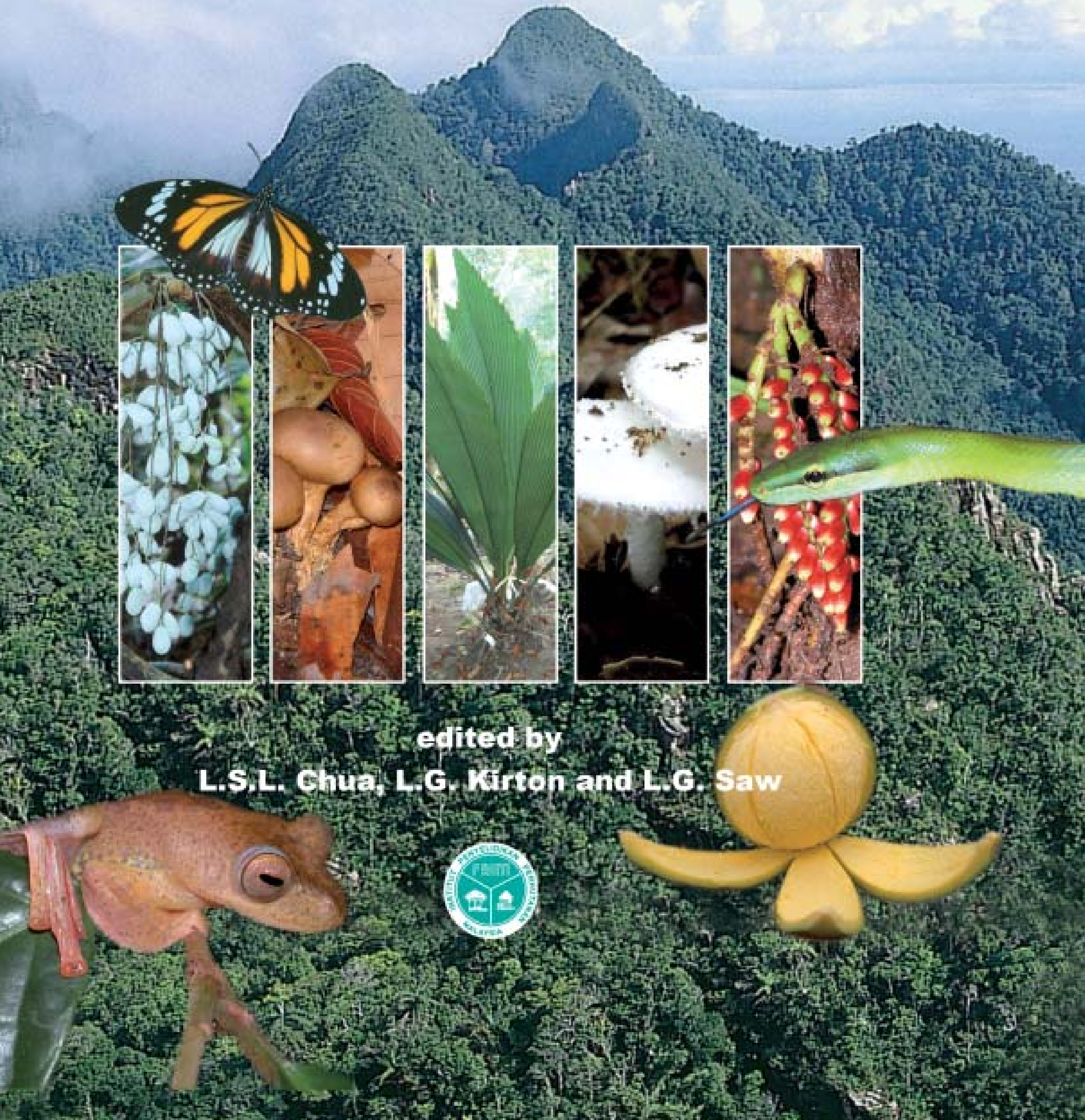
Status of Biological Diversity in Malaysia and Threat Assessment of Plant Species in Malaysia

Proceedings of the Seminar and Workshop

28–30 June 2005



edited by

L.S.L. Chua, L.G. Kirton and L.G. Saw

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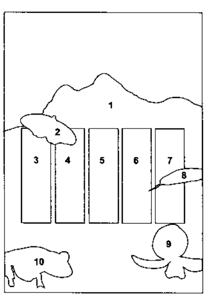

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1. Machinchang Range, Langkawi Islands. Photo courtesy L.S.L. Chua
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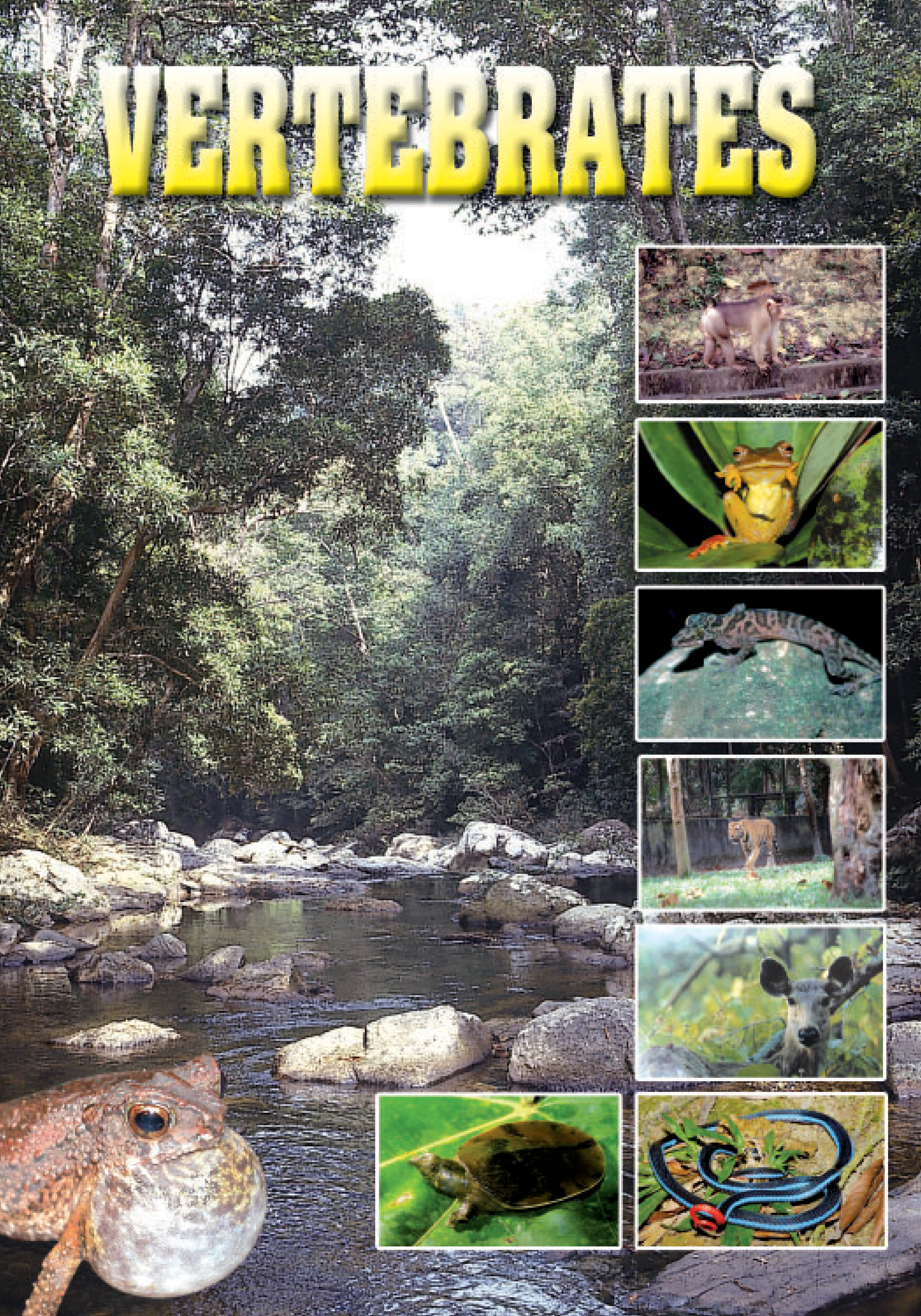
Foreword

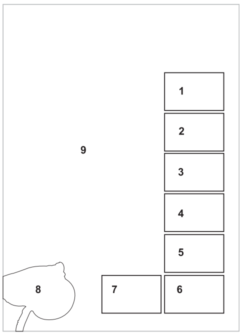
This publication is of great significance to Malaysia. Malaysia's National Policy on Biological Diversity, formulated in 1998, set the agenda for biological diversity research in Malaysia. Prior to this, however, many decades of research work has been dedicated towards unravelling the extent of our country's biodiversity and in more recent decades, on its conservation. Tremendous amount of work has been done and much has been learned about Malaysia's diverse biota and its conservation status. While much of this work has been published in notable journals or presented in international forums, this seminar was unusual in concentrating on biodiversity inventory, specimen collections, and status of knowledge and expertise in Malaysia. The Proceedings, culminating from a national forum held in June 2005, present the most recent revisions and additions to the checklists in their respective taxonomic fields. The Proceedings also contain some findings with respect to threat assessment and conservation status of plant species in Malaysia. In particular, the Proceedings highlight areas where information is absent and where future research attention should be given.

I am convinced that the Proceedings mark another milestone in a series of long-awaited actions aimed at improving the conservation of the unique and diverse flora and fauna of Malaysia. The Proceedings will further harness the cooperation between the network of scientists and forestry officers dedicated to the monitoring, protection and conservation of our rich and diverse botanic heritage. Finally I wish to express my sincere appreciation to the paper presenters and to all research groups working diligently behind the scenes.

Dato' Dr. Hj. Abdul Razak Mohd. Ali
Director General
Forest Research Institute Malaysia

VERTEBRATES





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THE STATUS OF MAMMALIAN BIODIVERSITY IN MALAYSIA

[1]G.W.H. Davison & [2]Zubaid Akbar

ABSTRACT

There are approximately 298 valid named species of non-marine mammals within the political borders of Malaysia. This total includes 229 species in Peninsular Malaysia, and 221 species in East Malaysia (Sabah and Sarawak), of which 152 species are shared. Over the past 22 years the list for Peninsular Malaysia has expanded by 22, and over the past 25 years the list for East Malaysia has expanded by 30. Most of the additions are bats. Two genera of mammals (*Pithecheirops, Diplogale*) and 30 species are endemic to Malaysia, so far as records now show. Biodiversity questions range from historical uncertainty, to the definition of geographical limits, continued survival, synonymy, species already described elsewhere but newly recorded (various examples) and taxonomy of cryptic species. Since these questions are so varied in type, scattered across a range of taxa, and each involve few species, it will be inefficient to focus research effort on a major untargetted build-up of museum specimens. Two important fields to concentrate on are genetic diversity/biosystematics (including within-species diversity), and conservation (population dynamics, habitat availability, community structure). These will be important for retaining the genetic viability of increasingly fragmented populations of forest mammals, and can only be effective if adequate resources are available to support research as well as management posts with associated capacity-building.

INTRODUCTION

The status of the biodiversity of mammals, like that of other biological groups, can be divided into two main themes: first, the description of the diversity that exists at the various genetic, population and species levels of taxonomy; and second, documenting the changes in numbers of each species in the wild, as a response to development and other pressures.

Knowledge about the total number of mammal species that occur in Malaysia is still increasing rapidly, and there are still several taxonomically difficult groups (for example *Cynopterus; Crocidura; Myotis; Haeromys; Petaurillus; Glyphotes*). There are approximately 298 valid named species of non-marine mammals within the political borders of Malaysia (Table 1;

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Appendix), and perhaps another four known but unnamed species. This total includes 229 species in Peninsular Malaysia, and 221 species in East Malaysia (Sabah and Sarawak), of which 152 species are shared. This means that 77 of the species in Peninsular Malaysia have not been found in Sabah or Sarawak, and for 68 species the reverse is true. Over the past 22 years there have been 23 additions and one deletion (a mongoose) from the list for Peninsular Malaysia. One species (Javan Rhino *Rhinoceros sondaicus*) has become locally extinct there in historical time. Over the past 25 years there have been 31 additions and one deletion (the squirrel *Glyphotes canalvus*, sunk in the synonymy of *Callosciurus orestes*) to the list in East Malaysia. Nearly all of the additions are of bats.

Table 1. Diversity of mammals in the three major political divisions of Malaysia*.

