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Conservation Gap Analysis of Dipterocarp Hotspots in Sarawak Using GIS, Remote Sensing and Herbarium Data

(Analisis Jurang dalam Pemeliharaan Dipterokap di Sarawak Menggunakan GIS, Penderiaan Kawalan Jauh dan Data Herbarium)

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ABSTRACT

Dipterocarpaceae is the dominant tree family in the tropical rain forests of Southeast Asia. Borneo is the centre of diversity for the dipterocarps. Identification of hotspots is important for forest and biodiversity conservation efforts. Species Occurrence Models (SOMs) were generated for all 247 species of dipterocarps recorded in Sarawak using herbarium occurrence data and based on the best model selected. The species occurrence density map for each genus and category (endemic and non endemic) was generated by overlaying the SOMs of all species in each genus or category. The species occurrence density maps were analyzed with land cover map from Landsat 7-EMT+ images and protected forest areas for identifying hotspots for conservation in Sarawak. Overlaying the SOM maps revealed that areas in central Sarawak and the southwest region (northwest Borneo around Kuching) are the main hotspots of dipterocarp diversity in Sarawak while the coastal lowland areas in the lower Rejang and Baram River which are mainly peat swamp forest are poorer in species occurrence density. In terms of endemism, as with dipterocarp diversity, the mixed diptercarp forest of central Sarawak is also the most important hotspot. Gap analysis revealed that most protected forest areas are in southwest Sarawak (Bako, Kubah, Tanjung Datu and Gunung Gading National Parks) and in the northern part of Sarawak (Niah, Lambir Hills and Mt Mulu National Parks). This leaves the hotspot in the central part of Sarawak least protected. Protected areas only cover between 2 and 4% of the total areas for the different hotspots (75% species density) while majority of the hotspots that are still forested are outside the protected areas.

Keywords: Dipterocarps; endemic; non-endemic; protected areas; Sarawak

ABSTRAK

Dipterocarpaceae merupakan famili pokok dominan hutan hujan tropika Asia Tenggara. Borneo adalah pusat kepelbagaian dipterokarpa. Pengenalpastian titik panas adalah penting dalam usaha pemeliharaan kepelbagaian biologi dan hutan. Model Kehadiran Spesies (SOMs) diperoleh untuk kesemua 24 spesies dipterokarpa yang direkod di Sarawak menggunakan data herbarium serta memilih model terbaik. Peta kepadatan spesies bagi setiap genus dan kategori (endemik dan bukan endemik) diperoleh dengan menindih kesemua SOM bagi kesemua spesies di dalam setiap genus atau kategori. Peta kepadatan spesies ditindih dengan peta penutupan bumi daripada imej Landsat 7-EMT+ dan kawasan hutan terlindung untuk pengenalpastian titik panas untuk pemeliharaan di Sarawak. Pertindihan peta SOM menunjukkan bahawa kawasan di Sarawak tengah dan kawasan barat daya (barat laut Borneo sekitar Kuching) merupakan titik panas utama kepelbagaian dipterokarpa di Sarawak manakala kawasan tanah rendah di hilir Sungai Rejang dan Sungai Baram yang merupakan hutan gambut adalah rendah kepadatan spesiesnya. Daripada segi endemisme, seperti kepelbagaian dipterokarpa, hutan dipterokarpa campuran Sarawak tengah adalah titik panas yang paling penting. Analisis jurang menunjukkan bahawa kawasan hutan terlindung yang paling banyak adalah di barat daya Sarawak (Taman Negara Bako, Kubah, Tanjung Datu dan Gunung Gading) dan di sebelah bahagian utara Sarawak (Taman Negara Niah, Bukit Lambir dan Gunung Mulu). Ini meninggalkan titik panas di bahagian tengah Sarawak paling kurang terlindung. Kawasan terlindung hanya merangkumi antara 2 dan 4% keseluruhan kawasan bagi pelbagai titik panas (75% kepadatan spesies) manakala titik panas selebihnya adalah di luar kawasan terlindung.

Kata kunci: Dipterokarpa; endemik; kawasan terlindung; Sarawak; tidak endemik

INTRODUCTION

Dipterocarps are the dominant tree species of the tropical forests of Southeast Asia. Borneo is the centre of diversity of this important timber-producing tree family, where at least 267 species are recorded (Ashton 2004). The northern part of Borneo is thought to be a refugium for plant species during the last ice-age (Corner 1960; Wong 1998). This is illustrated by the fact that Sarawak in northern Borneo alone harbours 247 or 92% of all species recorded from Borneo. In order to conserve dipterocarps, identification of hotspots is important for forest conservation and management efforts. However, many natural areas are large, making it unfeasible to inventory the entire area and necessitating the use of Species Occurrence Models (SOMs) to identify hotspots and conservation gap. Provided appropriate data and methods are used, species density maps can be generated and hotspots identified for the species and area of interest which will be of use for biodiversity conservation. This study aimed to identify hotspots for diversity and endemism specific to dipterocarp to be used for conservation gap analysis at a landscape scale through an integrated approach that combines remote sensing, GIS and field data.

A gap analysis is a technique for determining the steps to be taken in moving from the current state to a desired future-state. A gap analysis is necessary to compare the current situation and the need to improve it. Gap analysis is also used in biodiversity conservation to identify gaps in conservation lands (protected areas and nature reserves) or other wildlands where significant plant and animal species and their habitat or important ecological features occur. Conservation managers or scientists can use it as a basis for providing recommendations to improve the representativeness of nature reserves or the effectiveness of the protected areas so that these areas provide the best value for conserving biological diversity.

