands in the world. The movement of the islands is not firmly established, Hall (2009, 2012) has many theories over this region, how the islands moved and when the landmass came to existence.

There are in total nine different areas, all separated from each other by a natural barrier. In these nine areas many endemic plant species are present (van Welzen *et al*., 2011). This makes it ideal for biogeographic research. For this research plant species of two islands of the Malayan Archipelago are used, New Guinea and Borneo. Both islands are well known for their high biodiversity and relative high ratio of endemism.

New Guinea, this island lies on the boundary between the Indo-Australian and Pacific plates and is part of the ring of fire. Tectonically still very active (Johnson, 1976). The main island consists of over 30 terranes that collided with each other. In the middle of the island lies the huge Central Cordilla, with the highest peak around 4800 m, this formed after the collision of the Australian and Asian plates. This all took places when the southern part of New Guinea was still part of the Australia plate. The northern part of the island consists of several microplates. The plants higher in the mountains are mostly related with Southern derived plant families, while the plants of the low lands have more in common with the Northern derived plants (Paijmans, 1976).

Borneo has from the middle to the North of the island a few mountain ranges. The upper Northern part, the Crocker Range, is the most well studied place of Borneo as Mount Kinabalu is part of it. A well-known mountain for its expeditions but also for its high biodiversity. And with its 4095 m height, it is also the highest peak of Borneo. Originally the island is part of the Sunda plate (Tjia, 2012), though it is composed of varies united microplates.

Barthlott et al. (1996) published a study about the global species diversity of vascular plants and they found a significant high amount of biodiversity in the tropical areas, see fig. 1. Some of these high biodiversity places are correlated with cordillera areas. This raises the question of endemic plant species occur more often on higher altitudes than non-endemic species. Could there be a correlation between higher altitudes and endemism?

Van Welzen *et al*. (2003) showed that there is a high ratio of endemic species on higher altitudes in New Guinea. It can be expected that there will be more endemic species on higher altitudes in New Guinea. As well on Borneo, more endemic plant species on higher altitudes than non-endemic plant species.

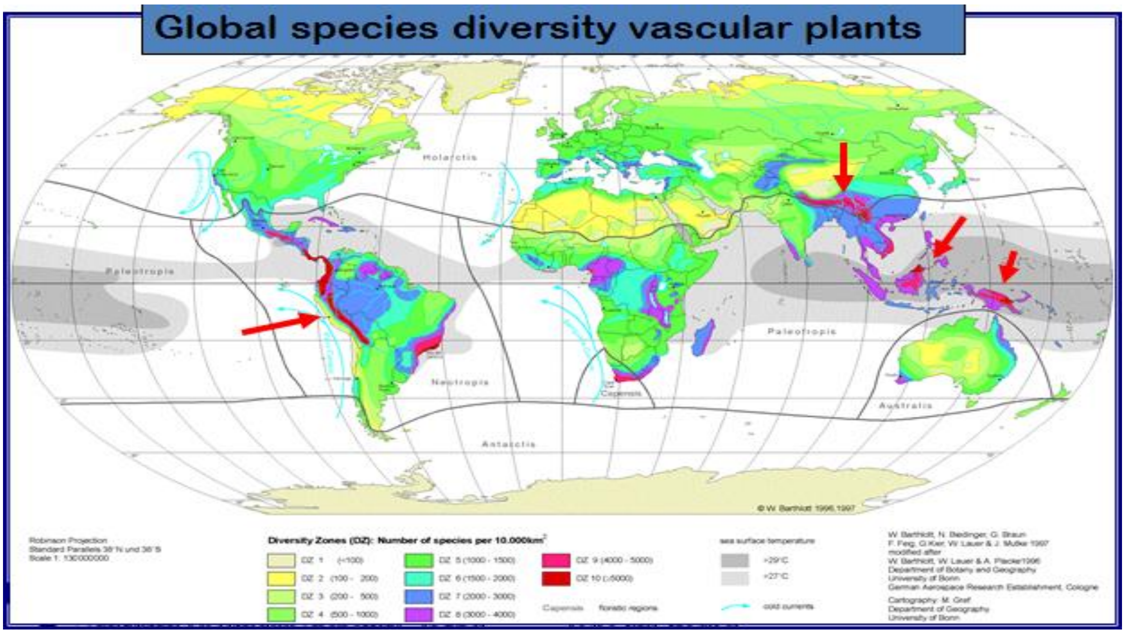

Figure 1: Biodiversity distribution worldwide map made by Barthlott et al. The red arrows indicate high biodiversity and cordillera areas (after Barthlott et al., 1996).