	Peninsular Malaysia	Sarawak	Sabah	Sabah & Sarawak
Total species recorded	229	180	203	221
Total genera recorded	108	98	104	105
Total families recorded	32	30	31	31
Non-bats	123	118	120	129
Most speciose orders	Bats (106), Rodents (55)	Bats (62), Rodents (56)	Bats (83), Rodents (58)	Bats (92), Rodents (62)
Most speciose genera	*Rhinolophus* (18), *Hipposideros* (18), *Myotis* (9)	*Rhinolophus* (8), *Hipposideros* (8), *Tupaia* (8),	*Myotis* (10), *Rhinolophus* (8) *Tupaia* (8)	*Hipposideros* (11), *Rhinolophu* (10), *Myotis* (10)
No. of genera with 1 species	63	58	61	61
No. of families with 1 species	9	12 (2†)	13	13
No. of orders with 1 species	3	2	3	3

* Compiled after various authors.

† The two families that were each represented by a single species, now locally extinct, in Sarawak are Bovidae (*Bos javanicus*) and Rhinocerotidae (*Dicerorhinus sumatrensis*)

Of 128 bats recorded from Malaysia, 106 are known from Peninsular Malaysia and 92 from Sabah and Sarawak. Of 178 non-flying terrestrial mammals recorded from ‘Malaysia, 123 are known from the Peninsula and 129 from Sabah and Sarawak. Thus only 22 (24%) of the bats known from Sabah and Sarawak are not shared with the Peninsula, whereas 55 (42.6%) of the non-flying mammals from Sabah and Sarawak are not shared. There is greater similarity between the bat faunas of these geographically separate areas than between their non-bat faunas.

Two genera (*Pithecheirops*, *Diplogale*) and 30 species are known only from records within the political boundaries of Malaysia, and for the time being they can be considered endemic (Table 2). There is obviously a strong possibility that species known from Peninsular Malaysia and lowland Sabah/Sarawak may also occur in Kalimantan, Sumatra and/or Brunei.

Table 2. Mammals so far known only from specimens and sightings within the political boundaries of Malaysia

Suncus ater	Sabah (Kinabalu)	Montane
Crocidura baluensis	Sabah (Kinabalu)	Montane
Tupaia montana	Sarawak, Sabah	Montane
Rhinolophus convexus	Peninsular Malaysia	Montane
Rhinolophus chiewkweeae	Peninsular Malaysia	Lowland
Hipposideros 'bicolor' 142 kHz	Peninsular Malaysia	Lowland
Hipposideros coxi	SW Sarawak	Lowland
Hipposideros nequam	Peninsular Malaysia	Lowland
Myotis ridleyi	Peninsular Malaysia, Sabah	Lowland
Myotis gomantongensis	Sabah	Lowland
Pipistrellus cuprosus	Sabah	Lowland
Pipistrellus societatis	Peninsular Malaysia	Lowland
Hesperoptenus doriae	Peninsular Malaysia, Sarawak	Lowland
Hesperoptenus tomesi	Peninsular Malaysia, Sabah	Lowland
Murina aenea	Peninsular Malaysia, Sabah	Lowland
Murina rozendaali	Peninsular Malaysia, Sabah	Lowland
Kerivoula sp. nov.	Peninsular Malaysia	Lowland
Callosciurus (Glyphotes) simus	Sabah, Sarawak	Montane
Lariscus hosei	Sabah, Sarawak	Largely montane
Dremomys everetti	Sabah, Sarawak	Montane
Petaurillus emiliae	Sarawak	Lowland
Maxomys alticola	Sabah	Montane
Maxomys baeodon	Sabah, Sarawak	Montane
Maxomys inas	Peninsular Malaysia	Montane
Lenothrix malaisia	Peninsular Malaysia, Sabah, Sarawak	Lowland
Pithecheirops otion	Sabah	Lowland
Chiropodomys major	Sabah, Sarawak	Lowland and submontane
Melogale everetti	Sabah	Montane
Diplogale hosei	Sabah, Sarawak	Montane
Herpestes hosei	Sarawak	Unknown

Endemic to PM	7 (Lowland 5; Montane 2)
Endemic to Sabah	7 (Lowland 3; Montane 4)
Endemic to Sarawak	3 (Lowland 2; Unknown 1)
Endemic to Sabah + Sarawak	7 (Lowland 1; Montane 6)
Endemic to PM + Sabah and/or Sarawak	6 (Lowland 6)
Total endemic to Malaysia	30 (Lowland 17; Montane 12; Unknown 1)

Several species can be considered near-endemic, that is, they have been recorded from within and also from just beyond the borders of Malaysia, or almost certainly occur beyond Malaysia based on habitat requirements (Table 3). The number of endemics and near-endemics is uncertain for two main reasons: some species (especially bats) are known from only a handful of specimens, so they could easily turn up elsewhere; and suitable habitat in adjacent territories (e.g., Kalimantan) may have been insufficiently studied. A couple of montane forms in Peninsular Malaysia, otherwise endemic, might extend just across the border into Thailand. One bat, *Myotis oreias*, is known from only a single specimen from Singapore, where later surveys have failed to find it; if the species is valid, it might still survive in Malaysia or elsewhere in the region.

Table 3. Species of mammals known predominantly from within the political boundaries of Malaysia, but which are either known or almost certainly occur in similar habitats in adjacent territories.

*Tupaia longipes**	Sabah and Sarawak, southwards into East Kalimantan
Dendrogale melanura	Mountains of north & central Borneo – under-recorded Kalimantan?
Hipposideros ridleyi	Extinct in Singapore, otherwise only known within Malaysia
Callosciurus baluensis	Mountains of north & central Borneo – under-recorded Kalimantan?
Callosciurus adamsi	Not recorded yet from Kalimantan?
Callosciurus orestes	Mountains of north & central Borneo – under-recorded Kalimantan?
~~*Petaurillus hosei / kinlochi**~~	~~Peninsular Malaysia, Sabah, Sarawak; known from Brunei~~

*Taxonomic status uncertain

In addition to endemics and near-endemics, Malaysia possesses some mammal populations of major significance; either they represent a significant proportion of the whole species, or they are genetically distinctive. Bennett (1991) estimated about 2000 to 3000 Proboscis monkeys *Nasalis larvatus* in Sabah, and fewer than 1000 in Sarawak. Numbers in Kalimantan are not known, but the Malaysian population might be one quarter or one third of the world population. There are about 11,000 Orang-utans *Pongo pygmaeus morio* in Sabah, and perhaps 500 *Pongo pygmaeus pygmaeus* in Sarawak. The Sabah population is one of the largest in the world, with tremendous conservation importance. The Sabah population of the Asian Elephant *Elephas maximus*, which just extends into East Kalimantan, may amount to 1600 individuals. Not only is this a relatively large proportion of the whole species (about 5%), but the population is genetically distinctive, and therefore it is also internationally important (Fernando *et al*., 2003). These are just three examples of mammals for which Malaysia has special conservation responsibilities.

Around 87 out of the total number of Malaysian mammals (about 292, according to the splitting taxonomy adopted by IUCN 2004) have been given some sort of conservation risk status (Table 4). They include six Critically Endangered, 15 Endangered, 24 Vulnerable, 33 Lower Risk, and nine Data Deficient species. They represent about 30% of Malaysia's mammals. Of the 30 Malaysian endemics, 3 are Critically Endangered, 4 Endangered, 5 Vulnerable, 2 Lower Risk and 3 Data Deficient, making 17 or 57% of the endemics under some degree of threat, as far as they have been assessed. IUCN (2004) in fact lists 111 species at risk, but their total includes 18 marine mammals not considered here—for some of these, occurrence is anecdotal—and three terrestrial species that have not in fact occurred in Malaysia (*Macaca leonina*, *Prionailurus viverrinus* (possible), and *Ursus thibetanus*).

Pangolin, elephant and flying lemur are the three mammalian orders with only one local representative each. Loss of genetic diversity in any of these could be ranked as a more serious national loss than, say, the loss of genetic diversity in a family or genus with many representatives.

Since the last edition of the most recent taxonomic summaries (Medway 1983; Payne *et al*. 1985) there has been one significant change at family level (Herpestidae is often now recognized as separate from Viverridae); nine changes at generic level (a new genus *Pithecheirops*; generic splits e.g. *Arielulus*, *Hypsugo*, etc.), and about 23 changes at species level (truly new discoveries; taxonomic splits; sunk as synonyms; name changes).

Table 4. List of threatened terrestrial mammals in Malaysia (listing and taxonomy follow IUCN, 2004).

CR = Critically Endangered (6 species)
EN = Endangered (15 species)
VU = Vulnerable (24 species)
LR/nt = Lower Risk/near-threatened (33 species)
DD = Data Deficient (10 species)

Species	Category	Criteria (IUCN 2004)	
Chimarrogale hantu	CR	B1+2c (= *C. phaeura* part)	
Dicerorhinus sumatrensis	CR	A1bcd; C2a	
Hipposideros nequam	CR	B1+2c	
Rhinoceros sondaicus	CR	C2a	Now extinct within Malaysia
Rhinolophus convexus	CR	D	
Suncus ater	CR	B1+2c	
Bos javanicus	EN	A1cd + 2cd; C1+	
Catopuma badia	EN	C2a(ii)	
Chimarrogale phaeura	EN	B1+2c	
Crocidura malayana	EN	B1+2c	
Cuon alpinus	EN	C2a(i)	
Cynogale bennetti	EN	A1ce; C2a	
Elephas maximus	EN	A1cd	
Hesperoptenus doriae	EN	B1+2c	
Maxomys alticola	EN	C2a	
Maxomys baeodon	EN	C2a	
Nasalis larvatus	EN	A2c; C1+2a	
Panthera tigris	EN	C2a(i)	
Pongo pygmaeus	EN	A2cd	
Rattus baluensis	EN	B1+2c	
Tupaia longipes	EN	B1+2c	(= *Tupaia glis*?)
Pipistrellus cuprosus	VU	A2c	
Bos gaurus	VU	A1cd + 2cd; C1+	
Capricornis sumatraensis	VU	A2cd	
Catopuma temminckii	VU	C2a(i)	
Dendrogale melanura	VU	B1+2c	
Diplogale hosei	VU	B1+2c	
Haeromys margarettae	VU	A1c; B1+2c	
Haeromys pusillus	VU	A1c	
Hipposideros coxi	VU	D2	
Hipposideros ridleyi	VU	B1+2c	
Hystrix brachyura	VU	A1d	
Lariscus hosei	VU	B1+2c	
Lutra perspicillata	VU	A2acd	
Macaca arctoides	VU	A1cd	
Macaca nemestrina	VU	A1cd	
Melogale everetti	VU	B1+2c	
Neofelis nebulosa	VU	C2a(i)	
Pardofelis marmorata	VU	C2a(i)	
Prionailurus planiceps	VU	C2a(i)	
[*Prionailurus viverrinus*]	VU	C2a(i)	(Doubtful record)
Rousettus spinalatus	VU	C2a	

Suncus hosei	VU	B1+2c	
Sundasciurus jentinki		VU	B1+2c
Tapirus indicus	VU	A2c+3c+4c	
Aethalops alecto	LR/nt		
Aonyx cinereus	NT		
Chaerephon johorensis	LR/nt		
Cheiromeles torquatus	LR/nt		
Chiropodomys muroides	LR/nt		
Coelops robinsoni	LR/nt		
Dyacopterus spadiceus	LR/nt		
Hapalomys longicaudatus	LR/nt		
Harpiocephalus mordax	LR/nt		
Hipposideros lekaguli	LR/nt		
Hipposideros lylei	LR/nt		
Hylobates agilis	LR/nt		
Hylobates lar	LR/nt		
Hylobates muelleri	LR/nt		
Hystrix crassispinis	LR/nt		
Kerivoula intermedia		LR/nt	
Kerivoula minuta	LR/nt		
Macaca fascicularis	LR/nt		
Manis javanica	LR/nt		
Murina aenea	LR/nt		
Murina huttoni	LR/nt		
Murina rozendaali	LR/nt		
Myotis macrotarsus	LR/nt		
Myotis montivagus	LR/nt		
Myotis ridleyi	LR/nt		
Pipistrellus kitcheneri	LR/nt		
Presbytis femoralis	LR/nt		
Pteromyscus pulverulentus	LR/nt		
Rhinolophus creaghi	LR/nt		
Rhinolophus marshalli	LR/nt		
Rhinolophus philippinensis	LR/nt		
Sundasciurus brookei		LR/nt	
Symphalangus syndactylus	LR/nt		
Pipistrellus societatis		DD	
Helarctos malayanus	DD		
Hipposideros doriae	DD	(= *H. sabanus*)	
Lutra sumatrana	DD		
Myotis gomantongensis	DD		
Presbytis frontata	DD		
Presbytis hosei	DD		
Suncus malayanus	DD		
[*Trachypithecus villosus*]	DD	(= *Presbytis cristata* part)	
Apparently rare but not yet assessed:			
Hipposideros orbicularis	?		
Rhinolophus chiewkweeae	?		
Kerivoula sp. nov.	?		