The term 'Biodiversity hotspots' was first coined by Myers (1989, 1990). Hotspots have been defined based on both species richness and endemism. McNeely et al. (1990) noted that megadiversity countries, for example, are nations that either have extremely species richness of plants and vertebrates (Brazil, Colombia and Indonesia) or are relatively less species rich but have extremely high level of endemism. Plant-diversity hotspots on a global scale are well established, but smaller local hotspots within these must be identified for effective conservation of plants at the global and local scales (Murray-Smith et al. 2009).

Probabilistic or predictive mapping using GIS has been used to identify areas for conservation and has variously been used for conservation of owl through identification of its breeding site (Browyn et al. 2008) and identification of habitat for species richness, diversity and biomass of the habitat of reef fish (Anders et al. 2010). Probabilistic or predictive mapping of plant species has been employed for conservation gap analysis such as in a Southern Mongolian Mountain Range (von Wehrden et al. 2009) and the Mediterranean (Vogiatzakis et al. 2008).

The goal of a gap analysis is to identify those species and plant communities that are not adequately represented on the existing conservation lands. By identifying their habitats, gap analysis gives land managers, planners, scientists and policy makers the information they need to make better-informed decisions when identifying priority areas for conservation (Anon. 2011). Only by protecting regions already rich in habitat can we adequately protect the plant and animal species that inhabit them and gap analysis can indicate how well plants and animals are protected (Anon. 2011). The gap analysis programme has been carried out in the United States and uses hotspots to identify gaps in the existing network of protected areas (Kiester et al. 1996; Scott et al. 1993).

Raes et al. (2009) identifies hotspot of diversity and endemism in Borneo for all species taxonomically revised in Flora Malesiana project by overlapping all their Species Distribiton Models. However, they combined plants of different life-form (Epiphytes- orchids and trees/shrubs –Euphorbiaceae) which can have different distributional pattern. It should be noted that species-rich areas or hotspots frequently do not coincide for different taxa (Flather et al. 1997; Prendengast et al. 1993). Besides, Raes et al. (2009) study taxa that form mycorrhizal association (Dipterocarpaceae) and those that do not (Euphorbiaceae).

Materials and Methods

Four models (two statistical – binary logistic regression (BLR) and multivariate adaptive regression spline (MARS)) analyses and two geostatistical models (Inverse Distance weighting (IDW) and Universal Kriging (UK) were tested using ten dipterocarp species (three genera) for the best species occurrence model based on prediction accuracy. The accuracy assessment indicates that IDW produces the best model. IDW and UK produce an average accuracy of about 85% and 70%, respectively, while statistical models give an average accuracy of 60% for MARS while BLR produces no results for a few of the species. The study area encompasses the whole of Sarawak.

SOMs were therefore generated for all 247 species of dipterocarps in Sarawak using the IDW model by means of ArcGis 9.0 software. The species occurrence density map for each genus was then generated by overlaying the SOMs of all species in that genus. Similarly, overlay of SOMs of all endemic dipterocarp species or generated the endemic species or non-endemic species occurrence density maps. SOMs of species belonging to the respective category (non-endemic species, endemic (Borneo), endemic (Sarawak) and species belonging to the each of the nine genus) were added using raster calculator in ArcGis 9.0. The resulting species density maps for the whole of Sarawak were then reclassed into 4 classes (i.e. 0-25%, 26-50%, 51-75% and 76-100%) expressed in percentage of the total species in that genus or category. For instance, if the species occurrence density of a particular genus is 5 and the total number of species in that genus is 28, therefore the percentage will be $5/28 \times 100\% = 17.8\%$ and falls under the class 0-25%. Hotspots of diversity and endemism (represented by the 76-100% class) were then identified from the reclassed density maps. The total areas of hotspots inside and outside the Protected Areas as well as in forested and deforested areas were determined using the overlapping Protected Areas and Land Cover (from Landsat 7 ETM+ images) maps.

Results

Hotspots for diversity and endemism

Overall, the major hotspot for dipterocarp diversity is in central Sarawak irrespective of endemics or non-

