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CAN SPECIES RICHNESS AND RICHNESS OF RANGE RESTRICTED SPECIES BE USED AS A TOOL FOR CONSERVATION?

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SUMMARY

An attempt is made to identify species to be targeted for conservation action when information about them are scarce. We try to identify areas rich in range restricted species using hepatics occurring in Malesia by calculating a range restriction index for each species and a rarity index for each area. Borneo showed up as most species rich, richest in range restricted species and with the highest rarity index, followed by the Philippines and Java. Lesser Sunda Islands were had the lowest values for all measures. When dividing Borneo into 3 parts, Sabah (with Mt. Kinabalu) turned out to have the highest values, while Sarawak and Kalimantan showed much lower values. Thus, the small area of Sabah makes up for the majority of the richness of Borneo.

It is concluded that this rough method can be used to identify under explored areas but that it is too sensitive for variations in exploration degree within areas to be useful as a conservation tool. For that, smaller units have to be used.

KEYWORDS: Malesia, liverworts, range restriction, rarity, species richness

INTRODUCTION

It is always difficult to evaluate conservation needs for species with poor data, both in the case of poorly known species and poorly known areas. Most tropical regions are bryologically insufficiently known which means that it will take a very long time before we know enough about the species to be able to evaluate their individual conservation needs. In order not to lose too many species meanwhile, other type of evaluation methods must be used. One such method is to identify species rich areas and areas rich in rare species.

Rarity is a complex concept and a rare species is not necessarily threatened (Söderström, 2006). A species may be rare along several gradients. Rabinowitz (1981) identified e.g. three variables along which a species can be rare, distribution ranges, habitat requirements and population sizes, and the combinations of them. They are all important, but for badly known species, population size is the first variable that lacks data (Söderström *et al.*, 2007).

There are usually a bit more information about habitat requirements, but the information is often only general observations like "epilithic in moist shaded forests" etc. and based on collection data instead of systematic research.

The variable that is usually least badly known is distribution, although suffering from the lack of knowledge of certain areas. As distribution ranges is the best known variable of Rabinowitz rarity criteria, we wanted to test if this could be used to identify areas richer than average in range restricted species. Here we try to define range restricted species and relative importance of areas for range restricted species. To test the idea, we use liverworts in Malesia to map the species richness and the richness of range restricted species in a very coarse and quick way.

MATERIALS AND METHODS

Geographical units and statistical analysis

The geographical units we use follow mainly Brummit (2001) and are scored on 3 levels. Level 1 is basically the continents and has 9 units. Level 2 is regions within continents and has 51 units (4 in Europe, 10 in North America, 10 in Africa, etc.). Level 3 are basically countries except that large countries (e.g. Russia and China) are separated in smaller units and that very small countries are included in a neighbour (e.g. Singapore in Malaya and Brunei in Borneo). We also recognize the new European countries at level 3 although not recognized in Brummit (2001). This gives a total of 384 units (50 in Europe, etc.). In this paper we do not use the level 1 units and use the term region for level 2 units and areas for level 3 units. Malesia region is thus defined to include 10 areas (Malayan Peninsula, Sumatra, Java, Borneo, Philippines, Sulawesi, Moluccas, Lesser Sunda Islands, Keeling I and Christmas I). We include the last two islands in the calculations but do not pay much attention to them as only 6 and 0 species, respectively, are reported from there. All statistical analysis was performed with SPSS 15.0.

Species lists and distribution

We have used as many sources as possible to find out both what species there are in Malesia (i.e. tried to sort out taxonomy and include recent synonymisation) and where they occur. Checklists are very helpful for that. Unfortunately, there are only 3 good checklists for Malesia that we are aware of, Borneo (Menzel, 1988), Philippines (Tan & Engel, 1986) and Sulawesi (Gradstein *et al*., 2005). For the other areas, the references are very scattered in the literature and many reports are 100-150 years old. Thus it is possible that we have overlooked some reports but not so many that the overall picture will change.

Distributions were registered world-wide for all species recognized to occur in Malesia.