Material en Methods

Dataset

Only two islands of the region have been taking into account, Borneo and New Guinea. The plant species (endemic and non-endemic) that are used are described in Flora Malesiana. Though some altitudes of the samples (dried plant specimens) were given in feet, most of the known data was in meters, that is why the used parameter is meter. For a better overview of the data, the altitudes were divided into five categories per island. The categories for New Guinea are low (0-400m), middle-low (401-1000m), middle (1001-1500m), middle-high (1501-2300m) and high (2301-4500m). For Borneo they are low (0-300m), middle-low (301-900m), middle (901-1400m), middle-high (1401-2000m) and high (2001-4100m).

The dataset of the species described in Flora Malesiana were compared to a dataset of herbarium specimens in the computer system Brahms (Botanical Research And Herbarium Management System, Oxford UK; A dataset system for, among others, the label data of dried plants). Only a small part of the species available in the herbarium is described in the dataset of Brahms. From this dataset the altitudes of the digitized species were used in the dataset of all the species. The non-digitized plant specimens were checked in the herbarium.

For all species the altitudes given on the labels per specimen were noted and the categories at which they occur were noted. Height generalist can then be easily spotted then and a total of all the categories can be easily calculated. The plant species with no known height or collecting localities, were erased from the final dataset. This gave a total of 2533 plant species for New Guinea and 2769 plant species for Borneo.

Statistical analysis

Both datasets of New Guinea and Borneo are ranked data. They are not independent and not normally distributed. This is why the statistical tests are restricted to the coefficient of determination (R^2) for the non-endemic and endemic plant species.

To determine the trend between non-endemic and endemic species, a Pearson correlation and a Chi Square test have been used. A Spearman correlation is used for the correlation between altitude of the endemic and non-endemic species.

To calculate the coefficient of determination tables of the percentages were made. For the percentage of the non-endemic and endemic species separately, the total observations of an altitude was divided by the total of all the observations. For the total comparisment of the percentage of non-endemic and endemic species per altitude, the total observations were counted per altitude and total observations of non-endemic and endemic per altitude was parted by the total observations of that altitude.

Results

New Guinea

All the observation of non-endemic and endemic species per altitude were compared with each other (Fig. 2). The bars show a decline of the non-endemic species per increasing altitude. The endemic species tend to increase somewhat with the increasing altitude. Percentages of both the non-endemic and endemic species (Fig. 3) show that in the middle altitudes, 1001-1500 m, a shift is present. From a majority of non-endemic species at the low altitudes to a majority of endemic species at the higher altitudes. Both species groups are faintly correlated (Pearson correlation $r=-0.2427887$). The endemic species are independent of the non-endemic species (Chi Square test $p=5.9689E-171$).

The non-endemic species have a clear decline with increasing altitude (Spearman correlation $r=-0.932$). While the endemic species have a very weak correlation with the increasing altitude (Spearman correlation $r=0.075$), see fig. 4.

Table 1 shows the numbers of specimens (of non-endemic and endemic species) per height and at what percentage they occur. The expected endemic species show how many observations of endemic species were expected if they had a trend with the non-endemic species.