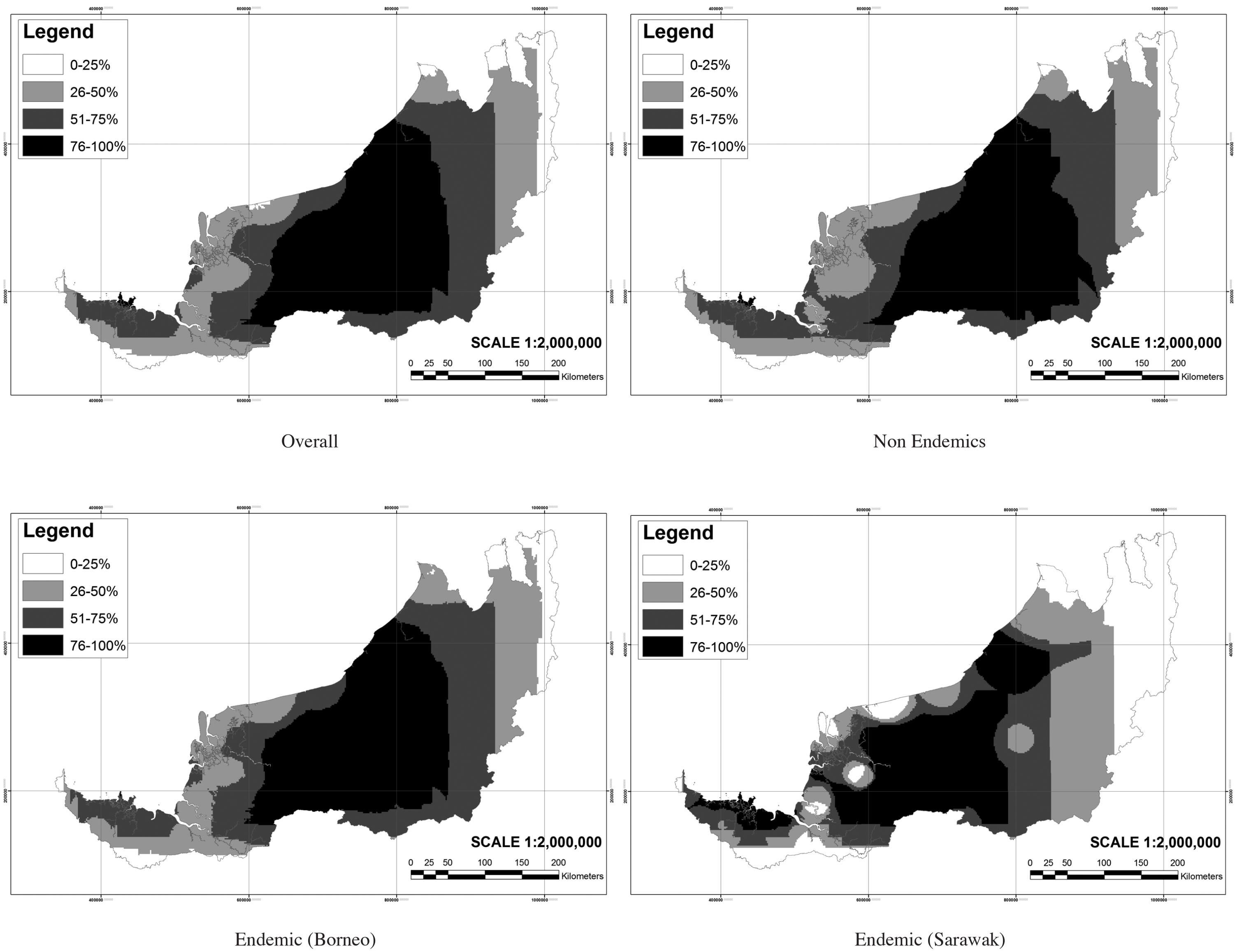


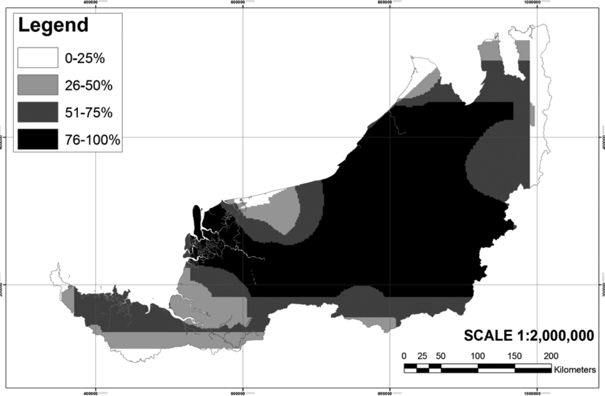
FIGURE 1. Species density maps for overall, non endemic species, endemic species (Borneo) and endemic species (Sarawak)

endemics (Figure 1). For Sarawak's endemic species, southwest Sarawak is the other major hotspot apart from central part of Sarawak and as secondary hotspot for non endemic as well as Borneo's endemic species (Figure 1). Areas with low species density are in the main coastal peat swamp areas of the Lower Rejang, Kuala Baram as well as around Lawas and Limbang. The species density maps of the non-endemics and endemics are shown in Figure 1.

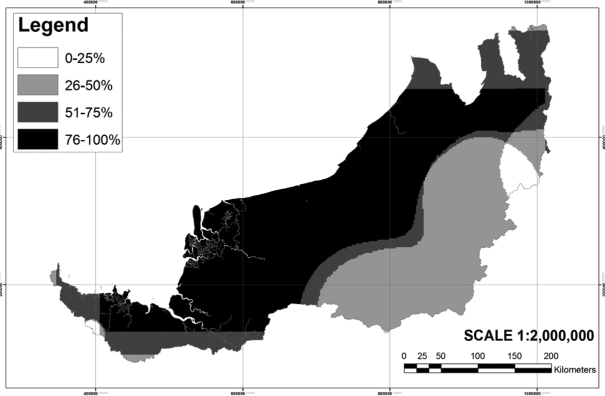
For the nine genera of the dipterocarps found in Sarawak, the hotspot of species density are more or less similar as the endemic and non endemic species density maps (Figure 2). The main hotspot region is in central Sarawak for all the genera with southeast Sarawak as primary hotspot for genera like *Cotylelobium*, *Dryobalanops*, *Parashorea*, *Shorea*, *Upuna* and *Vatica* and as secondary hotspot for *Anisoptera*, *Dipterocarpus*, *Hopea*. Figure 2 shows the species density maps for all the nine genera.