Defining range restricted species

Distribution ranges were calculated in a way analogous with diversity in ecological investigations. The simplest measure is to count the number of known areas a species occur in. This is analogous with species richness in ecology. However, when talking of diversity in ecology one often use other measures including both number of species and their relative abundance. One of the most used diversity index is the Shannon-Wiener index (Zar, 1984) which indicate how large chance there is that the next individual you see or catch is a different species. We transformed this index to estimate how large chance there is to see the same species in the next region visited. The diversity index often uses number of individuals or cover as the abundance measurement. The most obvious here would be to use number of areas in each region. However, as number of areas varies in regions, the only suitable variable to use as abundance variable is the proportion of areas occupied in each region. Thus, we get the following formula

$$H' = -\Sigma\, p_i \ln p_i$$

where p is the proportion of areas occupied in each region.

The correlation between H′ and total number of areas a species occur in is highly significant (Pearson corr. coeff. = 0.755, n = 1112 , $P < 0.001$). All species only occurring in one region will get H′ = 0 irrespective of how many areas in that region they occur in and species having the occurrence concentrated mainly to one region will get very low H′ values. When number of areas are low, H′ increases rapidly with increased number of area, but when the number of areas increase, the increase of H′ levels off (Fig. 1). In this study 269 species (24.2%) had an H′ = 0 and 577 species (51.2%) had H′ < 1. Those figures are similar to the occurrence of the species in the Lophoziaceae/Scapaniaceae complex (Söderström & Séneca, 2006).

We tried to define range restricted species in 2 ways, the 1/3 of the species with lowest H′ ($H' \leq 0.62$, 370 species) and all with $H' \leq 1$. The general pattern of the following analysis did not differ with these two measures but as Malesian endemics dominate the more restricted measure, we prefer to use H′ < 1.

Defining importance of areas for range restricted species

Proportion of range restricted species may be used as a measure on the relative importance of an area for range restricted species. However, this measure has some unwanted effects. A range restricted species occurring in a species poor area will give a much higher proportion than a range restricted species in a species rich area. Thus, species poor areas will come out as more important just because they are species poor. Therefore, we created a

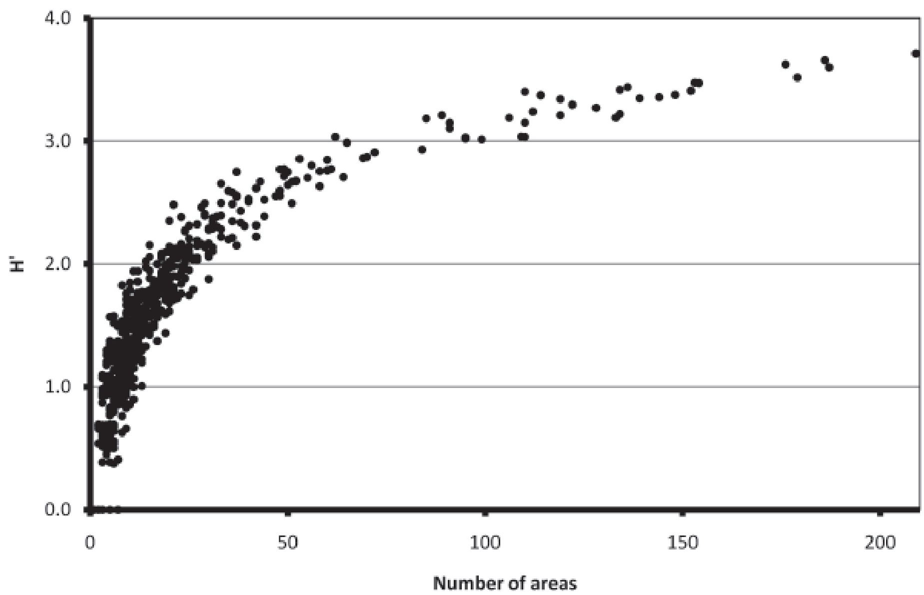

Fig. 1. Relation between total number of areas the 1112 Malesian hepatic species occur in and the H′ value for them.

Rarity Index by multiplying the proportion of range restricted species with the absolute number of them as

$$RI= p_r * n_r$$

where p_r is the proportion of range restricted species occurring in the area and n_r is the number of range restricted species in that region.

RESULTS AND DISCUSSION

Number of species

We registered a total of 1112 species in Malesia. However, there is a large variation in number of species between the different areas (Fig. 2). For Borneo *c.* 682 species are reported while only 61 for Lesser Sunda Islands (Keeling and Christmas Is. have very few species reported and is included in this analysis only for calculation of distribution ranges but not further commented).

