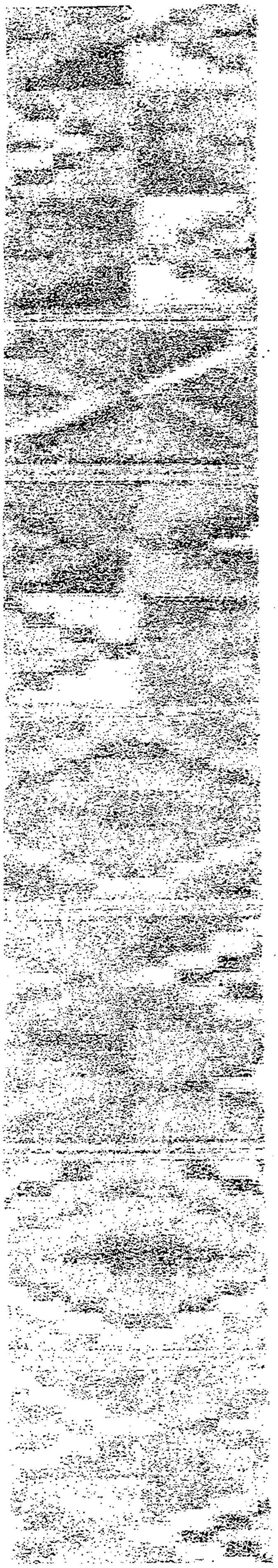

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APPLICATION
OF BIOGEOGRAPHICAL DATA OF FROGS
TO PRIORITIZE CONSERVATION AREAS IN BORNEO

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INTRODUCTION

Prioritization of conservation areas is an important aspect of conservation biology to enhance biodiversity conservation. With the increase in threats to biodiversity and environment, prioritization of conservation areas has become crucial as it reviews areas with the best representation of biodiversity so that conservation efforts can be targeted. Feasibility and effectiveness of conservation translate to saving of time, money, personnel and most importantly, the limited natural resources. Prioritization of conservation areas requires four components: analytical tool, biodiversity value, selected organism and selected site.

Prioritization of conservation areas needs an analytical tool that is fast and able to handle large biogeographical data sets. WORLDMAP program (version IV), which was used for this research, appears to have the capacity to fulfill the criteria. WORLDMAP is a PC-based and tailor-made analytical tool to map biodiversity and allows users to directly update the data (Williams, 1994). It uses a 15' X 15' grid cell system as its smallest representation unit for

Borneo. The grid cells show results of various analyses solely based on the data digitalized into WORLDMAP that correspond to the actual localities represented by the grid cells.

Biodiversity has to be quantified into biodiversity value for the purpose of prioritization of conservation areas. The most popular measure is by using species richness (e.g., Lombard *et al.*, 1995; Gaston, 1996; Williams & Humphries, 1996; Fjeldsa & Rahbek, 1997, 1998; Humphries *et al.*, 1999; Mahadimenakbar, 1999; Fjeldsa, 2000; Fjeldsa & De Klerk, 2001).

Biogeographical data of frogs (Anura: Amphibia) were utilized in this research. When the word 'frog' is used throughout the paper, it includes the entire group of anuran amphibians. Frogs were the selected organisms because their systematics and distribution are well documented (Inger & Tan, 1996) and are appropriate environmental indicators, mostly because of their extreme vulnerability to environmental deterioration (Payne, 2000).

Glaw & Köhler (1998) found that 4,780 species of frogs were described worldwide, up to the year 1995. The total number of valid species of frogs at present must be close to 5,000, significantly larger than 3,500 – 4,000 species reported by Beebee (1996) and Inger & Stuebing (1997).

The number of species in Borneo was 143 in 1997 (Inger & Tan, 1996; Inger & Stuebing, 1997) and is increasing almost annually with the discovery of new species. Additionally, about 69% of the fauna is endemic to Borneo (Inger & Stuebing, 1997) making frogs politically appealing. This aspect has helped attract public and governmental interest (Mohamed Zakaria, 2000). Besides, frogs belong to one of the most successful group of vertebrates as they are near cosmopolitan in distribution, except Antartica, and are most diverse in the tropics.

The selected site for this research, Borneo, is situated on the Sunda Continental Shelf. Borneo has a wide variety of habitats spanning from mangrove forests to alpine forest on Gunung Kinabalu, Sabah, northern Borneo. These habitats contribute to various microhabitats which support floral and faunal richness in Borneo. The faunal component of Borneo is unique.

The uniqueness can be seen in comparison to Sulawesi and other islands on the Sunda Continental Shelf (Moss & Wilson, 1998).