GAP ANALYSIS

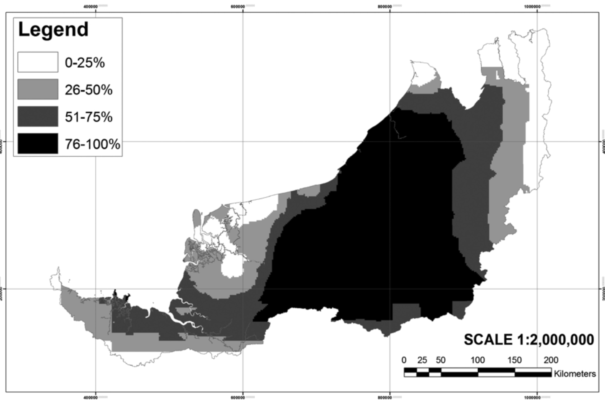
Overall Overall, this study shows that only a mere 3% of the area with high diversity (those with species density



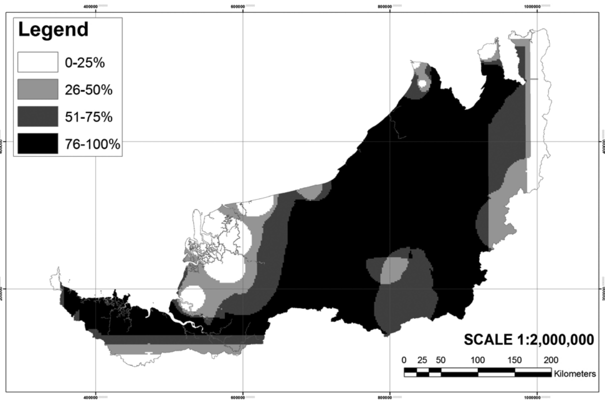
(a) *Anisoptera*



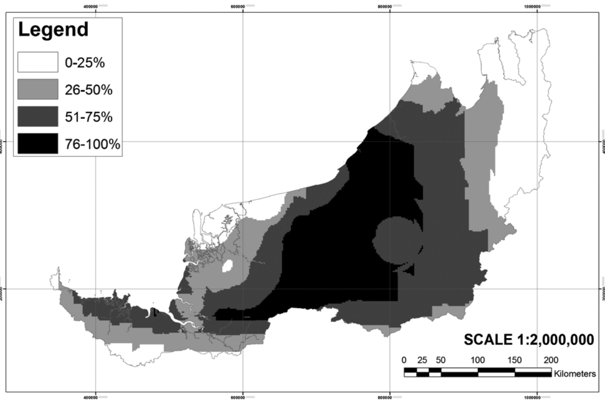
(b) *Cotylelobium*



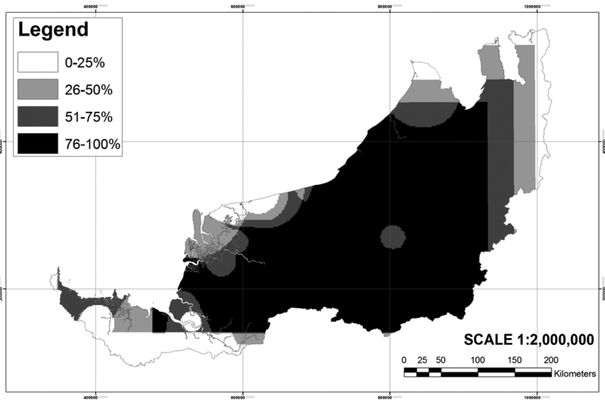
(c) *Dipterocarpus*



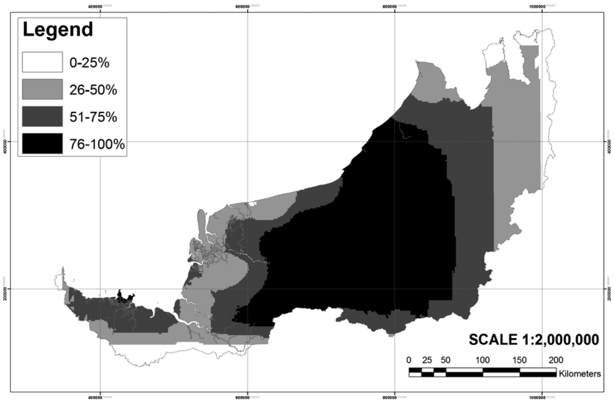
(d) *Dryobalanops*



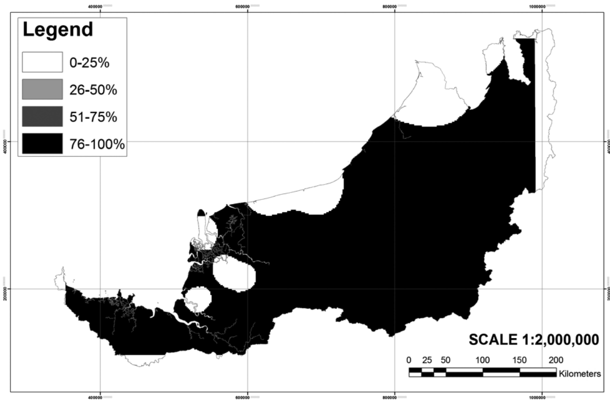
(e) *Hopea*



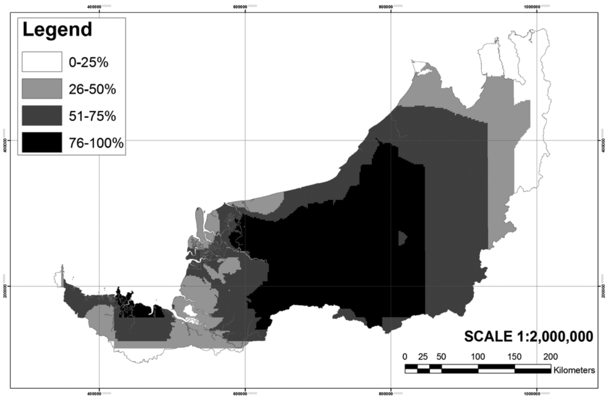
(f) *Parashorea*



(g) *Shorea*



(h) *Upuna*



(i) *Vatica*

FIGURE 2. Species density maps for the nine genera of dipterocarps in Sarawak

>75% of the total dipterocarp species) or hotspots are inside the protected areas while the majority (97%) are outside the protected areas with only 28% that are still with primary forest. Table 1 and Figure 3 illustrate the situation.

Endemic/non-endemic For Borneo's and Sarawak's endemic dipterocarp species, only about 3 and 4% of the total area of Sarawak (with species density >75% of the total endemic species) are inside the protected areas, respectively (Table 2). For area outside the protected areas, about 69 and 72% are still with intact natural forest for area of high species density (>75%) for Borneo's and Sarawak's endemic, respectively (Figure 4). This indicates that diptercarp species, irrespective of endemic or non endemic, are inadequately conserved in Protected Areas.

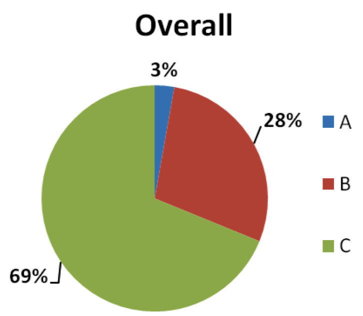


FIGURE 3. Percentage of hotspot area (>75% species density) inside Protected Areas (A), area outside protected area but with primary forest cover (B) and area outside Protected areas but without primary forest cover (C)