Species richness is influenced by several factors e.g. size of the area and altitudinal range (Table 1). The latter presumably creating more habitat types. However, the areas in Malesia are all rather high and no values were correlated with elevation range. Thus, we do not expect that Lesser Sunda Islands should have as many species as Borneo that is both larger and a bit higher. However, there is no reason why Lesser Sunda Islands should have only 20% as many species as Moluccas that is lower and of the same size, or why Sulawesi should have less than half the number of species than Java as they have similar size and elevation. We were curious why Borneo is so species rich compared with the other areas. Our feeling was that it is the effects of Mt. Kinabalu, both as it is a high mountain and thus have potentially more habitat

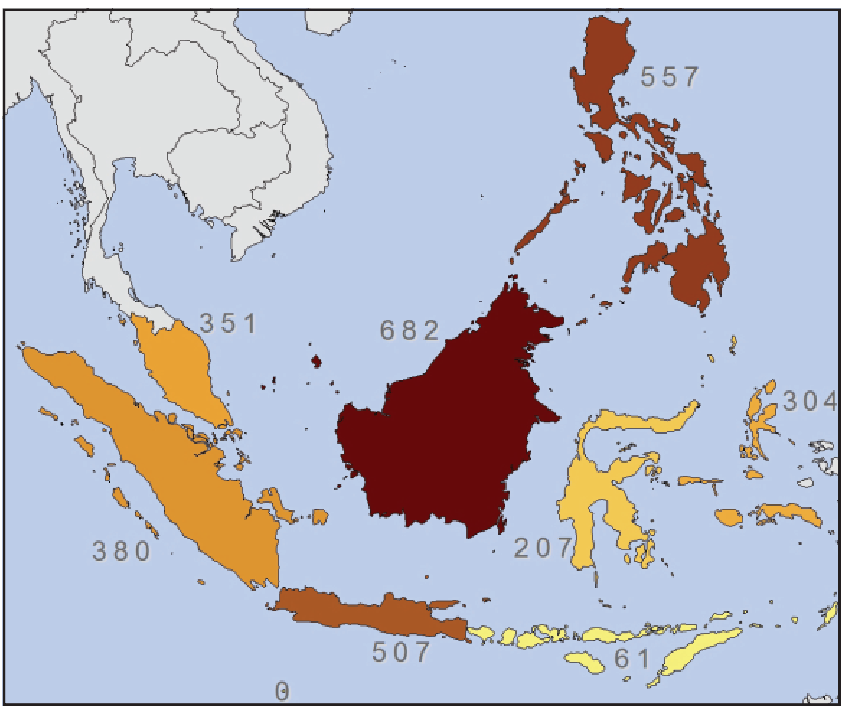

Fig. 2. Number of hepatic species in different areas of Malesia. Cocos I (outside the map) have 6 species.

Table 1. Size and maximum elevation of areas in Malesia, excluding Keeling and Christmas Islands.

Area	Size (km^2)	Elevation (m)
Borneo	743,000	4101
Sabah	*76,000*	*4101*
Sarawak	*124,000*	*2423*
Kalimantan	*537,000*	*2987*
Java	127,000	3676
Lesser Sunda Islands	86,000	3726
Malaya	180,000	2190
Moluccas	84,000	3055
Philippines	300,000	2954
Sulawesi	175,000	3455
Sumatra	470,000	3800

types, and that it probably is the best explored part of Malesia.

When treating Sabah, Sarawak, Brunei and Kalimantan separately we got another picture (Fig. 3). Sabah is about as species rich as the Philippines (although smaller but higher) while the other provinces become almost as, or a bit less, species rich than the neighbouring areas. We also split Kalimantan into its 4 provinces and then they became about as or less species rich than Sulawesi.

From classical island biogeography theory the number of species should be linearly related to area. In this study (Fig. 4) the species richness was close to significantly correlated with size (Pearson corr. coeff. = 0.692; n = 8; P = 0.057). However, when dividing Borneo (Brunei not included) all tendencies of correlation disappeared completely as the smallest unit (Sabah) is the most species rich and the largest unit (Kalimantan) the least species rich. The failure to find any area-number of species correlations is probably an effect of the under-explored areas which do host many more species than so far reported.