METHODS

Site

Borneo, the world's third largest island (after Greenland and New Guinea), covers 751, 929 km^2 and comprised of Sabah (74, 500 km^2) and Sarawak (124, 450 km^2) in Malaysia, Kalimantan (547, 214 km^2) belonging to Indonesia and Brunei Darussalam (5, 765 km^2). Within the allocated time frame and limits of resources, sampling sites were confined to selected areas in Sabah. The selection of the areas was based on the overview of areas in Sabah with little or no sampling of frogs before. This was done to fill up the gaps of sampling efforts.

Data collection

For WORLDMAP, data are categorized into level 1 and level 2 data (Kueh, 2000, 2001, in press). Level 1 data are assumed presence of frogs based on the knowledge of the preferred habitats of frogs. Data were compiled from the ecological notes of all the frogs species in Borneo from *A Field Guide To The Frogs Of Borneo* (Inger & Stuebing, 1997) and *The Systematics And Zoogeography Of The Amphibia Of Borneo* (Inger, 1966).

Level 2 data refer to the presence of frogs based on field notes, monographs, scientific papers, sampling records and wet specimens from other herpetologists and institutions working or which have worked on frogs of Borneo.

Level 2 data gathered through collaboration with other herpetologists and institutions were supplemented with data from personal samplings. Samplings were done by opportunistic examination of natural habitats as well as habitats created through human activities. All frogs from personal samplings were identified based on their morphological features by using the dichotomous key in Inger & Stuebing's *A Field Guide To The Frogs Of Borneo* (1997). All information on the 'Class', 'Order', 'Family', 'Species', 'Locality', 'Collector', 'Date' and 'BORNEENSIS number' were recorded. The information on the locality of each species is the biogeographical data for the analyses reported here.

Data gathered from other herpetologists and institutions did not have geographical coördinates. Thus, coordination was done for each datum based on its locality by referring to Tangah & Wong's *A Sabah Gazetteer* (1995) or reading the map of Sabah (Periplus travel maps: Malaysia regional maps: Sabah. Singapore: Periplus Editions Ltd.). For localities in Sarawak, the map of Sarawak (Periplus travel maps: Malaysia regional maps: Sarawak. Singapore: Periplus Editions Ltd.) was used while for Kalimantan and Brunei Darussalam, the map of Kalimantan (Nelles maps: Indonesia 4: Kalimantan. Germany: Nelles Verlag) was used. Coordinates were also extracted from gazetteers for Malaysia, Brunei Darussalam and Indonesia, produced by the Defense Mapping Agency, U.S. Board of Geographic Names, Washington, D.C., also accessible through http://164.214.2.59/gns/html.

Coordinates for the data from personal samplings were read from Global Positioning System (GPS) (Garmin). Each of the coordinates was given after the GPS managed to track signals from at least three out of four satellites.

Data digitalization

Each species and genus was coded with a code system with one digit and five capital letter alphabets specially created for frog data (Kueh, 2000, 2001, in press). The code system bore the randomly selected digit '8', 'A' to represent Class Amphibia, another 'A' to represent Order Anura and randomly selected representative alphabets to represent families, genera and species, respectively. The code for each species and genus was highly distinctive and there was no repetition. All data were digitalized into WORLDMAP manually based on their coordinates and codes.

WORLDMAP analyses

(e.g., Fjeldsa & Rahbek, 1997, 1998; Humphries *et al.*, 1999; Fjeldsa, 2000; Williams *et al.*, 2000)

WORLDMAP analyses used in this research were: (a) 'richness': analysis of the number of species in every grid cell, (b) 'hotspots by species richness': analysis of (ten) grid cells with the highest number of species, (c) 'range-size rarity': analysis of the total inverse number of grid cells occupied by each species in every grid cell, (d) 'hotspots by range-size rarity': analysis of (ten) grid cells with the highest range-size rarity, (e) 'near-minimum sets': analysis of grid cells to represent all the species and (f) 'Gap Analyses': analyses on the feasibility of the conservation priority areas which involve comparison of conservation priority areas with the current protected areas network and present human settlements pattern in Borneo.

The intensity of the species richness and range-size rarity was shown with colours ranging from red to light blue. Red is superlative while light blue is the opposite. The colouration is strictly based on the data digitalized into WORLDMAP.

RESULTS

Species richness

Overall, species richness of the frogs of Borneo is concentrated at four major grid cells or their aggregations. The four concentrations of species richness are along the Crocker Range at western Sabah, lowland to hilly and lower montane zones at eastern Sabah, lowland zone on northwestern Sarawak and lower montane zone at southwestern Sarawak. The concentrations encompass grid cells with 60 - 85 species / genera out of the 139 species / genera (43.17 - 61.15%) of frogs data gathered and digitalized into WORLDMAP (Figure 1).