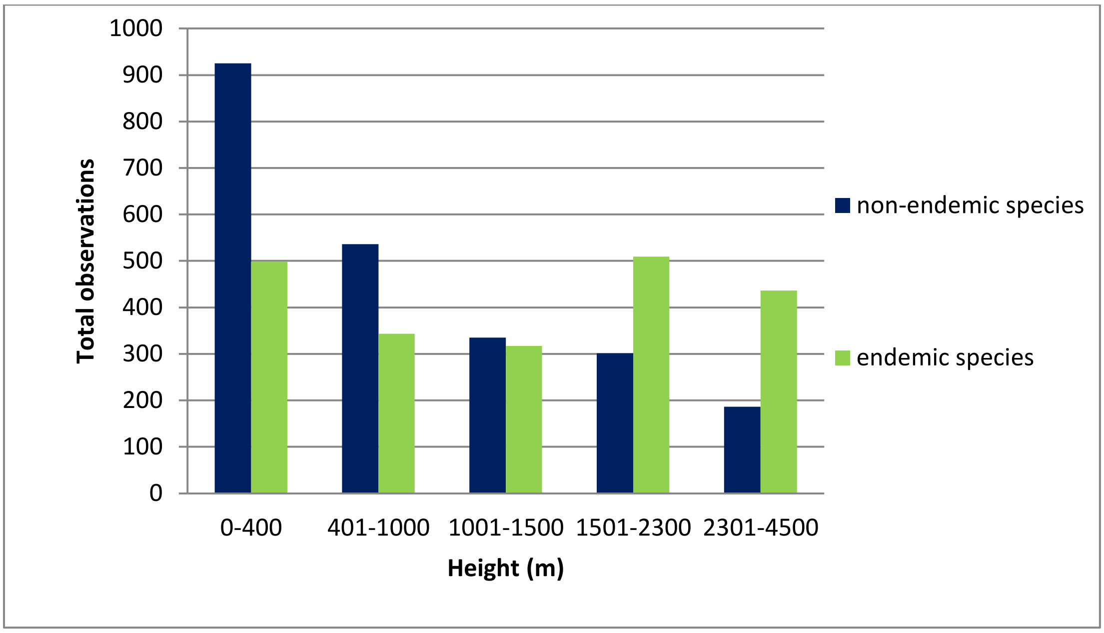

Figure 2: The total of all observation for both the non-endemic and endemic species of New Guinea. At lower altitude more non-endemic are collected and at higher altitude more endemic species are collected.

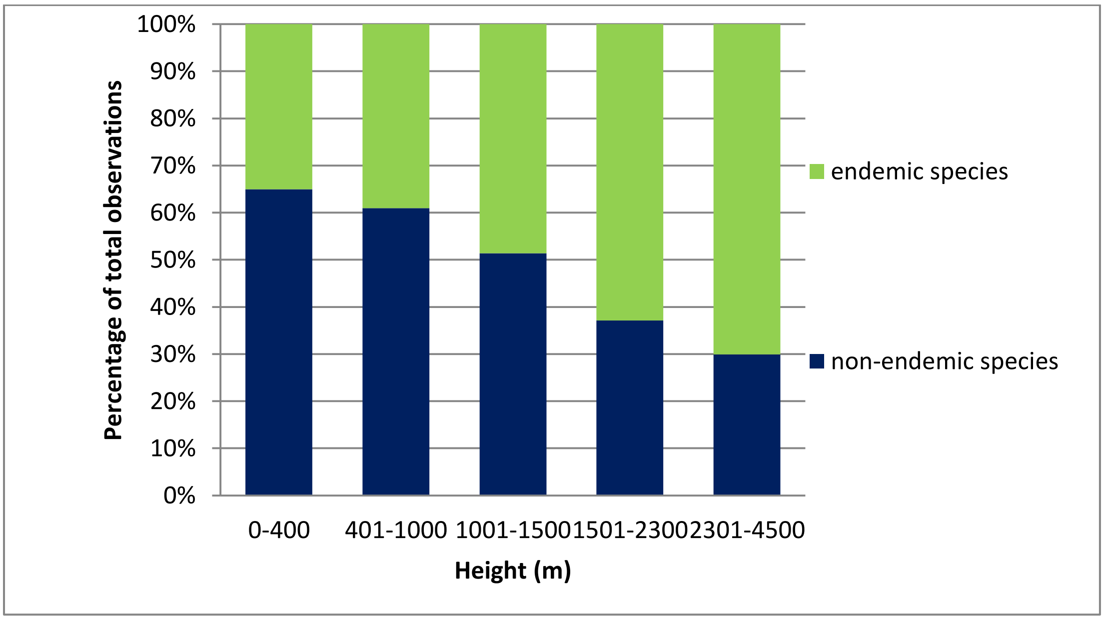

Figure 3: The percentage of all the observation per height of New Guinea. At lower altitudes more non-endemic species are observed. At higher altitudes more endemic species are observed.