LITERATURE REVIEW

The basis for an understanding of mammal diversity in Peninsular Malaysia was set in place by the work of H.C. Robinson, C.B. Kloss and F.N. Chasen, in the period from 1902 until 1941. Their work was primarily taxonomic and geographical, sampling and listing, describing species and subspecies, especially island races, of nearly all mammals. They deposited their collections in the Federated Malay States Museums and/or the Raffles Museum Singapore, with duplicates going largely to the British Museum (Natural History). Chasen (1940) published the definitive Handlist that summarises all of the earlier literature. Between them these three scientists produced nearly 200 publications on mammals of the region, including 38 by Chasen (Tweedie 1948) and a massive 86 by Kloss (Banks 1951), mostly concerning Peninsular Malaysia but extending as far as India, Vietnam, Hainan and Java.

In Sarawak, an equivalent process was undertaken first by A.H. Everett (1893), who collected natural history specimens and published a first list of mammals for Borneo, and then by the directors of the Sarawak Museum. Sarawak and Sabah received some attention from the Federated Malay States Museums (e.g., Chasen & Kloss 1931), while Hill (1960) provided a long publication on the Robinson Collection of mammals in the British Museum (Natural History) that included Bornean as well as Malay Peninsula material. Knowledge about the mammals of Sabah was added to by Davis (1962) and by Harrison (1964).

Beginning at a slightly later period, agencies such as the Institute for Medical Research, the Department of Wildlife & National Parks, related institutions such as the Malaysian Agricultural Research and Development Institute (MARDI) and the Palm Oil Research Institute Malaysia (PORIM and its successors), as well as Malaysian universities have contributed to a wide array of mammalian studies. Thus, while the main taxonomic collections were museum-based and dated largely from the colonial era, more specialized collections for particular research purposes were also developed on a smaller scale within local institutions. The range of taxonomic methods applied has become highly sophisticated, including DNA hybridization (e.g., Han *et al*. 2000), gene sequencing (e.g., Fernando *et al*. 2003), and analysis of ultrasound (e.g., Kingston *et al*. 2001) and audible sound (Ross 2004). The emphasis of recent taxonomic work has been on cryptic species within traditionally difficult taxa, using a combination of new and classical morphometric techniques to separate out the species, e.g. by Ruedi (1995, 1996). The following paragraphs touch on some main areas of work, but are far from complete; many other studies of equal interest could be mentioned. Many relevant papers have appeared in the Journal of Wildlife & Parks, the Malayan Nature Journal and the Sarawak Museum Journal.

Bio-medical studies, especially of mammal-borne zoonoses, have been the province of the Institute for Medical Research (e.g., Lim 1973; Lim *et al*. 1977). There has been a very strong emphasis on small mammals such as rats and squirrels, but a liberal research policy has led to publications on many species of mammals large and small, and on community ecology, altitudinal zonation and other topics. As vectors of economically and socially important diseases, the parasites of Malaysian mammals have come under scrutiny for many years (e.g. Mullin *et al*. 1972; Zunika *et al*. 2002). Escalante *et al*. (2005) have recently shown that South-east Asia—rather than Africa, as previously thought—may be the origin of the human-infecting *Plasmodium vivax*, now existing nearly worldwide. Furthermore, the dependence of endoparasites and ectoparasites (e.g., Fain *et al*. 1984) on mammalian (and, of course, many other) hosts adds a level of meta-diversity to the diversity of the hosts themselves. If a species of mammal declines or disappears, it sets in progress a whole train of other extinctions.

Physiological studies have been rather limited, but examples include, e.g., Pevet & Yadav (1980), Rudd (1965), Medway (1971), Whittow & Gould (1976), Whittow *et al*. (1977a, 1977b). This still leaves great scope for investigating the potential range of diversity in physiological mechanisms and responses, seasonality and environmental cues, unusual digestive physiology, responses to lunar cycles, and other features that might be expected in a tropical forest fauna with high species diversity and many behavioural specializations.

Zoogeographical studies (e.g., Chasen 1940, Raven 1935, Shukor 1996, Meijaard 2003) and t**axonomic** studies have been the staple of Malaysian-based and foreign-based research, at least until the advent of single-species ecological research projects in the 1960s. Of many possible examples, the more genetically-based studies include those by Medway & Yong (1976), Yong (1970, 1975, 1982) and Yong & Dhaliwal (1972) on rodents. A detailed genetic analysis of 200 individual orang-utans *Pongo pygmaeus* by Goossens *et al*. (2005) is not only one of the most intensive DNA samplings of any wild primate, but has practical implications in demonstrating bottlenecks and in recommending the maintenance of forest corridors between isolated groups.

Synecological studies have been carried out to a rather limited extent, examining niche differentiation between species in small groups such as primates (e.g., MacKinnon & MacKinnon in Chivers 1981); squirrels (Payne 1979); and other rodents including flying squirrels (Muul & Lim 1978). Barrett (1984) studied the community ecology of nocturnal mammals; Johns (e.g., 1986, 1992) examined the effects of logging; and Jephte (1996) has looked at some impacts of hunting.

It has been shown that forest over alluvial ground in the extreme lowlands at Kuala Lompat, Krau Game Reserve, has the richest species composition of bats in the world (Kingston *et al*. 2003). The much smaller community of small carnivores in lowland forest has also been looked at (e.g., Rajaratnam 2001, Heydon & Bulloh 1996). Emmons (2000) was able to complete an intensive study of treeshrews, including both diurnal and nocturnal species, and to demonstrate their extraordinary maternal physiology. Community structure, representing the ecological basis of biodiversity, has been described by Harrison (1962) and by Wells *et al*. (2004). Camera trapping has emerged as a significant research tool (Miura *et al*. 1997; Kawanishi 2002; Azlan & Sharma 2003; Numata *et al*. 2005).

Autecological studies, detailed species-by-species investigations, have been conducted on about 7% of Malaysian mammals (about 11% of the non-bats). Not a single one of Malaysia's endemic mammals has been the subject of an autecological study, but admittedly they tend to be small, less charismatic species that do not play a key ecological role (compared, for instance, with widespread key species like elephant or tiger). Table 5 lists many of the species for which there have been such studies, together with some indication of the duration of the study (as a rough guide to the intensity of the research); but this does not pretend to be a complete list. About 17 species have been the subject of detailed studies in Peninsular Malaysia, and about 8 species in Sabah and Sarawak (excluding the treeshrews). There have been fewer single-species studies in Sarawak than elsewhere (e.g., red banded langur *Presbytis melalophos cruciger* at Maludam; proboscis monkey *Nasalis larvatus*; flying fox *Pteropus vampyrus*) but

Table 5. Partial list (for additions and improvements) of single-species ecological studies, with a rough indication of the length of studies and names of researchers or institutions. Many shorter studies, and mixed field and laboratory studies, could be added to this list, which emphasizes graduate-level field research. DWNP = Dept. of Wildlife & National Parks.

Tiger	>5 years	(Kawanishi; DWNP; WWF)
Siamang	>5 years	(Chivers; Raemaekers)
White-handed Gibbon	>5 years	(Chivers; Raemaekers; Vellayan)
Orang-utan	>5 years	(MacKinnon, Ancrenaz, short studies)
Elephant	>5 years	(Olivier, Mohd Khan, DWNP)
Long-tailed Macaque	>3 years	(Aldrich-Blake; Mah)
Pig-tailed Macaque	3 years	(Caldecott)
Banded Langur	3 years	(Bennett; Curtin; Ahmad)
Dusky Langur	3 years	(Hardy; Curtin)
Maroon Langur	3 years	(Davies)
Proboscis Monkey	>3 years	(Boonratana, Bennett *et al*.)
Tapir	3 years	(Williams, DWNP)
Seladang	>3 years	(Conry, DWNP)
Wild Boar	3 years	(Ickes, Diong)
Sumatran Rhino	>3 years	(Flynn, Tajuddin, DWNP)
Flying Fox	3 years	(Gumal)
Spotted-winged Fruit-bat	3 years	(Hodgkison)
Sun Bear	3 years	(Wong Siew Te)
Agile Gibbon	2 years	(Gittins)
Plantain Squirrel	2 years	(Hafidzi)
Slow loris	2 years	(Barrett)
Rusa	Intermittent	(DWNP)
Serow	Intermittent	(DWNP)

more emphasis on single-issue studies such as the effects of hunting, fire, and logging.

From the earliest days there have been site-specific expeditions, to investigate places where taxonomic novelties were expected, and to fill in gaps of geographical coverage. Early examples were the expeditions led by the Federated Malay States Museums to Gunung Tahan and Gunung Kinabalu. Later examples have included Gunung Benom (Medway 1972), Pulau Tioman, Gunung Lawit (no consolidated publication), Danum Valley (Kiew 1977), Gunung Mulu (Anderson *et al.* 1979), and Lambir Hills (Soepadmo 1984). Furthermore, important series of papers on the conservation of mammalian diversity have been published by Wyatt-Smith & Wycherley (1961), and by Bennett (1991), Payne & Andau (1991), Ratnam *et al.* (1991) and Zaaba *et al.* (1991).

AVAILABLE CHECKLISTS AND REVISIONS

Checklists and revisions have formed the basis for all of the medical-related, physiological, synecological and autecological work mentioned above. There are formal checklists as well as field guides for all parts of Malaysia. The essential lists for Peninsular Malaysia were given by Medway (1969, 1978, 1983), and the relevant field guide is by Francis (2001). The list for Borneo was compiled by Medway (1965, 1977), and the relevant field guide with additions to the list is by Payne *et al.* (1985). Corbet & Hill (1992) provide the authoritative regional taxonomic work.

There have been several revisions by group. Hill (1963) revised the genus *Hipposideros*, Jenkins & Hill (1981) revised the *Hipposideros cervinus/galeritus* complex, and Hill & Francis (1984) have made contributions on the distribution of bats generally. Zubaid (e.g., 1994), Francis (e.g., 1995), Abdullah (e.g., 2003) and their co-workers have added many records.

Mongooses, a small but difficult group because of sexual dimorphism in skull size, were revised by Wells (1989). Other workers who have revised particular groups include Medway & Yong (1976) on rats; Brandon-Jones (1984) on colobines; Jenkins (1982), Davison (1984) and Ruedi (1995, 1996) on shrews; Meijaard & Groves (2004) on mouse-deer; Fernando *et al*. (2003) on elephants; and Han *et al*. (2000) on tree-shrews.

SPECIMENS – WHERE ARE THEY HELD?

The largest collections of relevant skins, skeletons and spirit-preserved material are in the Natural History Museum (BMNH), London; the American Museum of Natural History (AMNH), New York; the Field Museum of Natural History in Chicago; the United States National Museum in Washington; Naturalis in Leiden; the Raffles Museum of Biodiversity Research in Singapore; and in the Sarawak Museum and Sabah Museum.

There are also important collections within Malaysia at the Institute for Medical Research (IMR), the Department of Wildlife & National Parks, and at Universiti Malaya and other institutions of higher learning. These tend to have enhanced value in cases where they are linked to related studies (e.g., the link between medical studies, parasite collections and mammalian host collections in IMR), and where the collections are specialized (e.g., skeleton collections at Universiti Malaya).

SPECIALISTS AND THE NEED FOR ASSISTANCE

Many possible taxonomic and systematic questions could be posed for which information is needed. For example, are *Petaurillus hosei* and *P. kinlochi* conspecific? Is the highland form of *Rhinolophus trifoliatus*, known from one specimen from Sabah and one from Kalimantan, a full species? What are the systematics of the *Hipposideros bicolor* group (including *H. dyacorum*, *H. pomona*, *H. ater* and *H. cineraceus*)? Such questions generally involve a few species, scattered across many taxonomic groups. These are not the sort of questions that occupy a taxonomist full time, but often arise as adjuncts to other related studies.

Although checklists are fun to compile, and can encourage the search for rare or seldom-found species, their value is strictly limited unless they are directed towards a particular purpose. Such a purpose could include a distribution atlas, follow-up investigations of community ecology, or looking at the impacts of development activities. Further knowledge of numbers, population dynamics, sustainability, and management for conservation would all be worthy targets that can build on checklists only if they are followed by intensive research.