As we mapped the full world distribution of the Malesian species we are able to illustrate affinities with other areas (Fig. 5). It seems clear that Malesia has the closest affinities with New Guinea and the surrounding areas, much more so than with SE mainland Asia. However, some species occurring in Malesia can also be found in most areas of the world. Most northern hemisphere occurrences are cosmopolitan species like e.g. *Marchantia polymorpha*, while an increased number in the tropics reflects occurrences of pantropical species like e.g. *Frullania ericoides*.

Number of range restricted species

Number of range restricted species (Fig. 6) is highly correlated with species richness (Pearson corr. coeff. = 0.946, n = 8, P < 0.001) and shows thus the same pattern with Borneo having the highest number.

Number of range restricted species is also correlated with area (Pearson corr. coeff. = 0.803, n = 8, P = 0.016). However, the relation between number of species and restricted species is not strictly linear but better cubic (Fig. 7), which means that as species are added a higher and higher proportion of the added species are range restricted species. Proportion of range restricted species (Fig. 8) thus follows the same pattern as species richness, although accelerated.

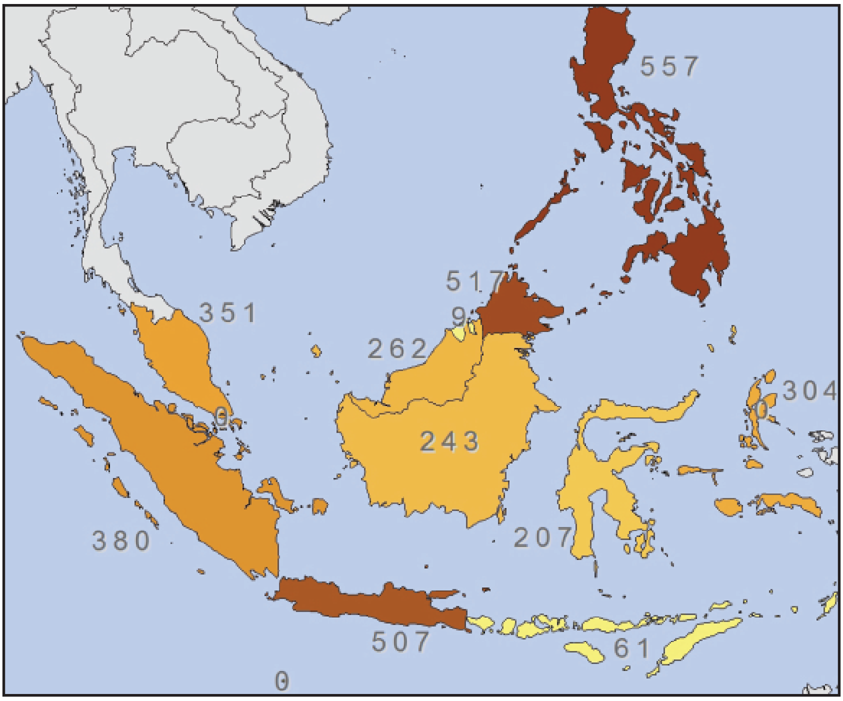

Fig. 3. Number of hepatic species in different areas of Malesia but with Borneo separated into 4 sub-areas.

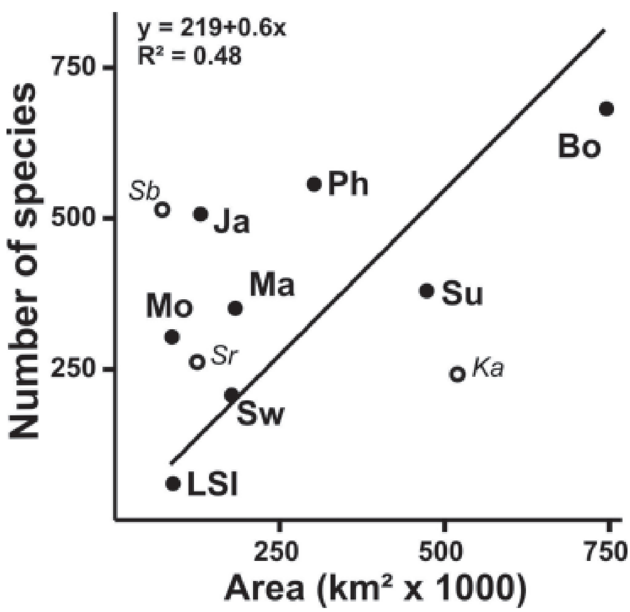

Fig. 4. Relationship between number of species and area. The linear regression is not significant (P = 0.057). Bo = Borneo, Ja = Java, LSI = Lesser Sunda Islands, Ma = Malaya, Mo = Moluccas, Ph = Philippines, Su = Sumatra, Sw = Sulawesi. Values for 3 sub-areas of Borneo, Kalimantan (Ka), Sabah (Sb) and Sarawak (Sr) is shown but not included in the regression.