The species richness concentration along the Crocker Range has 43.17 – 61.15% of species richness with the only red grid cell produced in the species richness analysis. Besides the Crocker Range National Park, prominent localities included in this species richness concentration are Kinabalu Park, Poring Hot Springs, Gunung Alab, Rafflesia Forest Reserve, Tambunan, Bunsit Park, Keningau, Gunung Lumaku Forest Reserve, Tenom and Mendolong. It includes three of Sabah's divisions namely Kudat, West Coast and Interior.

The next species richness concentration is at eastern Sabah with 43.17 – 50.36% of species richness. It represents localities like Tabin Wildlife Reserve, Danum Valley Conservation Area, Tawau Hills Park and Maliau Basin Conservation Area. It covers Sandakan and Tawau Divisions.

Another species richness concentration is at northwestern Sarawak. It has 67 species / genera of frogs (48.20%) making it the richest grid cell in Sarawak. Tubau, Bintulu Division is situated in the concentration.

The fourth species richness concentration is at southwestern Sarawak with 45.32% of species richness. It represents Sungai Mengiong, Kapit Division which is at the southwestern border of Sarawak and Kalimantan.

Low species richness is clearly projected from the middle of Borneo which covers several mountain ranges at southwestern Sarawak, East Kalimantan, South Kalimantan, Central Kalimantan and West Kalimantan. Each of the grid cells merely accommodates one to seven species / genera of frogs and is shown either as blue or light blue.

Hotspots by species richness

Top ten hotspots by species richness are at western Sabah (Figure 2). Each of the ten hotspots houses 70 or more species / genera of frogs. Collectively, hotspots 1, 2, 5, 7 and 9 represent Kinabalu Park. On a similar ground, hotspots 1 - 8 except 5 represent Crocker Range National Park. Hotspot 10 is the most southern hotspot which represents Mendolong and Gunung Lumaku in Sipitang District as well as Belumbang, Tomani, Melutut and Sungai Tomani in Tenom District, Interior Division.

Range-size rarity

Range-size rarity of the frogs of Borneo peaks at five areas represented by grid cells or their aggregations. The peaks are at montane zone at western Sabah, lowland to hilly and lower montane zones at eastern Sabah, lowland zone at northwestern Sarawak, montane zone at northeastern Sarawak and lower montane zone at southwestern Sarawak (Figure 3). All the grid cells involved have range-size rarity of 10.00 - 22.16% and are shown as red or dark orange.

The range-size rarity peak at western Sabah is in the range of 10.13 – 18.84%. The peak covers localities in Sabah such as the Crocker Range National Park, Kinabalu Park, Gunung Tambuyukon, Poring Hot Springs, Mamut, Gunung Alab, Rafflesia Forest Reserve, Sunsuron, Rompon, Tambunan, Keningau, Tenom, Membakut, Bunsit Park, Mendolong, Tomani, Gunung Lumaku and numerous rivers. It spans across the divisions of Kudat, West Coast and Interior.

The next range-size rarity peak is at eastern Sabah with range-size rarity of 10.08 – 17.19%. It covers three conspicuous protected areas in Sabah namely Danum Valley Conservation Area, Maliau Basin Conservation Area and Tawau Hills Park. The areas are in Tawau and Interior Divisions.

Northwestern Sarawak shows the highest range-size rarity of 22.16%. It is the only red grid cell produced in the range-size rarity analysis. The peak includes localities like Tubau and Sungai Pesu in Bintulu Division.

Another range-size rarity peak is at northeastern Sarawak. It shows range-size rarity of 10.08%. It is the northeastern edge of Gunung Mulu National Park, Miri Division. The grid cell houses the pinnacle of Gunung Mulu too.

The fifth area with high range-size rarity is at southwestern Sarawak with range-size rarity of 13.48 – 13.54%. The peak represents Sungai Mengiong, Kapit Division.

Low range-size rarity is concentrated at the middle of Borneo which covers mountain ranges at southwestern Sarawak, East Kalimantan, South Kalimantan, Central Kalimantan and West Kalimantan, especially at western Schwaner Range. Another low range-size rarity concentration is at the focul point of the interior of Sibu Division, eastern Sarikei Division and western Kapit Division in Sarawak. It includes localities such as Sibu, Julau and Kanowit.

Hotspots by range-size rarity

Top ten hotspots by range-size rarity are scattered in Sabah and Sarawak (Figure 4). Each of the ten hotspots has range-size rarity of 15.65% or above. Collectively, hotspots 2 - 5 and 7 represent Kinabalu Park. Hotspot 8 stands for localities like Tambunan, Sunsuron and Rompon in Tambunan District, Interior Division. Hotspots 6, 9 and 10 represent Danum Valley Conservation Area. Hotspots 2 – 10 are all in Sabah. Hotspot 1 is the only top ten hotspot by range-size rarity in Sarawak. It represents Tubau and Sungai Pesu in Bintulu Division. It is the only grid cell with range-size rarity above 20.00%.