TABLE 1. Area size (sq km) under the different land categories for the respective percentage of total species class

	Area inside protected areas (sq km)	Area outside protected areas (sq km)	Area outside protected areas with primary forest (sq km)
0 – 25%	331	7048	41901
26 – 50%	1433	28465	9788
51 – 75%	1357	39106	13614
76 – 100%	1767	43763	18052

TABLE 2. Area size (sq km) under the different land categories for the respective percentage of total species class

	Area inside protected areas (sq km)			Area outside protected areas (sq km)			Area outside protected areas with primary forest (sq km)		
	NE	EB	ES	NE	EB	ES	NE	EB	ES
0 – 25%	314	307	1423	6272	6553	24230	3926	28750	13229
26 – 50%	1138	1512	978	29186	28154	32618	9764	10075	11583
51 – 75%	2139	1336	567	37260	38616	26065	12910	13486	88810
76 – 100%	1297	1733	1922	45662	45058	35467	19045	18130	11961

NE – Non Endemic EB – Endemic Borneo ES – Endemic Sarawak

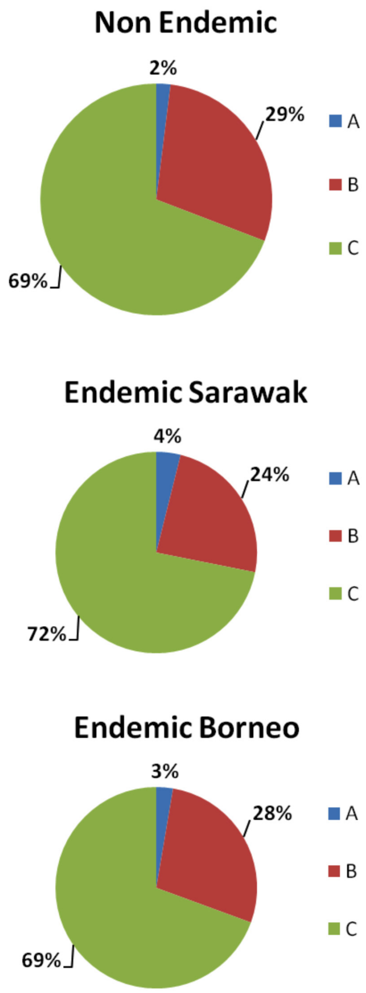


FIGURE 4. Percentage of hotspot area (>75% of the total species) inside Protected Areas (A), area outside protected area but with primary forest cover (B) and area outside Protected areas but without primary forest cover (C)

Dipterocarp Genera Similarly, for the different dipterocarp genera, areas with >75% species density or hotspot inside the protected area for the respective genus form only between 1.6 and 3.8% of the total Sarawak area (Figure 5) while those outside protected areas with intact natural forest cover ranges between 25 and 29%. This demonstrated that all genera of dipterocarps are also inadequately protected or conserved in the Protected Areas system in Sarawak (Tables 3, 4 & 5; Figure 5).