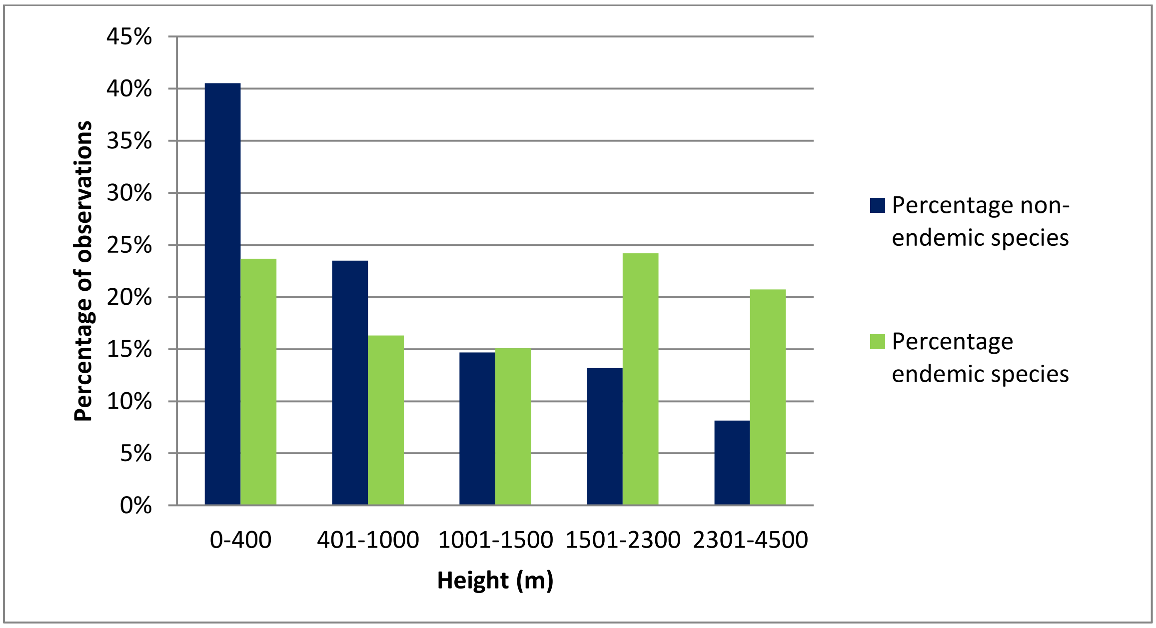

Figure 4: Percentage of observations of the non-endemic and endemic species of New Guinea. The non-endemic species decline per increasing height, with r= -0.932. The endemic species show a two peaked curve, with r= 0.075.

Table 1: Total observations and percentages for the non-endemic and endemic species of New Guinea. The non-endemic species show a decline per increasing altitude. The expected endemic species show the same decline per increasing altitude.

Height (m)	Total non-endemic species	Percentage non-endemic species	Total endemic species	Percentage endemic species	Expected endemic species
0-400	925	40.5%	498	23.7%	852
401-1000	536	23.5%	343	16.3%	494
1001-1500	335	14.7%	317	15.1%	309
1501-2300	301	13.2%	509	24.2%	277
2301-4500	186	8.1%	436	20.7%	171

Borneo

Both the non-endemic and endemic species decline with increasing altitude (Fig. 5). At the high altitudes the endemic species are slightly more common than the non-endemic species, see fig. 5 and 6. They are highly correlated with each other (Pearson correlation r=-0.997456). The endemic species are independent of the non-endemic species (Chi Square test p=3.17241E-20).

The percentage of the non-endemic and endemic species have a vast decline (Spearman correlation r=-0.991), see fig. 7.