Aquatic mammals (cetaceans, dugong) are very poorly known, from every aspect of their biology. A small research group has been established in Universiti Malaysia Sabah.

The only reasonably detailed distribution maps for mammals in Peninsular Malaysia are for primates (compiled and summarized by Marsh & Wilson 1981), and in Sabah for a selection of larger mammals (Davies & Payne 1982). A database of distribution records, which must have a high degree of taxonomic reliability, would be an important aim.

There are sometimes differences in the presence/absence of species between sites, even in contiguous forests a few kilometers apart, in apparently homogenous habitat. The ecological requirements of mammals are not sufficiently known to be sure of the reasons. They need study.

Rates of food intake, energetics, and even the diets of most Peninsular Malaysian mammals are very poorly known (e.g., the proportion of different prey species in the diet of predators, or of food-plants in the diet of herbivores).

Various species have been labelled as pollinators, seed dispersers or seed predators, or as destroyers of seedlings, but the detailed information base for this is limited primarily to squirrels (e.g., Payne 1979), primates (e.g., Chivers 1980) and bats (e.g., Hodgkison *et al*. 2003); hence the relevance of wildlife to land management practices such as forestry is hard to demonstrate.
Breeding seasonality, reproductive rates, survival rates and lifespan are poorly studied and documented, and unknown for many species of wildlife.

Not a single formalized, mathematical model for a Population and Habitat Viability Analysis exists for any Peninsular Malaysian animal (although the Peninsular Malaysian component of the populations of some species such as Asian elephant, Sumatran rhino, and tiger have been considered in less mathematically rigorous viability assessments, resulting in species action plans). One detailed study exists for one population of orangutans in Sabah (Goossens *et al*. 2005).

Virtually no information is available on the population densities of even common species such as mousedeer and wild pigs (but see Diong 1973 and Ickes 2001).

Thus, the biological basis for advising on the management of wildlife is extremely sketchy. Advice often has to rely on extrapolating from the same or similar species in other countries, common sense and guesswork.

INTERNATIONAL, REGIONAL OR NATIONAL PROJECTS THAT CAN HELP

Various cooperative ventures exist, in which Malaysia already participates, or could participate, to enhance knowledge of the diversity of mammals.

There are examples related to particular groups of mammals, such as bats. The Malaysian

Bat Research Group has been very active since the mid 1990s, with a long record of publications. Successful initiatives of this type deserve local support, in order to sustain output. They can serve as models for other research programmes, for example on rodents or on small carnivores, or on other vertebrate groups. Recent interest in bats has had spin-offs such as Bat Education workshops for children, and has spread from Malaysia to Singapore through a network of non-governmental organizations.

GenBank is an international cooperative web-based catalogue of available genome sequences. Participation in this network is up to the individual scientist, and at first sight it is most useful as a source of information. It is less obvious but just as valuable as a repository to upload information. This announces what a researcher is working on, provides a fuller range of data, acts as a form of citation in a similar way to publishing, and ultimately enhances reputation.

Suggestions to establish tissue banks have emerged from university research groups. If these are simply collections of tissue from road-kills, or untargeted trapping, tissue banks will be slow to develop to a point where any single collection can form a basis for research projects. The concept needs to be turned round, so that intensive research projects become a source of tissue samples, in specialized areas such as particular taxa, or to demonstrate inter- and intra-population variability.

Scientists in the Philippines and Brunei Museum have research programmes on cetaceans. Information from aircraft pilots has been collated (e.g., in Brunei) to document aerial sightings that supplement data from beached animals. There is plenty of scope in the region to expand observation networks of pilots, fishing crews, divers and photographers, and their observations can provide information not only about cetaceans but also about whale-sharks, sea-snakes, sea-birds, migratory birds at oil rigs, and turtles.

The IUCN Red Lists provide information about the conservation status of many species. Categorisation, species by species, is a cooperative venture that usually depends on scientists and conservationists from many countries because knowledge is dispersed, and because most species occur in more than one country. Malaysian mammalogists have a lot to contribute if the categories are to be realistic.

A spin-off use of these categories is as biodiversity indicators that measure Malaysia's progress towards the target of the Convention on Biological Diversity, to reduce the rate of biodiversity loss by 2010. Statistical methods are under development, and being applied group by group to the better-assessed taxa such as birds and amphibians. The turn of mammals will soon come, and Malaysian scientists can participate to refine both methodology and data.

CAN THIS WORK BE DONE IN MALAYSIA? IF SO, WHAT IS REQUIRED?

It is relatively straightforward to maintain species lists, although a level of uncertainty must always be accepted in defining species limits (Appendix). The uncertainty need not be an obstacle, even to researchers in fields other than taxonomy, even though they may express frustration at the 'failure' of classical taxonomy to settle names (Dayrat 2005). On the contrary, uncertainties about species boundaries are signposts to fruitful areas for research on physiology, genetics and behaviour. 'Official' lists of taxa will be supported if they prove useful, which means they must be flexible, accessible, and based on a broad range of taxonomists' views. A database of what has been done could be useful, but a database of scientists can only provide a minimum list. It cannot include every individual with an interest in mammals who is potentially a contributor to knowledge, and it is not very clear who would use a list of scientists, since each scientist should know all others within his or her research field. Possibly databases should be in the form of bibliographies and library resources, rather than lists of projects or individuals. Library resources would be useful to everyone, and bibliographies are in themselves databases about which researchers are active on what topics.

Better information flow should encourage the standardisation of field methods. There was a period in the 1960s and 1970s when it appeared that small-mammal trapping techniques were becoming well standardized (groups of three traps at 30 or 50 m intervals, one on the ground, one on a log, one in a tree). In the 1970s and 1980s similar uniformity was developed for census walks for primates and squirrels. This facilitated comparison between studies, and encouraged quantification. The use of mistnets, harp traps, radio telemetry and other techniques also require standardization.

The limited funding needs to be targetted – but how to target? Rather than judging taxonomic projects on their potential for commercial application, it might be possible to assign funds to improving equipment capabilities / techniques, e.g. investment in electron microscopy, facilities for DNA analysis, and cryopreservation of tissues. Such facilities could be used by many scientists, and would enable them to compete in the international science arena. Funding for postgraduate research would encourage intensive research on single topics for several years, which is the route to in-depth understanding and international publications. Investment is needed in developing career structures and training for taxonomy. Investment is also required in conservation management training, to ensure that the diversity of mammals persists.

A natural history museum, like tissue banks, will probably be effective only if collections are targeted. It must not be an excuse for indiscriminate collecting, but it could be a boon when populations of plants and animals are doomed by land conversion. Sharing on-line specimen data between museums, just as botanists have BRAHMS (Botanical Research and Herbarium Management System), is sorely needed.

Collecting specimens of all Malaysian mammals will not resolve all questions, because *comparison* is necessary, often with extra-limital material. On-site work such as that by Kingston *et al*. (2001) can only reveal a new species by a combination of field and lab work. Taxonomic work by Kawada *et al*. (2003), Meijaard & Groves (2004), Gorog *et al*. (2004) and Olson *et al*. (2004) continues to show that regional comparisons are needed. Even name changes (e.g., *Tragulus javanicus* back to *T. kanchil*; *Talpa micrura* to *Talpa klossii* to *Euroscaptor micrura*) are not just name changes, but result from splits within wider populations, over broad geographical areas. Malaysian taxonomists cannot afford to specialize in taxonomy within Malaysia's borders, but need the ambition, academic friendships and access to regional research material that will enable them to place Malaysia's mammals in a regional and international context. For example, the species status of *Tupaia glis* cannot be resolved without access to Thai, Burmese and Chinese *T. berlangeri*. The subspecies status of orang-utans in Sarawak and Sabah, and the viability of their populations, cannot be judged without reference to those in Kalimantan. The Red List status of *Rhinolophus creaghi* cannot be reliably decided until it is known that it also occurs in Palawan. Taxonomy needs a regional approach, sometimes even a global approach, and this means that international collaborations with colleagues and institutions elsewhere are essential. Museum collections in other countries will still be essential points of reference, even if large series of all Malaysian taxa are available within Malaysia.

Malaysian mammalogists need to participate in revision of the IUCN Red Lists. The current list includes *Macaca fascicularis* and *Coelops robinsoni* as both Lower Risk/near-threatened (LR/nt). It includes *Pipistrellus cuprosus* and *Bos gaurus* as both Vulnerable. Such contrasts make it clear that defining rigid one-word categories of status are just a first step. Much more crucial is the collection of information on their population biology and their response to pressures, because the conservation methodologies to be applied will be drastically different in each case.

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APPENDIX

Checklist of Mammals from Malaysia

Moonrat	*Echinosorex gymnurus*	PM	Srk	Sab
Lesser Gymnure	*Hylomys suillus*	PM	Srk	Sab
Short-tailed Mole	*Euroscaptor micrura*	PM		
House Shrew	*Suncus murinus*	PM	Srk	Sab
Black Shrew	*Suncus ater*			Sab
Malayan Pygmy Shrew	*Suncus (etruscus) malayanus*	PM	Srk	Sab
	Crocidura malayana	PM		
SEA White-toothed Shrew	*Crocidura fuliginosa*	PM	Srk	Sab
Kinabalu White-toothed Shrew	*Crocidura baluensis*			Sab
	Crocidura negligens	PM		
	Crocidura attenuata	PM		
Sunda Shrew	*Crocidura monticola*	PM	Srk	Sab
Sunda Water Shrew	*Chimarrogale phaeura*	PM	Srk	Sab
Flying Lemur	*Cynocephalus variegatus*	PM	Srk	Sab
Geoffroy's Rousette	*Rousettus amplexicaudatus*	PM	Srk	Sab
	Rousettus leschenaultii	PM		
Bare-backed Rousette	*Rousettus spinalatus*		Srk	Sab
Malayan Flying Fox	*Pteropus vampyrus*	PM	Srk	Sab
Island Flying Fox	*Pteropus hypomelanus*	PM		Sab
Malaysian Fruit Bat	*Cynopterus 'brachyotis'* open-country taxon	PM	Srk	Sab
	Cynopterus 'brachyotis' forest taxon	PM	Srk	Sab
Horsfield's Fruit Bat	*Cynopterus horsfieldi*	PM	Srk	Sab
Short-nosed Fruit Bat	*Cynopterus sphinx*	PM		
Dusky Fruit Bat	*Penthetor lucasi*	PM	Srk	Sab
Dayak Fruit Bat	*Dyacopterus spadiceus*	PM	Srk	Sab
Spotted-winged Fruit Bat	*Balionycteris maculata*	PM	Srk	Sab
Black-capped Fruit Bat	*Chironax melanocephalus*	PM	Sab	
Grey Fruit Bat	*Aethalops alecto*	PM		
	Aethalops aequalis		Srk	Sab
Tailless Fruit Bat	*Megaerops ecaudatus*	PM	Srk	Sab
Wetmore's Fruit Bat	*Megaerops wetmorei*	PM	?	
Cave Fruit Bat	*Eonycteris spelaea*	PM	Srk	Sab
Greater Nectar Bat	*Eonycteris major*		Srk	Sab
Common Long-tongued Fruit Bat	*Macroglossus minimus*	PM	Srk	Sab
Hill Long-tongued Fruit Bat	*Macroglossus sobrinus*	PM		
Greater Sheath-tailed Bat	*Emballonura alecto*		Srk	Sab
Lesser Sheath-tailed Bat	*Emballonura monticola*	PM	Srk	Sab
Black-bearded Tomb Bat	*Taphozous melanopogon*	PM	Srk	Sab