DISCUSSION

HOTSPOTS FOR DIVERSITY AND ENDEMISM

The results show that the location of hotspots for endemic and non-endemic species as well as the various genera do not differ significantly from each other. The Central Region of Sarawak as well as the southern part (northwest Borneo) appears to be the hotspots for both diversity and endemism for non-endemics and endemics alike as well all the dipterocarp genera in Sarawak. The areas with low diversity and endemism appear to be the coastal peat swamp areas that include the lower Rejang and Baram Rivers as well as around Limbang and Lawas. The results reinforce the region of high plant diversity in central Sarawak noted by McKinnon et al. (1996) and southwest Sarawak identified by Raes et al. (2009) as areas of high diversity and endemism for all the plant species taxonomically revised in the Flora Malesiana. Apart from that, WWF and IUCN (1995) also recorded an area in southwest Borneo as well as a few spots in central Sarawak as areas of high plant diversity.

Ashton (2004) noted that the central region of Sarawak is an overlap of three distinct phytogeographical provinces for dipterocarps:

1. North of the line from Pontianak following Kapuas River to Kapuas Lakes in Kalimantan and then across the Sarawak lowlands to Sipitang district in SW Sabah (a Borneo's extension of Corner's Riau Pocket- *Shorea curtisii* Dyer ex Brandis, *Shorea atrinervosa* Symington, *Shorea balanocarpoides* Symington, *Shorea bracteolata* Dyer). During the last Ice Age (Pleistocene), sea levels were lower (about 100-200 m) than present day and the sea that separates Peninsular Malaysia, Java, Sumatra, Borneo and the Riau Islands today were a continuous land mass then (known as Sunda Shelf) (Corner 1960). The sea then moved back up (at its maximum return about 40 m above its present level) and the land was once again divided leaving the Riau Pocket of related and relatively rare flora around widely dispersed part of the region (Corner 1960). There are two subprovinces of the Riau

TABLE 3. Land area inside protected areas for the different genera of dipterocarps under the various species density classes (in percentage)

	0 - 25%	26 - 50%	51 - 75%	76 - 100%
Anisoptera	373	611	2411	1493
Cotylelobium	1	1027	541	3321
Dipterocarpus	586	641	2437	1225
Dryobalanops	398	322	1202	2966
Parashorea	333	6787	1073	2805
Hopea	825	1353	1503	1208
Shorea	272	1529	1193	1896
Upuna	517	Nil	Nil	4372
Vatica	734	1181	1300	1674

TABLE 4. Land area outside protected areas for the different genera of dipterocarps under the various species density classes (in percentage)

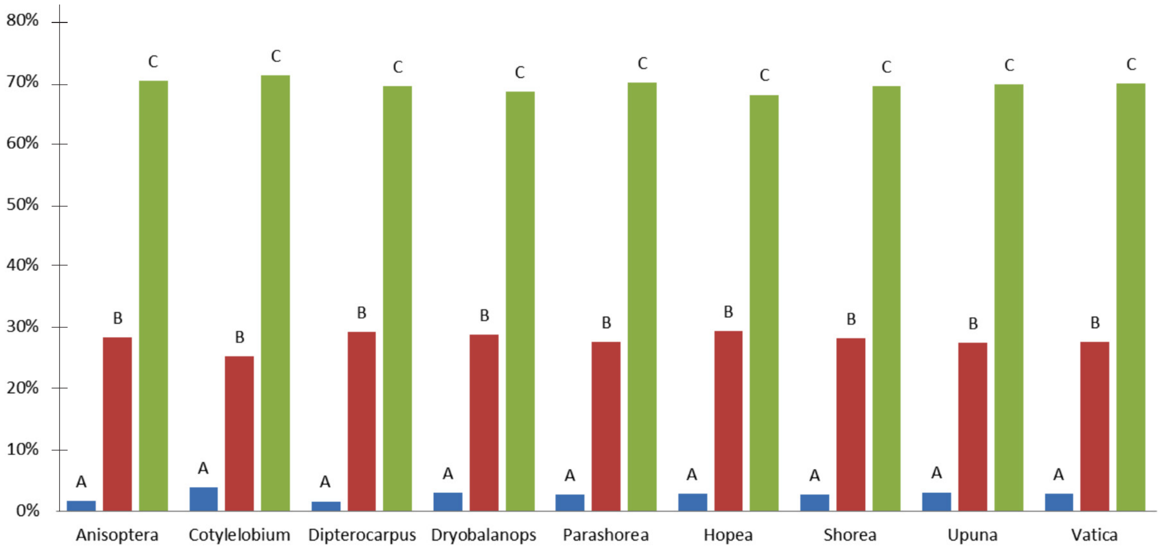
	0 - 25%	26 - 50%	51 - 75%	76 – 100%
Anisoptera	72417	14886	31779	64474
Cotylelobium	26116	34615	19120	62035
Dipterocarpus	13382	23302	27638	54058
Dryobalanops	13387	13925	22695	68374
Parashorea	13438	13719	16753	74470
Hopea	20646	25429	43321	28985
Shorea	7120	28033	34418	48809
Upuna	18614	Nil	Nil	99768
Vatica	9890	228020	44788	40902

TABLE 5. Land area outside protected areas with primary forest cover for the different genera of dipterocarps under the various species density classes (in percentage)

	0 - 25%	26 - 50%	51 - 75%	76 – 100%
Anisoptera	3776	2862	12983	26024
Cotylelobium	18237	14575	7215	22030
Dipterocarpus	5381	7521	99337	22809
Dryobalanops	4104	4304	84868	28750
Parashorea	3788	5615	67921	29449
Hopea	10627	6931	15561	12526
Shorea	3392	10670	11748	19835
Upuna	7184	Nil	Nil	39360
Vatica	6345	8336	14793	16171