Near-minimum sets

A total of 16 near-minimum sets are identified out of the 1,057 grid cells utilized (Figure 5). The near-minimum sets are in Sabah, Sarawak and Kalimantan.

There are nine near-minimum sets in Sabah. Six of these grid cells are at western Sabah and three are at the eastern region. In Sarawak, there are five near-minimum sets. The remaining two near-minimum sets are in Kalimantan. Both the grid cells are at the lowland of West Kalimantan.

Out of the 16 near-minimum sets, four are irreplaceable grid cells (red) while the rest are flexible grid cells (orange). One irreplaceable grid cell is at western Sabah representing localities like Dalit, Kalampon, lower Sungai Dalit, Sungai Sook, Sungai Punti and lower Sungai Keramatoi in Keningau District, Interior Division. Three irreplaceable grid cells are in Sarawak representing northeastern Gunung Mulu National Park and Long Napir in Limbang Division, Tubau and Sungai Pesu in Bintulu Division as well as Batang Ai National Park, Bukit Lanjak and Bukit Tinteng Putar in Sri Aman Division.

Combinations among hotspots by species richness, hotspots by range-size rarity and near-minimum sets

Combinations among hotspots by species richness, hotspots by range-size rarity and near-minimum sets produced 26 grid cells throughout Borneo (Figure 6). Nineteen grid cells are in Sabah, five are in Sarawak and two are in Kalimantan. Throughout Borneo there is merely one grid cell that combines a hotspot by species richness, hotspot by range-size rarity and near-minimum set representing Marak Parak and northern Kinabalu Park. On the other hand, combination of a hotspot by range-size rarity and near-minimum set produced three grid cells with two in Sabah and one in Sarawak. Combination of a hotspot by species richness and near-minimum set is observed at one grid cell throughout Borneo; in Sabah. Combination of two types of hotspots namely hotspot by species richness and hotspot by range-size rarity is at four grid cells in Sabah. Other than the mentioned combinations, there are 11 grid cells which are just near-minimum sets with five in Sabah, four in Sarawak and two in Kalimantan. Grid cells that are just hotspots by range-size rarity are both in Sabah. Lastly, all the four grid cells which are hotspots by species richness are in Sabah.

Gap Analyses

Gap Analyses see overlapping of the grid cells produced by the combinations among hotspots by species richness, hotspots by range-size rarity and near-minimum sets with the current protected areas as well as present human settlements in 22 corresponding grid cells each.

All of the 19 grid cells produced by the combinations among hotspots by species richness, hotspots by range-size rarity and near-minimum sets in Sabah overlap with protected areas or parts of them. A total of 32 protected areas: parks, forest reserves, conservation areas and wildlife reserves, are involved. In Sarawak, only three out of the five grid cells produced by the combinations overlap with protected areas or parts of them. Four protected areas are involved. However, unlike Sabah and Sarawak, both the grid cells produced by the combinations do not overlap with any protected area in Kalimantan.

Except for three, all the grid cells produced by the combinations among hotspots by species richness, hotspots by range-size rarity and near-minimum sets in Sabah overlap with human settlements. In Sarawak, three out of the five grid cells produced by the combinations coincide with human settlements. As for Kalimantan, both the grid cells produced by the combinations coincide with human settlements.

DISCUSSION

The application of biogeographical data of frogs to prioritize conservation areas in Borneo using the WORLDMAP program has never been done before. In Borneo, only butterflies (Mahadimenakbar, 1999; Bakhtiar Effendi, 2000), birds (Stabell, unpublished) and palms (Andersen, unpublished) data have been used by other researchers to prioritize conservation areas.

Species richness analysis of the frogs of Borneo derived from the utilization of 139 biogeographical data from 124 species and 15 groups that have been identified up to their genera. The 15 groups are level 2 data from other herpetologists and institutions. The 124 species represent 86.71% of the total taxonomically described species of frogs in Borneo (Inger & Tan, 1996; Inger & Stuebing, 1997).

Lowland which covers forests from 5 - 800 m above sea level provides a handful of habitats for the frogs of Borneo (Wong, 1994; Inger & Tan, 1996). These habitats are exemplified by sluggish streams with turbid and muddy bottoms as well as muddy banks due to low elevation. There are also streams with clear and rocky bottoms which are rather popular among frogs. Another diagnostic characteristic of lowland is its abundance of rain-filled depressions and temporary puddles, pools and ponds (Abdul Hamid & Wong, 1998). Further away from streams are shallow marshes and grassy fields.

Although Sabah and Sarawak each has 67,994.47 km^2 and 114,047.94 km^2 of lowland (Perumal, 2001), high species richness is observed only at northern Tabin Wildlife Reserve, northeastern Danum Valley Conservation Area and southern Tawau Hills Park towards the coastal zone of Tawau, all of which are at eastern Sabah as well as Tubau at northwestern Sarawak.