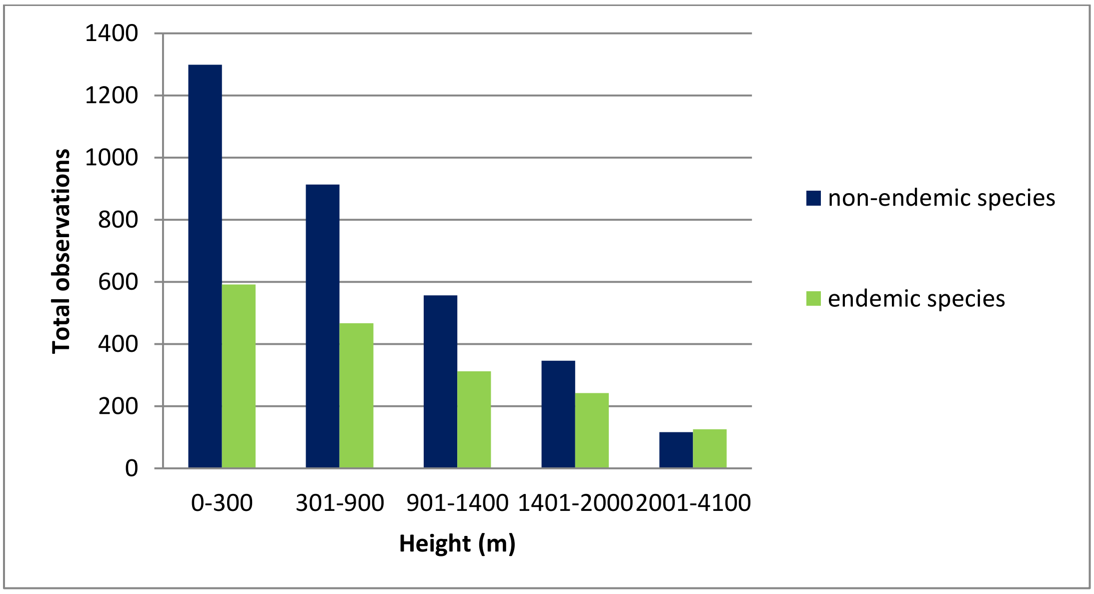

Figure 5: The total of all observation for both the non-endemic and endemic species of Borneo. At lower altitude more non-endemic are collected and at higher altitude more endemic species are collected.

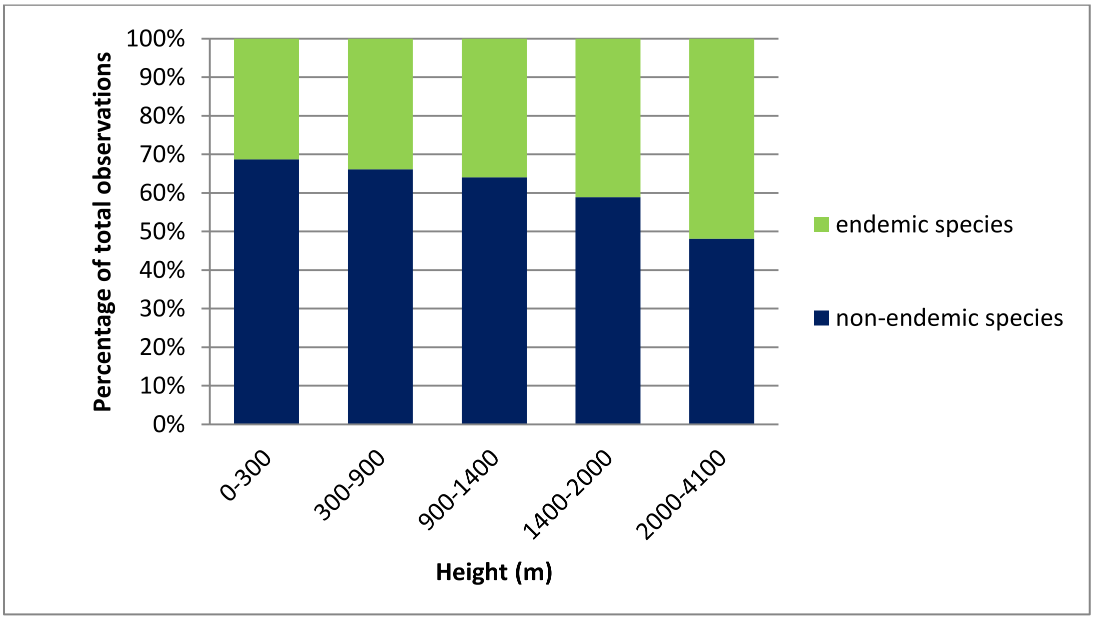

Figure 6: The percentage of all the observation per height of Borneo. At lower altitudes more non-endemic species are observed. Only at high altitude there are more endemic species than non-endemic species.