Pocket divided by the Lupar River. There are 'Riau Pocket' species that occurs on both side of the Lupar River which others are confined to either east or west (*Shorea dealbata* Foxw., *Shorea resinosa* Foxw.) of the geological divide;

2. Lowland province from Sandakan district in East Sabah southwards to Balikpapan and beyond in Northeast Kalimantan and includes some Philippines species, some of which extend westward to Northeast Sarawak and Brunei (*Shorea almon* Foxw., *Shorea argentifolia* Symington, *Shorea biawak* Ashton). Most of the species of the third province that extend to NE Sarawak reach up to Bintulu or Kapit/Belaga (*Shorea confusa* Ashton) area;
3. Central Borneo uplands centred around the Rejang hinterland extending to Ulu Barito, Kayan and Kapuas



A- Area inside protected area
B- Area outside protected areas but with primary forest cover
C- Area outside protected areas but without primary forest cover

FIGURE 5. Gap analysis for the different genera of dipterocarps for area with >75% of the total species in each genus

hinterland (*Shorea chaina* Ashton, *Shorea dispar* Ashton, *Shorea praestans* Ashton, *Shorea rotundifolia* Ashton) in Sarawak. Besides, Ashton (2004) noted that there are still other undescribed and inadequately known species found only in central Sarawak. The overlapping of these three phytoprovinces explains why central Sarawak is the major hotspot for dipterocarps in Sarawak.

The southwest Sarawak represents the 'Riau Pocket' province of Corner (1960). Besides, southwest Sarawak represents one of the two subprovinces of the 'Riau Pocket' divided by the Lupar River, the subprovince west of the Lupar River. A number of the 'Riau Pocket' species are restricted or do not cross the Lupar River which contribute to the uniqueness of this subprovince. The southwest Sarawak hotspots around Kuching is also characterized by a heterogenous assemblage of different soil and geological types in a small area and geologically older than the rest of Sarawak (Hutchinson 2005; Wilford 1955) which also carries endemics such as *Shorea bakoensis* Ashton, *Shorea alutacea* Ashton and *Hopea depressinerva* Ashton) which are only endemic to the southwest Sarawak region.

GAP ANALYSIS

The gap analysis revealed that most protected forest areas are in southwest Sarawak (Bako, Kubah and Gunung Gading National Parks) and in the northern part of Sarawak (Niah and Lambir National Parks). This leaves the hotspots in the central part of Sarawak which is the major hotspot of dipterocarp diversity and endemism least protected (Figure 6). This study further justifies the need and urgency to gazette the proposed Protected Areas in central Sarawak like the Proposed Hose Mountains-Batu Laga National Park, the Proposed Bukit Sarang National Park, the Proposed Bukit Mersing National Park as well as the Proposed Bukit Kana National Park and other forested areas in the central region as the current protected areas in the northeast and southwest Sarawak are not adequate.

CONCLUSION

This study identified the hotspots for dipterocarps diversity and endemism through the manipulation of Geographical Information Systems (GIS) using the SOMs. Identification of the hotspots is of value for dipterocarp biodiversity conservation. From this study, it is demonstrated that dipterocarp diversity hotspots are inadequately conserved inside the current system of Protected Areas (P.A.). The Protected Area system under-represents areas of high diversity, particularly in central Sarawak. Therefore, Sarawak's Protected Area system needs to be expanded to include those that are identified in this study, especially those in central Sarawak.

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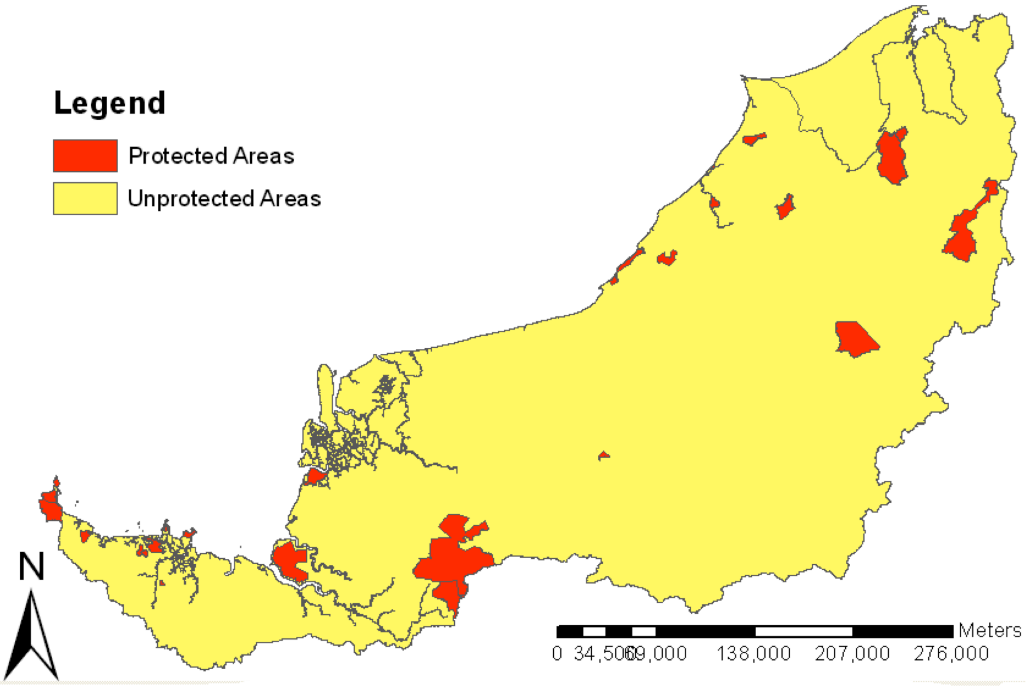

FIGURE 6. Totally protected areas for conservation in Sarawak

REFERENCES

Anders, K., LeDrew, E. & Brenning, A. 2010. Predictive mapping of reef fish species richness, diversity and biomass in Zanzibar using IKONOS imagery and machine-learning techniques. *Remote Sensing of Environment* 114(6): 1230-1241.