On the other hand, hilly and lower montane zones from above 800 - 1,200 m above sea level is a haven for frogs despite general postulation that frogs show negative correlation with altitude. Where the topography is hilly with gentle or steep slopes, there is a large variety of streams available. The spectrum ranges from seepages, trickles, slow flowing creeks, tributaries to major streams with sandy or rocky bottoms. There are also still some small rain-filled depressions at flatter areas providing temporary puddles and ponds. Surrounding the streams and rain-filled depressions are trees with strategic overhanging leaves and branches. Each of the habitats further provide a variety of microhabitats to support the greatest diversity of frogs (Inger & Tan, 1996). It is the availability of habitats and microhabitats that plays major role in determining the species richness of frogs (Inger *et al.*, 2000). Therefore, it is justifiable that species richness of frogs is more concentrated at hilly to lower montane zones than lowland and montane zones in Borneo.

However, species richness of frogs forms a large patch on western Sabah from Kinabalu Park to the southern tip of Crocker Range National Park. This species richness patch is also the top ten hotspots by species richness for Borneo. The phenomenon is highly attributed to the 'Refugia Hypothesis'. The glaciers from the Second Ice Age have retreated northwards and the cool climate has retreated up the mountains with species that have adapted to the climate (Inger & Tan, 1996; Plummer & McGeary, 1996; Cox & Moore, 2000; McNeely, 2000). Therefore, an assemblage of 'montane species' is grouped at the mountains like Gunung Kinabalu and Crocker Range. These become the refugia where organisms isolated by the habitats changes resulting from the periodic cold and dry periods of ice ages were able to survive until conditions returned to their former state and the organisms could then move out once again (McNeely, 2000). This explanation is also valid to elucidate the distributions of 'montane species' of frogs among Bornean mountains and mountain ranges across lowland gaps (Inger & Tan, 1996).

High range-size rarity is obvious at montane zones in Borneo. Frogs that live at high elevation have restricted distribution because they have adapted to the montane climate which does not exist throughout Borneo. Montane zones merely represent 6,007.22 km^2 of Sabah and 9,869.56 km^2 of Sarawak (Perumal, 2001). Hence, the total inverse range sizes covered by each species or range-size rarity is high at montane zones.

Low species richness and range-size rarity of frogs are at the mountainous central Borneo. The reason behind this could be a mixture of the actual distribution and paucity of biogeographical data of frogs from Kalimantan. As stated earlier on, montane zone is not favourable to most frogs. At the same time, relatively limited frogs inventories have been done in Kalimantan as a result of political as well as geographical causes (e.g., Das, 1995; Inger & Stuebing, 1997; Sutton, pers. comm.).

For all 139 species / genera of frogs to be represented at least once in the 1,057 grid cells for Borneo, it takes 16 near-minimum sets. The near-minimum sets correspond to a mere 1.51% of the total land mass of Borneo. Smaller coverage of near-minimum sets reflects better efficiency in the prioritization of conservation areas.

The near-minimum sets proffer a complete representation of the frogs diversity of Borneo and thus, hotspots by species richness can be ignored at this stage in order to avoid redundancy in representation. It is so unless the hotspots by species richness exist in combination with hotspots by range-size rarity and/or near-minimum sets. Therefore, 22 conservation priority areas (grid cells) in Borneo were identified by using WORLDMAP on the biogeographical data of frogs. The conservation priority areas cover the montane zones of Kinabalu Park, Crocker Range and Gunung Lumaku Forest Reserve, lowland to lower montane zones of Danum Valley Conservation Area, northwestern Maliau Basin Conservation Area and northwestern Tawau Hills Park in Sabah, montane zone of northeastern Gunung Mulu National Park, lower montane zone of Sungai Mengiong as well as lowland zones of Tubau, Batang Ai National Park and Kuching in Sarawak and Sanggau and Kubu in West Kalimantan.

Eighteen of the conservation priority areas are already in the current protected areas network. The other four conservation priority areas: Tubau and Sungai Mengiong in Sarawak as well as Sanggau and Kubu in West Kalimantan, are to be suggested as new protected areas in Borneo in order to achieve complete representation of the diversity and high range-size rarity of the frogs of Borneo.

Out of the four suggested new protected areas in Borneo, Tubau (Sarawak), Sanggau and Kubu (West Kalimantan) coincide with human settlements. The gazettment of protected areas at present cannot dismiss local communities, so they have to be involved and more importantly, made an active part of conservation efforts. As articulated by Fjeldsa & Rahbek (1998) and Fjeldsa (2000), the management of these suggested new protected areas needs to encompass political processes which include establishing and promoting new kinds of land use that are more environmentally sustainable.