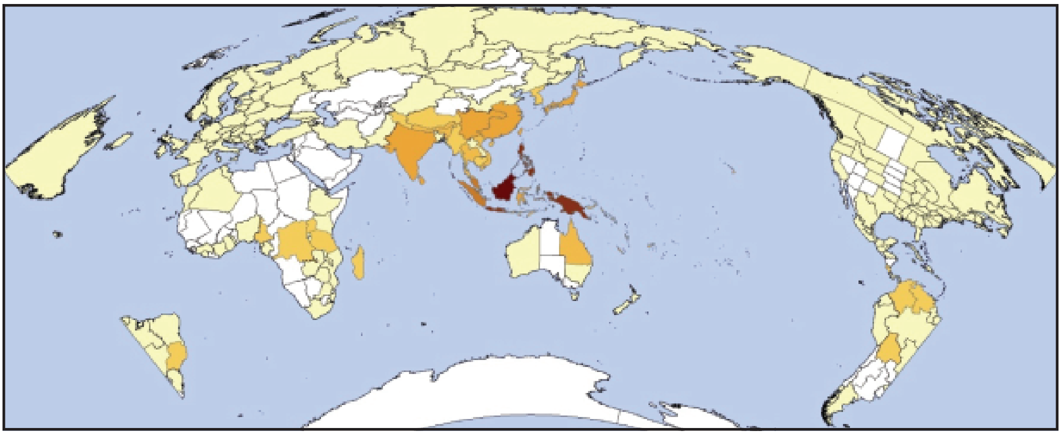

Fig. 5. Number of hepatic species in different areas of the world that also occur in Malesia.

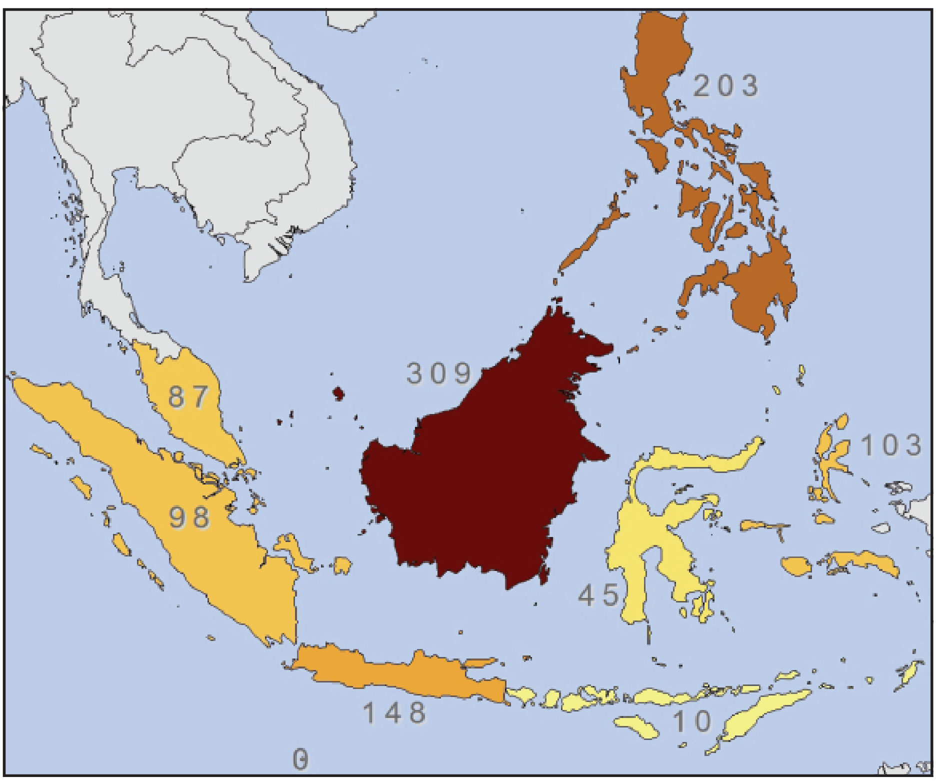

Fig. 6. Number of range restricted species in different parts of Malesia.