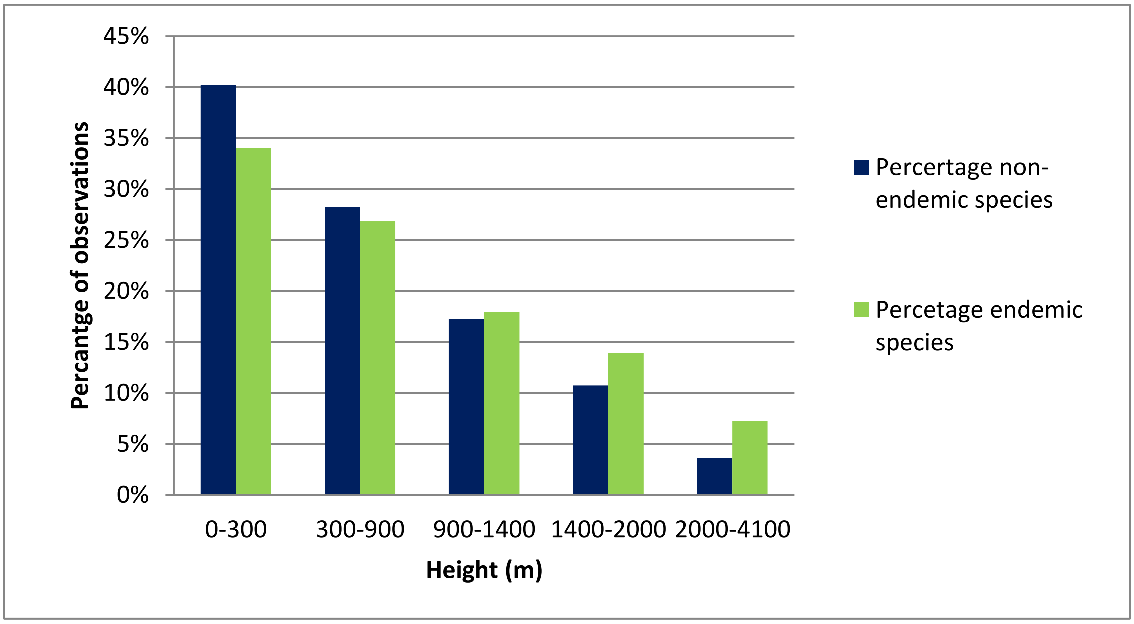

Figure 7: Percentage of observations of the non-endemic and endemic species of Borneo. Both show a decline with the increase of altitude, non-endemic species with r= -0.991 and endemic species with r= -0.994.

Table 2: Total observations and percentages for the non-endemic and endemic species of Borneo. Both have a decline per increasing altitude. The expected endemic species have also a decline, only with a more rapid decrease.

Height (m)	Total non-endemic species	Percentage non-endemic species	Total endemic species	Percentage endemic species	Expected endemic species
0-300	1299	40.3%	592	34.0%	698
301-900	913	28.2%	467	26.9%	491
901-1400	557	17.2%	312	17.9%	299
1401-2000	347	10.7%	242	14.0%	186
2001-4100	117	3.6%	126	7.2%	62

Discussion

The results of the Chi square test show a significant difference between the non-endemic and endemic plant species of New Guinea and Borneo. The expected endemic species, table 1 and 2, differ from the total observed endemic species. That means that there is no trend between the non-endemic and endemic species. The New Guinea data is extreme significant (p=5.9689E-171) and fig. 2 and 3 show that the number of non-endemic species declines with increasing altitude, while the endemic species slightly increase with altitude.

Fig. 3 gives a relative comparison between the non-endemic and endemic species. At low, middle-low and middle altitude percentually more non-endemic species occur. But at the middle-high and high altitudes more endemic species are present.

With Borneo the Chi square test and the Pearson seem to counter speak each other. The Chi square test shows a significant different between the non-endemic and endemic species, this could be because of the relatively more non-endemic species than endemic species, while the Pearson correlation shows that there is a negative correlation between the non-endemic and endemic species. Both the numbers of non-endemic and endemic species decrease with increasing altitude (fig. 6, 8, 9), but percentually the endemic species decrease less fast and become relatively more abundant on higher altitudes (fig. 7).

Thus, on New Guinea the numbers of endemic species increase with altitude. On Borneo they decrease less than the non-endemic species and are thus relatively also more common on higher altitudes. Which of these will be the normal condition? With increasing altitude the surface of the area decreases, which means that there is less space for all individuals. Thus it is to be expected that numbers decrease, both the non-endemic and endemic species. In New Guinea the rise is both in total and relative numbers and this is probably due to the fact that the majority of species on New Guinea is endemic (Van Welzen *et al*., 2011). Within the Malay Archipelago this is only the case with New Guinea. Borneo and the Philippines also have (relatively) many endemic species, but not the majority of all species (Van Welzen *et al.,* 2011).

Most of the specimens are found on low or (extreme) high altitudes. Some low places, like beaches, marshes and land that is easily reached by rivers, are frequently sampled. The (extreme) high altitudes are from mountain tops, easily reached by helicopter. Unlike other places that cannot be reached so easily. Some plant species (non-endemic and endemic) seem to occur only on the high and low places and not in between. This makes the data biased.

Also as mentioned in the introduction, many other factors besides altitude influence speciation. These could not be taken into account because the data (labels of the specimens) did not provide enough data. But especially in New Guinea where there are many more endemic species on the higher altitude, other (a)biotic factors could give rise to this effect.

Conclusion

Endemic plants species do occur more on higher altitudes than non-endemic species. On New Guinea there are more endemic species on higher altitudes and on Borneo there are relatively more endemic species present on higher altitudes. Many more factors, besides altitude, influence this pattern.

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