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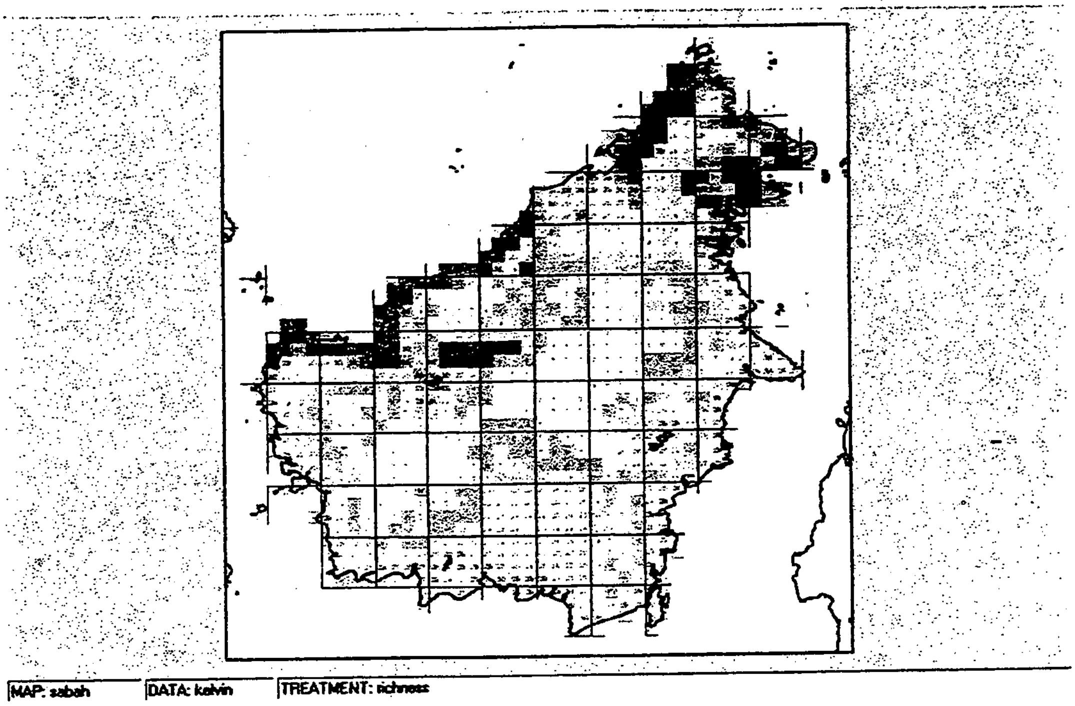

Figure 1 Species richness of the frogs of Borneo.

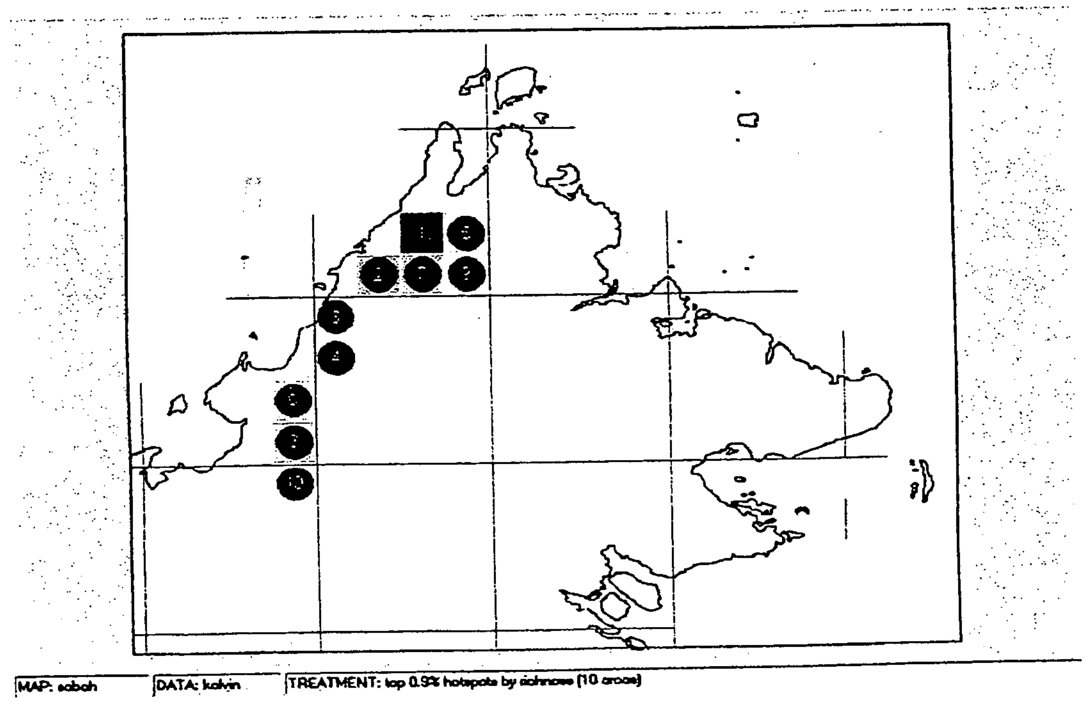

Figure 2 Top ten hotspots by species richness of the frogs of Borneo.