Anon. 2011. What is GAP? http://www.nbii.gov/portal/server.pt/gateway/PTARGS_0_2_17620_1849_6868_43/http%3B/cbi-lap7.cbi.cr.usgs.gov%3B7097/publishedcontent/. accessed on 7th January, 2011.

Ashton, P.S. 2004. Dipterocarpaceae. In *Tree Flora of Sabah and Sarawak* edited by Soepadmo, E., Saw, L.G. & Chung, C.K. R. FRIM, Forest Departments Sabah and Sarawak 5: 63-388.

Bronwyn, I., Cooke, R., Simmons, D. & Hogan, F. 2008. Predictive mapping of powerful owl (*Ninox strenua*) breeding sites using Geographical Information Systems (GIS) in urban Melbourne, Australia. *Landscape and Urban Planning* 84(3-4): 212-218.

Corner, E.J.H. 1960. The Malayan flora. In *Proc. Centenary and Bicentenary Congress of Biology*, edited by Purchon, R.D. Singapore.

Flather, C.H., Wilson, K.R., Dean, D.J. & McComb, W.C. 1997. Identifying gaps in conservation networks: Of indicators and uncertainty in geographic-based analyses. *Ecological Applications* 7(2): 531-542.

Hutchinson, C.S. 2005. *Geology of North-West Borneo: Sarawak, Brunei and Sabah*. Elsevier.

Kiester, A.R., Scott, M.J., Csuti, B., Noss, R., Butterfield, F., Sahr, B.K. & White, D. 1996. Conservation prioritation using GAP data. *Conservation Biology* 10: 1332-1342.

MacKinnon, K., Hatta, G., Halim, H. & Mangalik, A. 1996. *The Ecology of Kalimantan*. Ecology of Indonesia series. Periplus Edition.

McNeely, J.A., Miller, K.R., Read, W.V., Mittermeier, R.A. & Werner, T.B. 1990. Conserving the world's biodiversity. International Union for the Conservation of Natre and Natural Resources, the World Conservation Union, the World Resources Institute, Conservation International, Worldwide Fund for Nature and the World Bank, Gland, Switzerland and Washington. D.C.

Murray-Smith, C., Brummitt, N.A., Oliveira-Filho, A.T., Bachman, S.M., Lughadha, J., Eimear, M.N. & Lucas, E.J. 2009. Plant diversity hotspots in the Atlantic Coastal Forests of Brazil. *Conservation Biology* 23(1): 151-163(13).

Myers, N. 1989. Threatened biotas: 'Hotspots' in Tropical Forests. *Environmentalist* 8: 1-20.

Myers, N. 1990. The biodiversity challenge: Expanded hotspots analysis. *Environmentalist* 10: 243-256.

Prendergast, J.R., Quinn, R.M., Lawton, J.H., Eversham, B.C. & Gibbons, D.W. 1993. Rare species, the coincidence of diversity hotspots and conservation strategies. *Nature* 365: 335-337.

Raes, N., Roos, M.C., Ferry Slik, J.W.F., van Loon, E.E. & ter Steege, H. 2009. Botanical richness and endemicity patterns of Borneo derived from species distribution models. *Ecography* 32: 180-192.

Scott, J.M., Davis, F., Csuti, B., Noss, R., Butterfield, B., Groves, C., Anderson, H., Caicco, S., D'Erchia, F., Edwards, Jr.T.C., Ulliman, J. & Wright, R.G. 1993. Gap Analysis: A geographical approach to protection of biological diversity. *Wildlife Monograph* 123: 1-41.

Vogiatzakis, I.N., Mannion, A.M. & Griffiths, G.H. 2008. Mediterranean ecosystems: Problems and tools for conservation progress. *Physical Geography* 30(2): 175-200.

von Wehrden, H., Zimmermann, H., Hanspach, J., Ronnenberg, K. & Wesche, K. 2009. Predictive mapping of plant species and communities using GIS and landsat data in a Southern Mongolian mountain range. *Folia Geobotanica* 44(3): 211-225.

Wilford, G.E. 1955. *Geology and Mineral Resources of the Kuching-Lundu Area, West Sarawak Including the Bau*

Mining District. *Kuching, Sarawak*. Geological Survey Dept., British Territories in Borneo. pp. 254 (OCoLC)606421811.

Wong, K.M. 1998. Pattern in plant endemism and rarity in Borneo and Malay Peninsula. In *Rare, Threatened and Endangered Plants of Asia and the Pacific Rim,* edited by Peng, C.I. & Lowry, I. Monograph 16. Institute of Botany, Academia Sinica. pp. 39-169.

WWF and IUCN. 1995. *Centres of Plant Diversity, A Guide and Strategy for Their Conservation*. Vol. 2. Asia, Australasia and the Pacific – The World Wide Fund for Nature and the IUCN – The World Conservation Union.

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