Long-winged Tomb Bat	*Taphozous longimanus*	PM	Srk	Sab
Pouch-bearing Bat	*Taphozous (Saccolaimus) saccolaimus*	PM	Srk	Sab
Hollow-faced Bat	*Nycteris javanica*	PM	Srk	Sab
Malayan False Vampire	*Megaderma spasma*	PM	Srk	Sab
Indian False Vampire	*Megaderma lyra*	PM		
Intermediate Horseshoe Bat	*Rhinolophus affinis*	PM	Srk	
Lesser Brown Horseshoe Bat	*Rhinolophus stheno*	PM		
Peninsular Horseshoe Bat	*Rhinolophus robinsoni*	PM		
Glossy Horseshoe Bat	*Rhinolophus refulgens*	PM		
Least Horseshoe Bat	*Rhinolophus pusillus*	PM		
N. Malayan Horseshoe Bat	*Rhinolophus malayanus*	PM		
Acuminate Horseshoe Bat	*Rhinolophus acuminatus*	PM		Sab
Big-eared Horseshoe Bat	*Rhinolophus macrotis*	PM		
Lesser Woolly Horseshoe Bat	*Rhinolophus sedulus*	PM	Srk	Sab
Trefoil Horseshoe Bat	*Rhinolophus trifoliatus*	PM	Srk	Sab
Hill Trefoil Horseshoe Bat	*Rhinolophus* sp. (undescribed)			Sab
Woolly Horseshoe Bat	*Rhinolophus luctus*	PM	Srk	Sab
Croslet Horseshoe Bat	*Rhinolophus coelophyllus*	PM		
Marshall's Horseshoe Bat	*Rhinolophus marshalli*	PM		
Pearson's Horseshoe Bat	*Rhinolophus pearsonii*	PM		
Shamel's Horseshoe Bat	*Rhinolophus shameli*	PM		
	Rhinolophus convexus	PM		
Chiew Kwee's Horseshoe Bat	*Rhinolophus chiewkweeae*	PM		
Bornean Horseshoe Bat	*Rhinolophus borneensis*	PM	Srk	Sab
Arcuate Horseshoe Bat	*Rhinolophus arcuatus*		Srk	
Creagh's Horseshoe Bat	*Rhinolophus creaghi*		Srk	Sab
Philippine Horseshoe Bat	*Rhinolophus philippinensis*		Srk	Sab
Bicolour Roundleaf Horseshoe Bat	*Hipposideros 'bicolor'* 131kHz taxon	PM	Srk	Sab
Bicolour Roundleaf Horseshoe Bat	*Hipposideros 'bicolor'* 142 kHz taxon	PM	Srk?	Sab?
	Hipposideros pomona	PM		
Malayan Roundleaf Horseshoe Bat	*Hipposideros nequam*	PM		
Dusky Roundleaf Horseshoe Bat	*Hipposideros ater*	PM		Sab
Dayak Roundleaf Horseshoe Bat	*Hipposideros dyacorum*	PM	Srk	Sab
Lawas Roundleaf Horseshoe Bat	*Hipposideros sabanus*	PM	Srk	Sab
Least Roundleaf Horseshoe Bat	*Hipposideros cineraceus*	PM		Sab
Singapore Roundleaf Horseshoe Bat	*Hipposideros ridleyi*	PM		Sab
	Hipposideros orbicularis	PM		
Common Roundleaf Horseshoe Bat	*Hipposideros cervinus*	PM	Srk	Sab
Cantor's Roundleaf Horseshoe Bat	*Hipposideros galeritus*	PM	Srk	Sab
Cox's Roundleaf Horseshoe Bat	*Hipposideros coxi*		Srk	
Shield-faced Bat	*Hipposideros lylei*	PM		
Lekagul's Roundleaf Horseshoe Bat	*Hipposideros lekaguli*	PM		
Great Roundleaf Horseshoe Bat	*Hipposideros armiger*	PM		
Large Roundleaf Horseshoe Bat	*Hipposideros larvatus*	PM	Srk	
Pratt's Roundleaf Horseshoe Bat	*Hipposideros pratti*	PM		
Diadem Roundleaf Horseshoe Bat	*Hipposideros diadema*	PM	Srk	Sab
Trident Horseshoe Bat	*Aselliscus stoliczkanus*	PM		

Malayan Tailless Horseshoe Bat	*Coelops robinsoni*	PM	Srk	
East Asian Tailless Horseshoe Bat	*Coelops frithii*	PM		
Whiskered Bat	*Myotis (mystacinus) muricola*	PM	Srk	Sab
Burmese Whiskered Bat	*Myotis montivagus*	PM		Sab
Gomantong Whiskered Bat	*Myotis gomantongensis*			Sab
Himalayan Whiskered Bat	*Myotis siligorensis*			Sab
Horsfield's Bat	*Myotis horsfieldii*	PM	Srk	Sab
Lesser Large-footed Bat	*Myotis hasseltii*	PM	Srk	Sab?
	Myotis (formosus) hermani	PM		
	Myotis (ater) rozendaali	PM	Srk	Sab
Grey Large-footed Bat	*Myotis adversus*	PM		Sab
Pallid Large-footed Bat	*Myotis macrotarsus*		Srk	Sab
Ridley's Bat	*Myotis ridleyi*	PM		
House Bat	*Scotophilus kuhlii*	PM		Sab
New Guinea Brown Bat	*Philetor brachypterus*	PM	Srk	Sab
Lesser Flat-headed Bat	*Tylonycteris pachypus*	PM	Srk	Sab
Greater Flat-headed Bat	*Tylonycteris robustula*	PM	Srk	Sab
Large False Serotine	*Hesperoptenus tomesi*	PM		Sab
Blanford's False Serotine	*Hesperoptenus blanfordi*	PM		Sab
Doria's False Serotine	*Hesperoptenus doriae*	PM	Srk	
Noctule	*Nyctalus noctula*	PM		
Malaysian Noctule	*Pipistrellus stenopterus*	PM	Srk	Sab
Woolly Pipistrelle	*Pipistrellus petersi*			Sab
Brown Pipistrelle	*Pipistrellus (Hypsugo) macrotis*	PM		
Brown Pipistrelle	*Pipistrellus (Hypsugo) imbricatus*		Srk	
White-winged Pipistrelle	*Pipistrellus (Hypsugo) vordermanni*		Srk	
	May be conspecific with *P. (H.) imbricatus*			
Red-brown Pipistrelle	*Pipistrellus (Hypsugo) kitcheneri*			Sab
Coppery Pipistrelle	*Pipistrellus (Arielulus) cuprosus*			Sab
Gilded Black Pipistrelle	*Pipistrellus (Arielulus) circumdatus*	PM		
Benom Pipistrelle	*Pipistrellus (Arielulus) societatis*	PM		
Javan Pipistrelle	*Pipistrellus javanicus*	PM		Sab
Least Pipistrelle	*Pipistrellus tenuis*	PM		Sab
Dark Brown Pipistrelle	*Pipistrellus ceylonicus*			Sab
Thick-thumbed Pipistrelle	*Glischropus tylopus*	PM	Srk	Sab
Large Bent-winged Bat	*Miniopterus magnater*		Srk?	Sab
SEAsian Bent-winged Bat	*Miniopterus medius*	PM		Sab
Schreibers's Bat	*Miniopterus schreibersii*	PM	Srk?	Sab
Lesser Bent-winged Bat	*Miniopterus australis*		Srk	Sab
Brown Tube-nosed Bat	*Murina suilla*	PM	Srk	Sab
Round-eared Tube-nosed Bat	*Murina cyclotis*	PM	Srk	Sab
Hutton's Tube-nosed Bat	*Murina huttoni*	PM		
Bronzed Tube-nosed Bat	*Murina aenea*	PM		Sab
Gilded Tube-nosed Bat	*Murina rozendaali*			Sab
Hairy-winged Bat	*Harpiocephalus harpia*			Sab
	Harpiocephalus mordax	PM		Sab?
Papillose Bat	*Kerivoula papillosa*	PM	Srk	Sab
Hardwicke's Forest Bat	*Kerivoula hardwickii*	PM	Srk	Sab
Flores Woolly Bat	*Kerivoula flora*			Sab
Clear-winged Bat	*Kerivoula pellucida*	PM	Srk	Sab
Small Woolly Bat	*Kerivoula intermedia*	PM?		Sab
Least Forest Bat	*Kerivoula minuta*	PM		Sab
Painted Bat	*Kerivoula picta*	PM		

Whitehead's Woolly Bat	*Kerivoula whiteheadi*		Srk	Sab
	Kerivoula sp. nov.	PM		
Groove-toothed Bat	*Phoniscus atrox*	PM		Sab
Frosted Groove-toothed Bat	*Phoniscus jagori*	PM		
Free-tailed Bat	*Mops mops*	PM	Srk	
Wrinkled-lipped Bat	*Chaerephon plicata*	PM	Srk	Sab
Dato Meldrum's Bat	*Chaerephon johorensis*	PM		
Hairless Bat	*Cheiromeles torquatus*	PM	Srk	Sab
Common Treeshrew	*Tupaia glis*	PM	Srk	
	Tupaia 'longipes'		Srk	Sab
Mountain Treeshrew	*Tupaia montana*		Srk	Sab
Lesser Treeshrew	*Tupaia minor*	PM	Srk	Sab
Slender Treeshrew	*Tupaia gracilis*		Srk	Sab
Painted Treeshrew	*Tupaia picta*		Srk	
Striped Treeshrew	*Tupaia dorsalis*		Srk	Sab
Large Treeshrew	*Tupaia tana*		Srk	Sab
Pentailed Treeshrew	*Ptilocercus lowii*	PM	Srk	Sab
Smooth-tailed Treeshrew	*Dendrogale melanura*		Srk	Sab
Slow Loris	*Nycticebus coucang*	PM	Srk	Sab
Western Tarsier	*Tarsius bancanus*		Srk	Sab
Silvered Leaf Monkey	*Presbytis cristata*	PM	Srk	Sab
Dusky Leaf Monkey	*Presbytis obscura*	PM		
Banded Leaf Monkey	*Presbytis melalophos*	PM	Srk	
Grey Leaf Monkey	*Presbytis hosei*		Srk	Sab
Maroon Leaf Monkey	*Presbytis rubicunda*		Srk	Sab
White-fronted Leaf Monkey	*Presbytis frontata*		Srk	
Proboscis Monkey	*Nasalis larvatus*		Srk	Sab
Long-tailed Macaque	*Macaca fascicularis*	PM	Srk	Sab
Pig-tailed Macaque	*Macaca nemestrina*	PM	Srk	Sab
Stump-tailed Macaque	*Macaca arctoides*	PM		
White-handed Gibbon	*Hylobates lar*	PM		
Agile Gibbon	*Hylobates agilis*	PM		
Bornean Gibbon	*Hylobates muelleri*		Srk	Sab
Siamang	*Hylobates syndactylus*	PM		
Bornean Orang-utan	*Pongo pygmaeus*		Srk	Sab
Malayan Pangolin	*Manis javanica*	PM	Srk	Sab
Black Giant Squirrel	*Ratufa bicolor*	PM		
Cream-coloured Giant Squirrel	*Ratufa affinis*	PM	Srk	Sab
Plantain Squirrel	*Callosciurus notatus*	PM	Srk	Sab
Belly-banded Squirrel	*Callosciurus flavimanus*	PM		
Prevost's Squirrel	*Callosciurus prevostii*	PM	Srk	Sab
(Variable Squirrel)	*Callosciurus finlaysoni*	Feral		
Black-banded Squirrel	*Callosciurus nigrovittatus*	PM		
Kinabalu Squirrel	*Callosciurus baluensis*		Srk	Sab
Ear-spot Squirrel	*Callosciurus adamsi*		Srk	Sab

Bornean Black-banded Squirrel	*Callosciurus orestes*		Srk	Sab
Red-bellied Sculptor Squirrel	*Callosciurus (Glyphotes) simus*		Srk	Sab
Horse-tailed Squirrel	*Sundasciurus hippurus*	PM	Srk	Sab
Slender Squirrel	*Sundasciurus tenuis*	PM	Srk	Sab
Low's Squirrel	*Sundasciurus lowii*	PM	Srk	Sab
Jentink's Squirrel	*Sundasciurus jentinki*		Srk	Sab
Brooke's Squirrel	*Sundasciurus brookei*		Srk	Sab
Himalayan Striped Squirrel	*Tamiops macclellandii*	PM		
Three-striped Ground Squirrel	*Lariscus insignis*	PM	Srk	
Four-striped Ground Squirrel	*Lariscus hosei*		Srk	Sab
Shrew-faced Ground Squirrel	*Rhinosciurus laticaudatus*	PM	Srk	Sab
Bornean Mountain Ground Squirrel	*Dremomys everetti*		Srk	Sab
Red-cheeked Ground Squirrel	*Dremomys rufigenis*	PM		
Black-eared Pygmy Squirrel	*Nannosciurus melanotis*		Srk	
Plain Pygmy Squirrel	*Exilisciurus exilis*		Srk	Sab
Whitehead's Pygmy Squirrel	*Exilisciurus whiteheadi*		Srk	Sab
Tufted Ground Squirrel	*Rheithrosciurus macrotis*		Srk	Sab
Selangor Pygmy Flying Squirrel	*Petaurillus kinlochii*	PM		
Hose's Pygmy Flying Squirrel	*Petaurillus hosei*		Srk	Sab
Lesser Pygmy Flying Squirrel	*Petaurillus emiliae*		Srk	
Red-cheeked Flying Squirrel	*Hylopetes spadiceus*	PM	Srk	Sab
Grey-cheeked Flying Squirrel	*Hylopetes lepidus*	PM	Srk	Sab
Whiskered Flying Squirrel	*Petinomys genibarbis*	PM	Srk	Sab
White-bellied Flying Squirrel	*Petinomys setosus*	PM	Srk	Sab
Vordermann's Flying Squirrel	*Petinomys vordermanni*	PM	Srk?	
Horsfield's Flying Squirrel	*Iomys horsfieldii*	PM	Srk	Sab
Smoky Flying Squirrel	*Pteromyscus pulverulentus*	PM	Srk	Sab
Large Black Flying Squirrel	*Aeromys tephromelas*	PM	Srk	Sab
Thomas's Flying Squirrel	*Aeromys thomasi*		Srk	Sab
Red Giant Flying Squirrel	*Petaurista petaurista*	PM	Srk	Sab
Spotted Giant Flying Squirrel	*Petaurista elegans*	PM	Srk	Sab