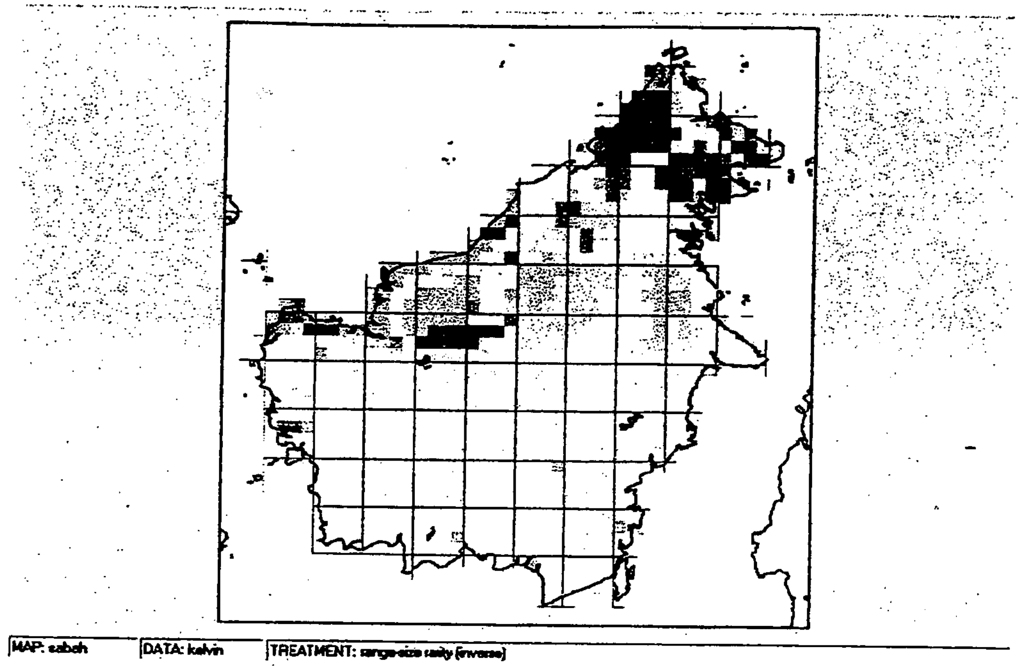

Figure 3 Range-size rarity of the frogs of Borneo.

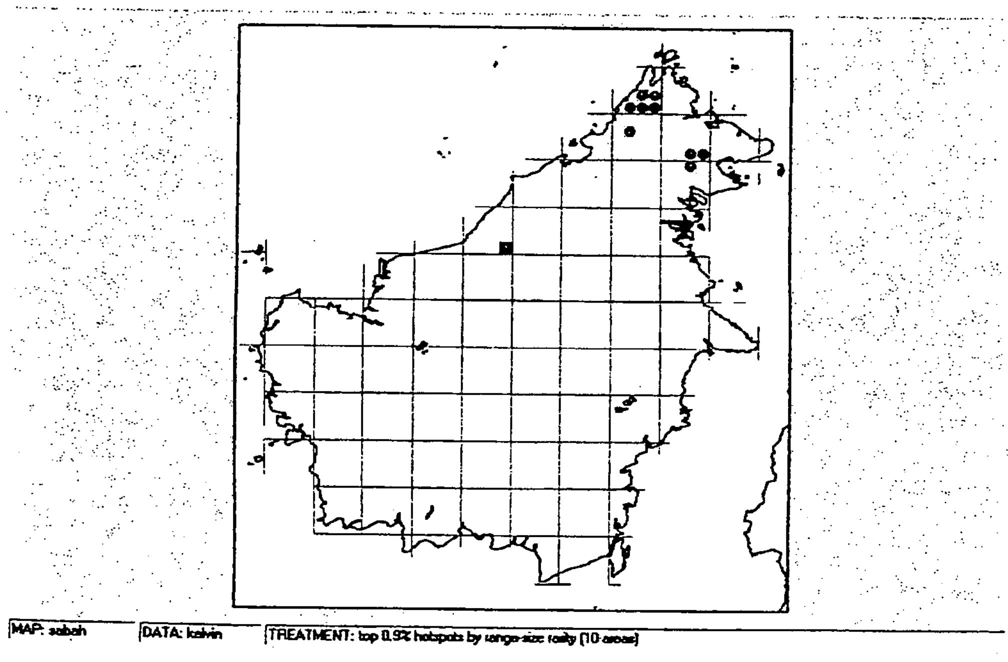

Figure 4 Top ten hotspots by range-size rarity of the frogs of Borneo.