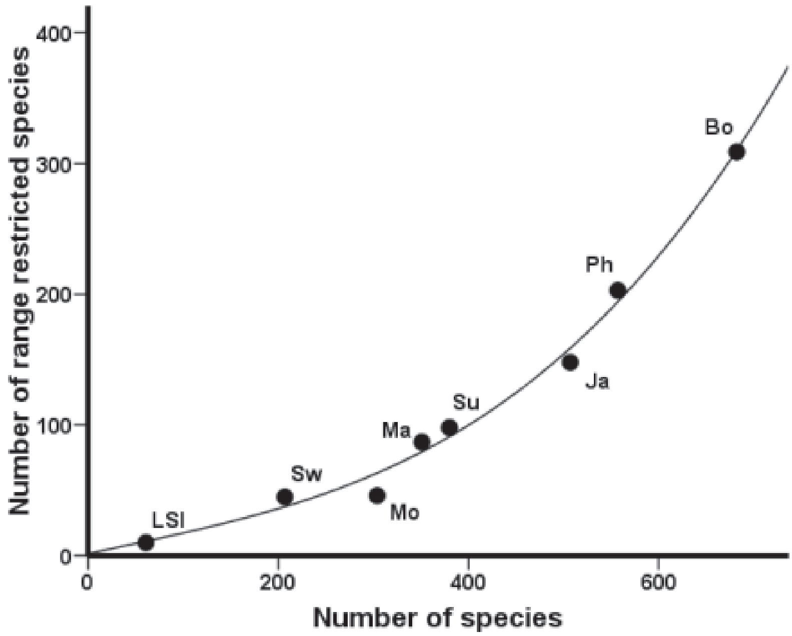

Fig. 7. Relation between number of species and number of restricted species. The best fitting regression line is cubic ($y=1.57+0.16x-8.89^{-5}x^2+7.6^{-7}x^3$; $R^2=0.99$).

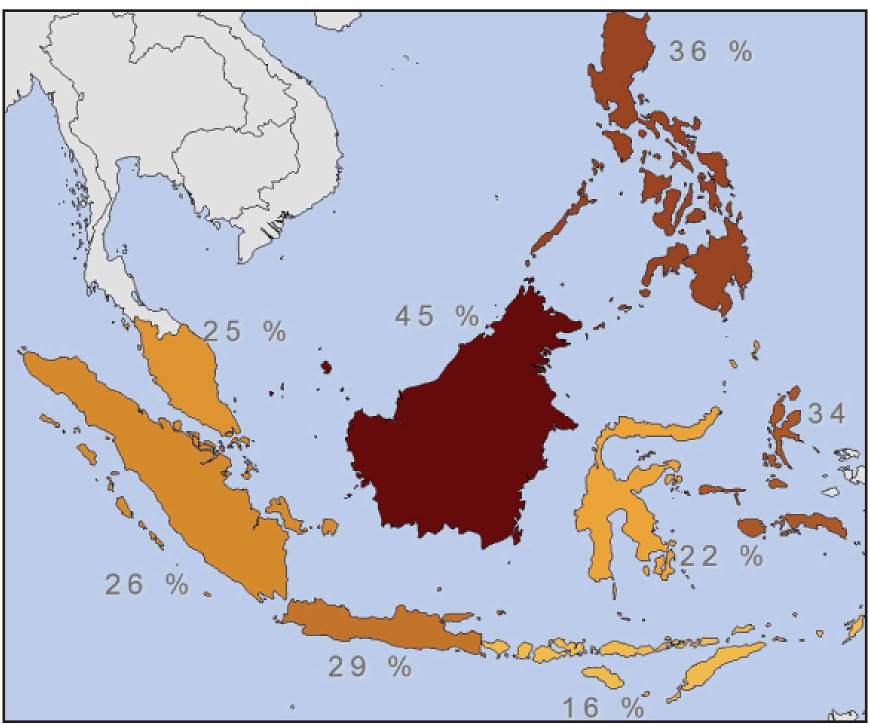

Fig. 8. Proportion of range restricted species in different areas of Malesia.

When dividing Borneo (Fig. 9) all correlations disappear. Also, Sabah is not as different from Sarawak as for the number of species. On the other hand, when dividing Borneo none of the sub-areas come up into the same values as for the whole Borneo. This is because the widespread species occur in many of the sub-areas while the range restricted only in one or a few of them. Thus, range restrictions occur also on this level.