Large Bamboo Rat	*Rhizomys sumatrensis*	PM		
Hoary Bamboo Rat	*Rhizomys pruinosus*	PM		

Pencil-tailed Tree-mouse	*Chiropodomys gliroides*	PM	Srk	Sab
Large Pencil-tailed Tree-mouse	*Chiropodomys major*		Srk	Sab
Grey-bellied Pencil-tailed Tree-mouse	*Chiropodomys muroides*			Sab
Marmoset Rat	*Hapalomys longicaudatus*			
Monkey-footed Rat	*Pithecheir melanurus*	PM		
	Pithecheirops otion			Sab
Ranee Mouse	*Haeromys margarettae*		Srk	Sab
Lesser Ranee Mouse	*Haeromys pusillus*		Srk	Sab
Asian House Mouse	*Mus castaneus*	PM	Srk	Sab
Ricefield Mouse	*Mus caroli*	PM		Sab?
House Rat	*Rattus rattus*	PM	Srk	Sab
Malaysian Wood Rat	*Rattus tiomanicus*	PM	Srk	Sab
Ricefield Rat	*Rattus argentiventer*	PM	Srk	Sab
Summit Rat	*Rattus baluensis*			Sab
Polynesian Rat	*Rattus exulans*	PM	Srk	Sab
Annandale's Rat	*Rattus annandalei*	PM		
Brown Rat	*Rattus norvegicus*	PM	Srk	Sab

Muller's Rat	*Sundamys muelleri*	PM	Srk	Sab
Mountain Giant Rat	*Sundamys infraluteus*		Srk	Sab
Bowers's Rat	*Sundamys bowersii*	PM		
Dark-tailed Tree Rat	*Niviventer cremoriventer*	PM	Srk	Sab
Long-tailed Mountain Rat	*Niviventer rapit*	PM	Srk	Sab
White-bellied Rat	*Niviventer bukit*	PM		
Red Spiny Rat	*Maxomys surifer*	PM	Srk	Sab
Brown Spiny Rat	*Maxomys rajah*	PM	Srk	Sab
Mountain Spiny Rat	*Maxomys alticola*			Sab
Malayan Mountain Spiny Rat	*Maxomys inas*	PM		
Chestnut-bellied Spiny Rat	*Maxomys ochraceiventer*		Srk	Sab
Small Spiny Rat	*Maxomys baeodon*		Srk	Sab
Whitehead's Rat	*Maxomys whiteheadi*	PM	Srk	Sab
Grey Tree Rat	*Lenothrix malaisia*	PM	Srk	Sab
Long-tailed Giant Rat	*Leopoldamys sabanus*	PM	Srk	Sab
Edwards' Rat	*Leopoldamys edwardsi*	PM		
Large Bandicoot Rat	*Bandicota indica*	PM		
Lesser Bandicoot Rat	*Bandicota bengalensis*	PM		
Malayan Porcupine	*Hystrix brachyura*	PM	Srk	Sab
Thick-spined Porcupine	*Hystrix crassispinis*		Srk	Sab
Brush-tailed Porcupine	*Thecurus macrourus*	PM		
Long-tailed Porcupine	*Trichys fasciculata*	PM	Srk	Sab
Wild Dog	*Cuon alpinus*	PM		
Malayan Sun Bear	*Helarctos malayanus*	PM	Srk	Sab
Yellow-throated Marten	*Martes flavigula*	PM	Srk	Sab
Malay Weasel	*Mustela nudipes*	PM	Srk	Sab
Ferret-badger	*Melogale everetti*			Sab
Teledu	*Mydaus javanensis*		Srk	Sab
Small-clawed Otter	*Aonyx cinerea*	PM	Srk	Sab
Hairy-nosed Otter	*Lutra sumatrana*	PM	Srk	Sab
Common Otter	*Lutra lutra*	PM		
Smooth-coated Otter	*Lutra perspicillata*	PM	Srk	Sab
Malay Civet	*Viverra tangalunga*	PM	Srk	Sab
Large Indian Civet	*Viverra zibetha*	PM		
Large Spotted Civet	*Viverra megaspila*	PM		
Little Civet	*Viverricula malaccensis*	PM		
Banded Linsang	*Prionodon linsang*	PM	Srk	Sab
Common Palm Civet	*Paradoxurus hermaphroditus*	PM	Srk	Sab
Masked Palm Civet	*Paguma larvata*	PM	Srk	Sab
Binturong	*Arctitis binturong*	PM	Srk	Sab
Small-toothed Palm Civet	*Arctogalidia trivirgata*	PM	Srk	Sab
Banded Palm Civet	*Hemigalus derbyanus*	PM	Srk	Sab
Hose's Palm Civet	*Diplogale hosei*		Srk	Sab
Otter Civet	*Cynogale bennettii*	PM	Srk	Sab
Short-tailed Mongoose	*Herpestes brachyurus*	PM	Srk	Sab
Indian Grey Mongoose	*Herpestes edwardsii*	PM (feral, extinct)		
Hose's Mongoose	*Herpestes hosei*		Srk	
Javan Mongoose	*Herpestes javanicus*	PM		

Collared Mongoose	*Herpestes semitorquatus*		Srk	Sab
Crab-eating Mongoose	*Herpestes urva*	PM		
Tiger	*Panthera tigris*	PM		
Leopard	*Panthera pardus*	PM		
Clouded Leopard	*Neofelis nebulosa*	PM	Srk	Sab
Golden Cat	*Catopuma temminckii*	PM		
Bay Cat	*Catopuma badia*		Srk	Sab
Leopard Cat	*Prionailurus bengalensis*	PM	Srk	Sab
Flat-headed Cat	*Prionailurus planiceps*	PM	Srk	Sab
(Fishing Cat	*Prionailurus viverrina*) Old skin, Tasik Bera (doubtful record)			
Marbled Cat	*Felis marmorata*	PM	Srk	Sab
Asian Elephant	*Elephas maximus*	PM		Sab
Malayan Tapir	*Tapirus indicus*	PM		
Javan Rhinoceros	*Rhinoceros sondaicus*	PM (extinct)		
Sumatran Rhinoceros	*Dicerorhinus sumatrensis*	PM	Srk (extinct)	Sab
Wild Pig	*Sus scrofa*	PM		
Bearded Pig	*Sus barbatus*	PM	Srk	Sab
Lesser Mouse-deer	*Tragulus kanchil*	PM	Srk	Sab
Greater Mouse-deer	*Tragulus napu*	PM	Srk	Sab
~~Barking Deer~~	~~*Muntiacus muntjak*~~	~~PM~~	~~Srk~~	~~Sab~~
Yellow Muntjak	*Muntiacus atherodes*		Srk	Sab
Sambar	*Cervus unicolor*	PM	Srk	Sab
Gaur	*Bos gaurus*	PM		
Banteng	*Bos javanicus*	PM	Srk	Sab
Serow	*Capricornis sumatraensis*	PM		

PM = Peninsular Malaysia; Srk = Sarawak; Sab = Sabah
SEA = South East Asia

AN ASSESSMENT OF THE CURRENT KNOWLEDGE OF MALAYSIA'S AVIFAUNA

Allen Jeyarajasingam

ABSTRACT

A total of 742 species of birds belonging to 85 families has been recorded within the political boundaries of Malaysia. Of these 43 are endemics, distributed between Peninsular Malaysia and the Bornean states of Sarawak and Sabah. This paper serves to assess and highlight the current state of knowledge of Malaysia's birds with special emphasis on status, distribution, breeding biology and conservation. Although a common checklist is maintained for the country, the gathering and processing of scientific information have to be separate between Peninsular Malaysia, Sarawak, and Sabah, because the latter are disjunct territories, separated by sea. High species diversity still remains in the rainforest, both lowland and montane with over 395 species or 53%. Despite nearly 150 years of specimen collection, field observations by both professional and amateur naturalists as well as other field and laboratory work, current knowledge remains relatively low, especially in Sarawak and Sabah. Most type specimens collected in the country by foreign collectors and scientists are currently deposited in museums abroad. Large gaps in the breeding biology of most resident species, together with knowledge of habits and conservation status exist. These can be eventually filled in if there is close co-operation and information sharing between government agencies, local universities and non-governmental organizations in establishing and effectively coordinating a systematic network in order to build up an easily accessible and user friendly database for the realization of conservation goals.

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STATUS OF KNOWLEDGE OF THE MALAYSIAN HERPETOFAUNA

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ABSTRACT

Altogether, 203 species of amphibians and 397 species of reptiles are now known from Peninsular Malaysia and its offshore islands, and from East Malaysia (Sabah and Sarawak, and associated islands, on Borneo). Although a total of 600 herpetofaunal species seems a large figure in comparison to other landmasses of similar size regionally, a number of species have been discovered or recognized as new only in the last half a decade. Most of the new discoveries have been made from montane regions and offshore islands, but important findings have also been made not too far from the urban areas. Identification resources for the fauna specific to Peninsular Malaysia are relatively few, although recent field guides exist for all groups of taxa (except caecilians) for Borneo. No major systematic institutions exist within Malaysia for either type material or recent voucher specimens of herpetofaunal species, the Sarawak Museum in Kuching being repository of a small collection of mainly secondary types and older general collections from this state; the Selangor Museum in Kuala Lumpur was destroyed in the bombing of the city during World War II. Besides a concerted effort to continue inventories of Malaysia's herpetofauna, urgently needed are the development of herpetology as a distinct discipline within the biological sciences of the university curriculum, and training of a generation of young biologists in relevant fields of systematics, ecology, genetics, biogeography, anatomy and morphology, in curatorship and an appreciation of the great outdoors.

INTRODUCTION

Malaysia supports a high species richness and endemicity in herpetofauna (Yong 1998), with 203 described species of amphibians and 397 described species of reptiles (Tables 1 & 2). This diversity is unequally distributed across the country, the majority occurring in the highlands, which support a disproportionately large area of primary forest, compared to the lowlands. Altogether, these species represent a panoply of evolutionary history and diversity, from ancient groups that may had been restricted to mountain-tops due to climatic variation during the Pleistocene, to modern ones represented by diverse lineages. The underpinning reasons for the high levels of herpetological diversity of the Malaysian herpetofauna are:

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Table 1. Composition of amphibian fauna in Malaysia. The listing includes introduced species

Family	Number of species
Bufonidae	35
Megophryidae	28
Microhylidae	34
Ranidae	51
Rhacophoridae	48
Ichthyophiidae	7
Total	**203**

Table 2. Composition of the reptile fauna in Malaysia. The listing includes introduced species

Family	Number of species
Acrochordidae	2
Anomochilidae	2
Boidae	4
Colubridae	144
Cylindrophiidae	3
Elapidae	10
Hydrophiidae	21
Typhlopidae	5
Viperidae	12
Xenopeltidae	1
Xenophidiidae	2
Agamidae	37
Anguidae	1
Eublepharidae	1
Dibamidae	5
Gekkonidae	46
Lacertidae	1
Lanthanotidae	1
Scincidae	61
Uromastycidae	2
Varanidae	4
Crocodylidae	4
Cheloniidae	4
Dermochelyidae	1
Emydidae	1
Geoemydidae	12
Testudinidae	3
Trionychidae	5
Total	**397**

i) parts of south-east Asia were not glaciated and were refuges during the height of the Pleistocene glaciation (see Heaney 1991, for a review);
ii) the region has a complex history of sea-level fluctuations that attached and detached islands to the Asian mainland, joining and severing populations in the process;
iii) the region shows a high diversity of geology and climate, and therefore, supports diverse ecological conditions; and
iv) the area still is clothed in relatively large unbroken tracts of primary forests, such as tropical rainforests and montane forests.

This paper presents a history and inventory of the herpetofauna of Malaysia, conducts an analysis of trends in research and provides some suggestions for the future.