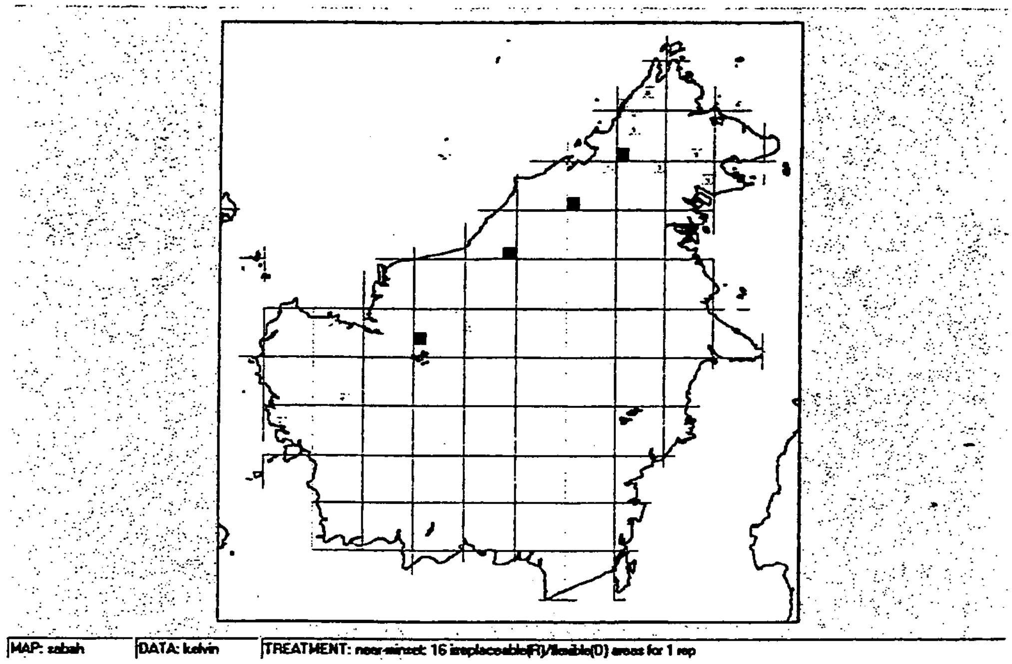

Figure 5 Near-minimum sets of the frogs of Borneo.

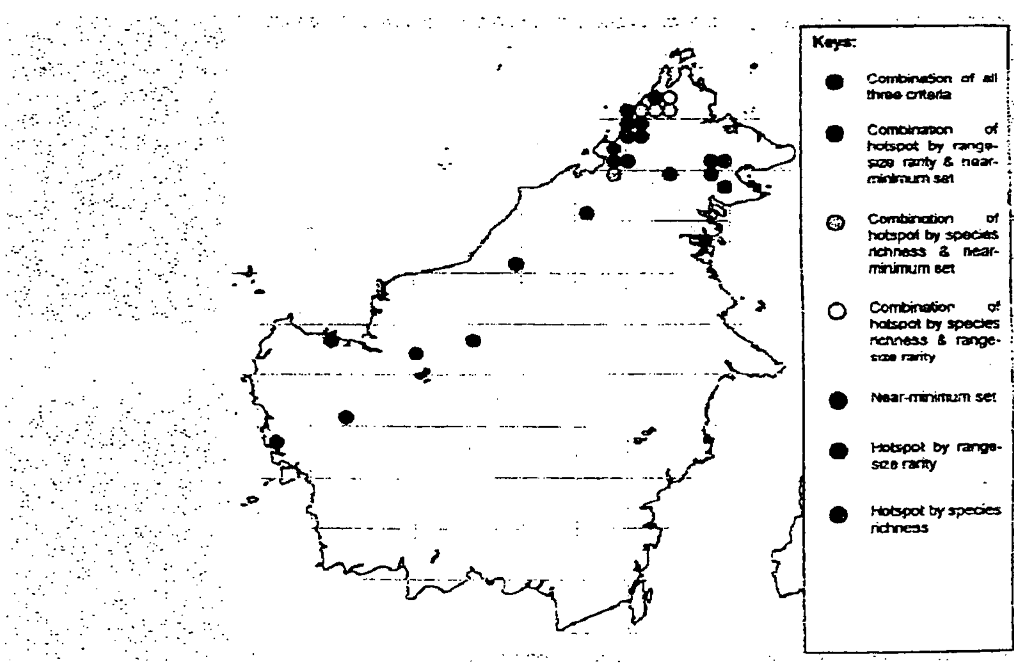

Figure 6 Combinations among hotspots by species richness, hotspots by range-size rarity and near-minimum sets.