Rarity index

When calculating the Rarity Index (Fig. 10) we got values between 140 (Borneo) and 1.6 (Lesser Sunda Islands). This picture differs from the proportion of restricted species emphasizing the importance of Borneo for range restricted species as it has a higher number of them compared with the other areas.

Again, when dividing Borneo, Sabah and Philippines show similar values of RI whereas the other areas trail far behind (Fig. 11). The RI is linearly related with size (Fig. 12). However, when Borneo is divided this relation disappears as Sabah, the smallest area, has the largest RI. It is therefore tempting to state that Sabah should be the focus for area conservation in order to save as many liverwort species as possible for the future. Although the concerns about the quality of the data expressed above, Sabah is certainly a hot spot for range restricted species.

CONCLUSION AND IMPLICATION FOR CONSERVATION

The knowledge of the hepatic flora of Malesia suffers from both the Linnean and the Wallacean shortfalls of Lomolino (2004). The former is that we need to

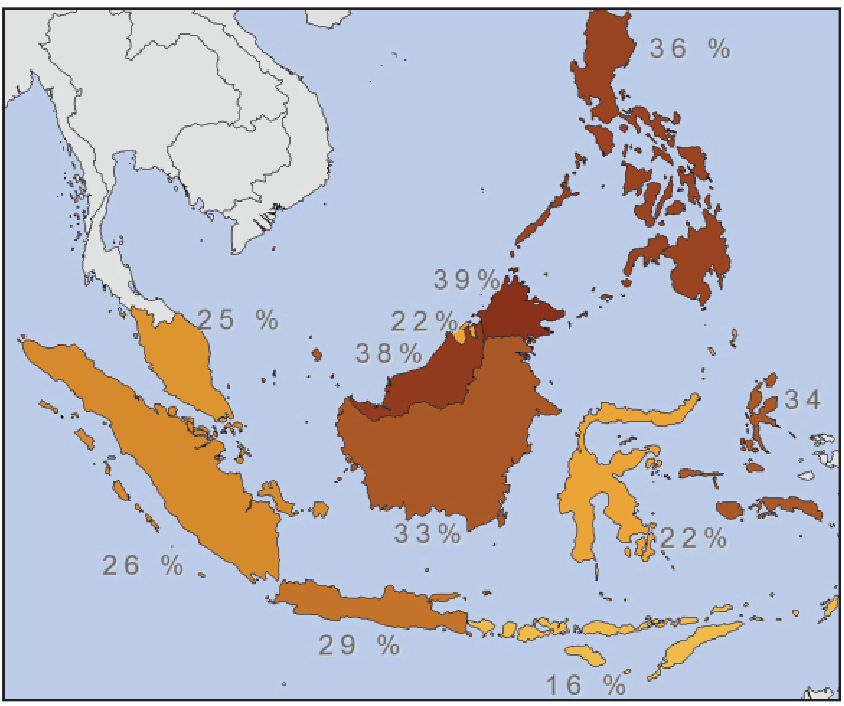

Fig. 9. Proportion of range restricted species in different areas of Malesia but with Borneo separated in 4 sub-areas.

Fig. 10. Rarity Index for areas in Malesia.