THE ROLE OF HERPETOFAUNA

Amphibians and reptiles often constitute significant biomass, exceeding that of all other vertebrates (Burton & Likens 1975; Iverson 1982), form important linkages in the ecosystem by providing dispersal mechanisms for plants (Moll 1980; Vogt & Guzman 1988; Varela & Bucher 2002; Liu *et al.* 2004; Rick & Bowman 1961; Moll & Jansen 1995; Fialho 1990; Iverson 1985), form an important link in the trophic structure through predation, sometimes of much larger animals (Singh 2000), scavenging (Furbank 1996); Spencer *et al.* 1998; Esque & Peters 1994), and form a potential prey-base themselves (Ernst *et al.* 1994; Souza & Abe 2000; Martuscelli 1995; Rhodin *et al.* 1993), contribute to environmental heterogeneity (Kaczor & Harnett 1990), have keystone functions in maintaining ecosystem structure (Thorbjarnarson 1992; Ross 1998) and foster important symbiotic associations with an array of organisms (Lago 1991; Witz *et al.* 1991). Several species of turtles regularly eat water hyacinths, *Eichhornia,* presumably helping to control this water weed (Davenport *et al.* 1992; Varghese & Tonapi 1986; Fachin-Terán *et al.* 1995). Population data on herpetofaunal species have been used for constructive predictive models of abundance of target taxa (Clawson *et al.* 1984).

Amphibians and reptiles are known to be important predators of insect (Bhanotar & Bhatnagar 1976; Gans 1994) and rodent (Lim 1974; Whitaker & Advani 1983) pests in agricultural ecosystems, and support a thriving trade based on export of froglegs (Niekisch 1986). Snake venom is used in medical research, for the production of life-saving drugs (Lim *et al.* 1977a; 1977b; Reid 1968; Stocker 1990) and over 500 alkaloids of 22 different structural classes have been found in skin extracts of amphibians (Daly *et al.* 2002), many with potential pharmaceutical value. Amphibians and reptiles are used in biomedical research, such as in transplant immunology, the culture of cells and tissues for studies of cell growth and association (Wake *et al.* 1975). In Malaysia, several species have high commercial value. Larger frogs, including *Limnonectes blythi, Fejervarya cancrivora* and *F. limnocharis*, are eaten including some large lizards, particularly *Varanus salvator* and *V. nebulosus* (see Khan 1969) and many turtle and tortoise species (Kiew 1984f; Lim & Das 1999). Several species of snakes, such as *Python reticulatus, Naja sumatrana, Ophiophagus hannah* and *Acrochordus javanicus* are prized for their meat and medicine (Lim 1961) as are crocodilians (Tweedie & Harrison 1970; Anonymous 1983). Finally, amphibians and reptiles, on account of their typically small body size, high species diversity and widespread distribution, poikilothermy and lack of parental care have been considered model organisms for the study of vertebrate life (Pianka 1986).

Little is known of the parasitic fauna of amphibians and reptiles in Malaysia. The few studies carried out by Lim *et al.* (1990), Lim & Shabrina Mohd. Sharif (1998), Ambu *et al.* (1982), Stiller *et al.* (1977) & Nadchatram (1979) reveal that some of the endoparasites are of medical and public health importance. Some of the helminthic parasites, such as the pentastomids are pathogenic to man. These group of parasites are fairly prevalent among pythons, elapid and viperid snakes. Ecto- and endoparasites of any animal taxa provide ecological labeling of the host species, as they are associated with the food habits in relation with the environment. To date, knowledge of the host-parasite relationship of amphibians and reptiles (viruses, bacteria, protozoa, helminthes and arthropods) is in its infancy, and this comprises another gap in the study of biological associations.

HISTORICAL ACCOUNT OF STUDIES

Peninsular Malaysia

Early herpetological collections in the Malay Peninsula were made by Cantor (1847) and Stoliczka (1870a, 1870b, 1870c; 1873), not surprisingly, focussing on former centres of European trade, including Penang, Malacca and Singapore. Biographies of these early explorers are in Kolmaš (1982) and Smith (1931b). Unusual for his time, Theodore Edward Cantor (1809–1860), Danish surgeon-naturalist with the English East India Company, included details of colouration and natural history. He observed that the now rare estuarine trionychid turtle, *Pelochelys cantorii* was commonly caught in fishing stakes. Cantor's material is at present in the Natural History Museum, London, with the painting of the species, and serves as iconotypes, being preserved at the Bodleian Library of Oxford University. Ferdinand Stoliczka (1838–1874), a member of the Asiatic Society of Bengal and palaeontologist of the Geological Survey of India, the 'high-altitude explorer' (sensu Kolmaš 1982), collected on Penang's highest mountain–Great Hill or Bukit Bendera, describing numerous new taxa, including the bufonid genus *Ansonia*, named after the Lieutenant-Governor of Penang, Major General Archibald Edward Harbord Anson (1826–1925) at the time of Stoliczka's visit.

Significant collections of amphibians and reptiles from the Malay Peninsula at the end of the Nineteenth Century were made by Major Stanley Smyth Flower (Flower 1896, 1899), of the Northumberland Fusiliers (obituary in Smith 1946). Flower also sent specimens to London (Boulenger 1896b). Early checklists of the amphibians of Peninsular Malaysia in 1902 and 1904 were compiled by Arthur Lennox Butler (1873–1939), Curator of the Selangor State Museum, who subsequently became Superintendent of the Sudan Game Preservation Department, and show 58 species. Herbert Christopher Robinson (1905) added additional species to the list, counting 63 nominal species, plus an "*Ixalus*". Local administrators (such as Dudley Francis Amelius Hervey, 1849–1911, of the Malayan Civil Service) sent material to George Albert Boulenger (1858–1937) at the British Museum (Natural History), London, who described new species (e.g., Boulenger 1887a). Butler too deferred to Boulenger for taxonomic opinion on the fauna, and sent specimens to London, eventually to be described by the latter (e.g., Boulenger 1900b; 1900c; 1900d; 1905).

The first public museum in Peninsular Malaysia was established at Taiping in 1883, with Leonard Wray (1852–1942), formerly an engineer with the Public Works Department of the Perak Civil Service, as the Curator (biography in Burkill 1927). The Selangor Museum opened to the public in 1888, Wray holding charge as Curator. The main museum building was completed in 1907, and in 1940, the Perak Museum and Selangor Museum were amalgamated to form the Federated Malay States Museum. Herpetological (and other zoological) surveys were carried out by the Selangor Museum throughout the Malay Peninsula, and reported in the Journal of the Museum. Following the government's programme of decentralisation in the 1930s, the two museums were again separated, and became state institutions. Museum staff continued to publish in the *Federated Malay States Museums Journal*, which issued 19 volumes between 1905 and 1939 (terminating with World War II). A misdirected load of bombs from an American B29 bomber landed on Selangor Museum on 10 March 1945. The collections were destroyed, and parts of the salvaged material were eventually transferred to the Perak Museum, Taiping in January 1946. In May 1949, the office of the Director of Museums moved from Kuala Lumpur to Taiping.

The most important collection of regional herpetological (and indeed, zoological) materials lies in the Raffles Museum of Biodiversity Research, National University of Singapore. The Museum's earliest collection originates from the 1840s, and contains much valuable material acquired by a succession of field-oriented curators, some of whom also acquired specimens through exchange programmes with other museums. In 1888, field collectors were hired and collections took place mainly from the region of the border between Selangor and Pahang. The following year, collectors were sent to Johor and Jelebu in Negeri Sembilan.

Compared to Borneo, there were fewer foreign expeditions in the Malay Peninsula in the Nineteenth and Twentieth Centuries. In 1899–1900, English biologists, together with students from the universities of Cambridge and Oxford conducted the Skeat Expedition, organised by Walter William Skeat (1866–1953), British ethnographer and member of the Malayan Civil Service (Skeat 1900). Its objective was to collect data on ethnology, zoology, botany and geology of the Pattani States of Siam (now Thailand), adjacent portions of northern Malaysian states, including Terengganu and Kelantan (sites listed in Skeat 1901), then under Siamese sovereign. The acquired herpetological materials were studied by Frank Fortescue Laidlaw (1876–1963) (Laidlaw 1900, 1901a, 1901b), a student of Trinity College, Cambridge, who was to later become an authority of the Odonata.

A second collection from the northern Malay Peninsula was made by Thomas Nelson Annandale (1876–1924), a student of Balliol College, Oxford, who was to later join the Indian Museum, and Herbert Christopher Robinson (1874–1929), who was appointed Curator of the Selangor Museum, between 1901 and 1902. Boulenger (1903) provided an extended account of the fauna in a special volume edited by Annandale and Robinson. In the species accounts were extensive ecological notes made by Annandale. New herpetological taxa described were named for the leaders of the expedition, include the rare rhacophorid, *Rhacophorus robinsonii*, for Robinson and *Cyclemys annandalii* (presently *Heosemys annandalii*), for Annandale.

An important collector was Count Nils Gyldenstolpe (1886–1961), 'Lord of the Bedchamber' to King Gustav V of Sweden, who was primarily interested in ornithological taxonomy (see Curry-Lindahl 1961), but also made significant herpetological collections in Thailand (1911–1912) and the Malay Peninsula (1914–1915). His material were described by Einar Lönnberg (1865–1942), professor in charge of vertebrates at Naturhistoriska Riksmuseet, Stockholm, Sweden (Lonnberg 1916), his assistant, Lars Gabriel Andersson (1868-1951) Swedish zoologist and for a while, a member of staff of the Museum (Andersson 1916), and by Gyldenstolpe

(1916) himself. One of Lonnberg's species, *Elachyglossa gyldenstolpei*, named for the leader of the expedition, was recently included in the genus *Limnonectes* by Ohler and Dubois (1999).

The German-born zoologist, Karl Richard Hanitsch (1860–1940), while primarily a specialist of the Blattidae, was hired as the Raffles Museum's first Curator (1895–1919). During this time, apart from donations from expatriates, the herpetological collection grew through expeditions organised by Hanitsch. In 1898, Hanitsch prepared a catalogue of herpetofauna of the Malay Peninsula and archipelago. Formerly of the Sarawak Museum, Major John Coney Moulton (1886–1926), was to succeed Hanitsch as the second Director of the Raffles Museum (1919–1923). Also primarily interested in entomology (especially the Rhopalocera and the Cicadidae), Moulton collected locally, as well as in Borneo. Between 1923 and 1932, Cecil Boden Kloss (1877–1949) was Director of the Raffles Museum. Boden-Kloss, with Museum Curator, Frederick Nutter Chasen (1897–1942), conducted a joint expedition with the Federated Malay States Museum to Cameron Highlands in Peninsular Malaysia, in addition to collecting in Gunung Angsi in Negri Sembilan. In 1927, Smedley made herpetological collections on Pulau Aur and Pulau Tioman, islands off the east coast. In 1929, the Raffles Museum commenced publication of its journal, the *Bulletin of the Raffles Museum,* since renamed the *Raffles Bulletin of Zoology*, and now in its 54th volume. Some of the herpetological material acquired by local collectors and expatriates were made available to Malcolm Arthur Smith (1875–1958; obituary in Tenison 1959), physician at the Royal Court of Siam (see Smith 1957), who published descriptions and faunal lists (Smith 1924, 1925c, 1935, 1940).

Another famous Curator of the Raffles Museum was Michael Willmer Forbes Tweedie (1907–1993), who was Assistant Curator in 1932 and Curator between 1932 and 1941, and Director between 1946 and 1957 (biography in Ng 1995). While primarily a carcinologist, he published a number of valuable herpetological papers, including the book, *The Snakes of Malaya*, first published in 1953, with subsequent editions in 1954, 1957, 1961 and 1983. In the post World War II era, the Raffles Museum received material from Lim Boo Liat (from throughout Peninsular Malaysia), Hugh Alistair Reid (Penang) and E.N.W. Oliver (Bukit Larut). Reid (1913–1983) was associated with the Penang General Hospital, and made observations on sea snake poisoning, and in 1961, founded the Penang Institute of Snake and Venom Research (Hawgood 1998).

In the decades before the closing of the last century, two substantial monographic inventories were published – those of Grandison (1972: reporting the Gunung Benom Expedition) and Dring (1979), presenting an inventory of Gunung Lawit in northern Terengganu). Lim Boo Liat (1926–), formerly with the Institute of Medical Research, Kuala Lumpur, and currently associated with the Department of Wildlife and National Parks, published extensively on the herpetofauna, especially snakes, covering locality inventories, food behaviour studies and captive behaviour including epidemiology of snake bites (e.g., Lim 1955; 1963b; 1967; Lim & Kamarudin 1975), produced a guide to the venomous snakes (Lim 1979, revised editions in 1982 and 1991) and described two new species of the genus *Macrocalamus* (see Lim 1963a; Norsham & Lim 2003).