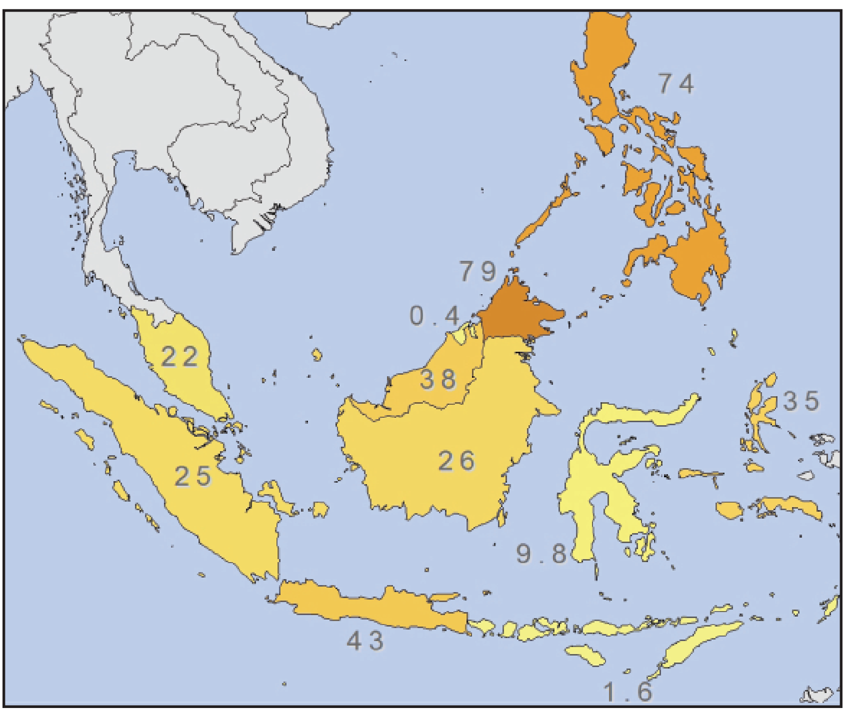

Fig. 11. Rarity Index for areas in Malesia but with Borneo separated in 4 sub-areas.

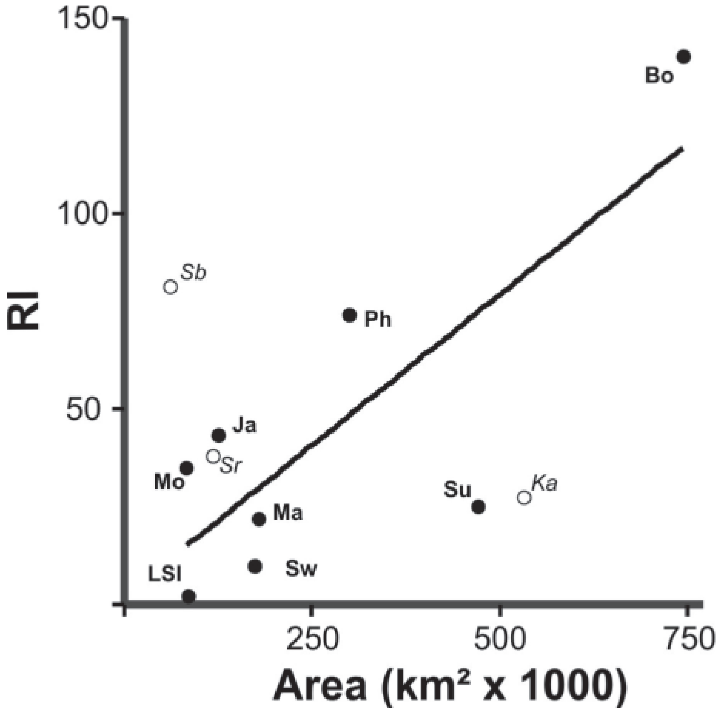

Fig. 12. Relation between RI and area. The linear regression line (y = 2.06 + 0.15x, $R^2 = 0.63$, $P = 0.018$) is significant. Area abbreviation as in Fig. 4. Sabah, Sarawak and Kalimantan (open circles) are not included in the regression.

know the taxonomy better. We have certainly included names that in the future will prove to be synonyms. Most of them will be the badly known, range restricted species. On the other hand, there will certainly be more species described from the region. Taxonomy of the liverworts is known enough that very few new widespread species will be detected. Most of the new species will fall within the range restricted group. Thus, the main turnover will be within range restricted species.

The Wallacean shortfall, the badly known distribution ranges, will probably have a larger effect on our results. First, as badly known areas are investigated, the full range of widespread species will rapidly be detected. In addition, some species that are regarded range restricted today will turn out to have a much wider distribution area. This will happen also with increased investigation of areas outside Malesia. Within Malesia, our data points out Lesser Sunda Islands, Sulawesi, Kalimantan and Sumatra (in that order) to be the most underexplored areas compared with their size. This is in contrast with the seemingly well-explored Sabah and Philippines.

This study shows how sensitive the calculations are to variations within the areas. When treating Borneo as a whole it seems to follow the expected linear relation between species number and size of the area. However, when dividing the island it becomes clear that the values are heavily influenced by the combination of high number of species (or richness of range restricted species, or RI) of Sabah and the large size of Kalimantan. In order to be useful for conservation, smaller units should be used. However, the use of these units is useful to find hot spot areas on a global perspective. But then more areas than just one region should be analyzed.

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