A number of papers specific to amphibians of the region were published in the second half of the 20th Century, culminating in the book on the fauna by Berry (1975). At about the same period, a number of papers of systematic and ecological value, by a large number of local university and research institutes, noteworthy amongst these being inventories and the description of a number of new amphibian species by Kiew (1972; 1984a; 1984b; 1984c; 1987); Yong's (1977) rediscovery of *Rhacophorus robinsoni* in Peninsular Malaysia; Berry and Hendrickson's (1963) description of *Leptobrachium nigrops*; sea snake inventories by Lim and Balasingam (1969); Hendrickson's (1966) account of the herpetofauna of Pulau Tioman; Yong *et al.*'s (1988) report of direct development in the frog genus *Philautus*; Denzer & Manthey's (1991) checklist of the lizards of Peninsular Malaysia and Singapore, to mention a few. Toward the end of the decade, a fine introductory work to the fauna of southeast Asia was published by Manthey & Grossmann (1997). With German text and richly illustrated with colour photos, the volume has a comprehensive species listing covering Sundaland (the Malay Peninsula, Borneo, Sumatra, Java, Bali and associated islands), and descriptions of representatives from every genera of amphibians and reptiles.

Ecological research on turtles has been conducted by a number of colleagues in Peninsular Malaysia. After the early observations on the natural history of the now endangered river terrapin, *Batagur baska*, by Khan (1964), intensive studies, involving radio telemetry, were conducted by Edward Owen Moll (1939–) of Eastern Illinois University (Moll 1980). The same worker also reported on natural history and exploitation of other non-marine turtles of West Malaysia (Dunson & Moll 1980; Moll 1976; 1978), and wrote a status paper on the estuarine and marine turtles of Peninsular Malaysia (Siow & Moll 1981). In the wake of Moll, studies on estuarine turtles, especially the painted terrapin, *Callagur borneoensis*, was conducted as part of a doctoral thesis by Dionysius Shankar Kumar Sharma, staff of World Wide Fund for Nature Malaysia—apart from internal reports, the results are not publicly available. A valuable report by Sharma (1999) is available on the trade in tortoises and freshwater turtles. Marine turtles of Peninsular Malaysia have been the subjects of intensive studies in comparison, primarily by Chan Eng Heng, Professor of Zoology at Kolej Universiti Sains dan Teknologi Malaysia. A number of scientific papers have resulted from these studies (Chan & Liew 1996); 1999; Liew & Chan 2002; Tan *et al.* 2000).

Starting in 2001, Larry Lee Grismer (1955–) and collaborators, including the authors of this essay, inventoried the Seribuat Archipelago, including its most famous island, Pulau Tioman, producing island lists, new species descriptions and biogeographic analyses (Grismer 2005; Grismer *et al.* 2006; Grismer & Das 2005; Grismer *et al.* 2003; Grismer *et al.* 2004a; Grismer *et al.* 2004b; Grismer *et al.* 2004c; Grismer & Leong 2005; Grismer *et al.* 2002a; Grismer *et al.* 2002b; Diaz *et al.* 2004; Grismer *et al.* 2006; Youmans & Grismer 2006). These studies are on going, and have in recent years, been extended to the Malay Peninsula and Pulau Langkawi, on the west coast (Grismer *et al.* 2006). Other important works from this century include Vogel *et al.* (2004), who revised the pit vipers previously referred to *Trimeresurus popeiorum* (at present, *Popeia popeiorum*), recognising several species within the group, David & Pauwels (2004) and Norsham & Lim (2003), described new species of *Macrocalamus*. Another colleague who made important contributions to regional herpetology is Tzi-Ming Leong (1972–), formerly a graduate student with the National University of Singapore, and currently with Singapore National Parks, who published extensively on the herpetofauna of the Malay Peninsula and adjacent areas (e.g., Grismer & Leong 2005; Leong 2000; Leong & Grismer 2004; Leong & Lim 2003b; Leong *et al.* 2003), and especially on amphibians and their larvae (e.g., Leong 2002; 2004; Leong & Lim 2003a; 2003c; Leong & Norsham 2002), as part of a recent doctoral thesis. Jeet Sukumaran (1971–), formerly with World Wide Fund for Nature-Malaysia and Universiti Malaya, and currently a graduate student at the University of Kansas, produced several site inventories (Sukumaran 2003; Sukumaran *et al.* 2006), an as yet unpublished thesis on amphibian distribution on Gunung Jerai, in addition to popular writing (Sukumaran 2002a; 2002b). He also maintains the website, *Frogs of the Malay Peninsula* (see Appendix III).

The work of the present authors (Das, born 1964; Norsham, born 1972) in Peninsular Malaysia includes surveys of montane and other highland environments, which have resulted in the discovery of a number of species new to science (e.g., Das 2005; Das & Haas 2005a; Das & Norsham 2003; Das *et al.* 2004; Norsham 2003; Norsham & Abdul 2000). The collection of the Raffles Museum was also examined, and the discovery of new species resulted (Das & Lim 2000; Das & Lim 2001a), apart from the herpetological type catalogue of the collection (Das & Lim 2001b), all undertaken with the collaboration of its Curator, Kelvin Kok Peng Lim (1966–).

Two recent works in popular format exist for the herpetofauna of Peninsular Malaysia: Chanard *et al.* (1999) published an innovative pictorial checklist for the area (including Thailand), updating the species list of both amphibians and reptiles. The field guide to the reptiles of the same region by Cox *et al.* (1998) covers the more common or interesting species. These help update the fauna, last treated to a monographic review by Boulenger (1912: *A vertebrate fauna of the Malay Peninsula from the Isthmus of Kra to Singapore including the adjacent islands. Reptilia and Batrachia*), with an update by Smith (1930).

Sarawak

The earliest herpetological specimens from Borneo were collected during the voyage of H.M.S. Sulphur, commanded by Captain (later Admiral) Edward Belcher (1799–1877). An account of the voyage to the Far East was written by Belcher (1843), where he described the ship as weighing 380 tons and had a crew of 109 men. Materials from this expedition, organised primarily to suppress piracy in the Malay Archipelago and other parts of south-east Asia, are extant in The Natural History Museum, London include (species marked with asterisk were described as new based on this collection) *Takydromus sexlineatus*, *Tropidophorus brookei, Mabuya multifasciata, Hemidactylus brookii**, *Hemidactylus frenatus, Cosymbotus platyurus, Cnemaspis kendallii** and *Gekko monarchus, Tropidolaemus wagleri* (see Gray 1845). Also collected were *Tarentola borneensis** and *Euprepis belcheri**, at present synonymous with *Mabuia delalandei* Duméril & Bibron, 1839, both known to be endemic to Cape Verde Islands. Apart from these erroneous records, the Belcher collections indicated that only the lowland fauna was sampled.

The first checklist of the herpetofauna of Borneo was compiled in 1848 by the Scottish botanist, Hugh Low (1824–1905), a self-described admirer of Rajah Brooke (see below) of Sarawak (biography in Cowan 1968) and author of a book on Sarawak at the time of the First Rajah Brooke (Low 1848), entitled, '*Sarawak. Its inhabitants and productions being notes during a residence in that country with His Excellency Mr. Brooke*'. It listed a mere 19 species of reptiles and three of amphibians (additional species were mentioned in the text itself, including unspecified "land tortoises" of two species and flying lizards). Some of the early zoological specimens in western museums originate from collections made by European residents of Sarawak. Lewis Llewellyn Dillwyn (1814–1892) and James Motley (1814–1892) wrote a book on the natural history of Labuan, an island off Borneo and now Federal Territory of Malaysia (Motley & Dillwyn 1855) and sent collections in 1864 to the British Museum (Natural

History), London (now, The Natural History Museum, London), which, in 1872 and 1893–1894, purchased a collection made by Alfred Hart Everett (Günther 1872; Boulenger 1895a; 1896a; 1906).

Sarawak was a hive of activity, both scientific and ethnographic, at that time. Two other Europeans, the Italian nobleman Marquis Giacomo Doria of Genoa (1840–1913) and botanist Odoardo Beccari (1843–1920) landed on the shores of Borneo in June 1865. The latter was to become famous for his botanical collections (biographies in Cranbrook 1986; Saint 1987), remained till 1868, and made some significant collections of amphibians and reptiles (see Shelford 1905b). Beccari's adventures were recounted in popular vein, initially in his native Italian (Beccari 1902), the work subsequently translated into English in 1904. The collections were described by Wilhelm Carl Hartwig Peters (1815–1883), of the Zoologisches Museum für Naturkunde, in Berlin (Peters 1861, 1862, 1871, 1872), and one in collaboration with Doria himself (Peters & Doria 1878). Another famous collector from the period was Alfred Russel Wallace (1823–1913), cofounder, with Charles Robert Darwin (1809–1882), of the theory of evolution through natural selection. Wallace's collections on Borneo were along the Simunjan and Sadong Rivers of Sarawak (see Bastin 1986; field sites listed in Baker 2001). Apart from his herpetological collections (listed by Cranbrook *et al.* 2005), Wallace influenced the then Rajah of Sarawak, James Brooke (1803–1868) to establish the Sarawak Museum (Banks 1983; Leh 1993), in 1886. A recent biography of Wallace was authored by his great nephew, Wilson (2000), and Wallace himself had described his time in Sarawak and other parts of south-east Asia in his entertaining memoir, entitled '*The Malay Archipelago: the land of the orangutan and the bird of paradise'* (Wallace 1869).

A series of professional curators, hired from Europe, was behind the success of the Sarawak Museum. The results of their researches were to be published in the scientific organ of this institution, the *Sarawak Museum Journal*. The first Curator of the Museum was John E.A. Lewis, appointed in 1888 (Harrisson 1961a). He was succeeded by George Darby Haviland (1857–1901) who served between 1893 and 1895. Herpetological research by the first two Curators were restricted to collections. The first Curator to collect and publish extensively was Edward Bartlett (ca. 1836–1908; see Das 2000, for a biography), who was associated with the Museum, between 1895 and 1897. Among Bartlett's largest work is a 24 page paper on the crocodiles and lizards of Borneo that were represented in the Sarawak Museum, including the description of eight new species of lizards (Bartlett 1895e). Additionally, he wrote a series of papers in *The Sarawak Gazette*, the monthly official gazette for the staff of the Sarawak Civil Service, on turtles and tortoises (1894a, 1895a, 1895b, 1896b), amphibians (1894b) and snakes (1895c, 1895d, 1896a, 1896c). These were reprinted in a book edited by Bartlett (1896d). In the late 19th Century, two officers in the pay of the Sarawak Civil Service, Charles Hose (1863–1929) and Alfred Hart Everett (1849–1898), made extensive zoological (and other) collections in Sarawak, that, via sale, made their way to European and American museums, to be described by curators there (e.g., Boulenger 1892; 1893; 1895a; 1895b; 1896a). Biographies and obituaries of Hose are in Nuttall (1927) and Durrans (1993), while those of Everett are in Anonymous (1898) and Sharpe (1898).

Arguably, the most famous curator the Sarawak Museum had was Robert Walter Campbell Shelford (1872–1912; see Poulton 1916 for a biography), between 1898 and 1905. Although primarily interested in entomology, he wrote two taxonomic papers on herpetological subjects (Shelford 1901b; 1905a; 1906), as well as a checklist of the reptiles of Borneo (Shelford

1901, with an addenda and corrigenda in 1902) and an incomplete account of his time in Sarawak (Shelford 1916), interrupted by his untimely death. A total of 212 species was listed as occurring (deleting erroneous records and including new reports in Shelford's 1902 note), and localities were provided for the species listed. Shelford continued the tradition of sending specimens to the British Museum, which were worked on by Boulenger, who described new species, including *Lygosoma shelfordi* Boulenger (1900a) honouring its collector.

Shelford was succeeded by John Coney Moulton (1886–1926), between 1908 and 1915. Although Moulton wrote no major herpetological papers during his time the Museum building was enlarged. Moulton was succeeded by Eric Georg Mjöberg (1882–1938, born Hallands Ian) for a couple of years (1922–1924). Nonetheless, his collections were from some of the remotest regions of Sarawak–Gunung Murud, Gunung Penrissen and Gunung Pueh, including the adjacent Gunung Berembut), and yielded many novelties, that were described by Smith (1925a; 1925b). Mjöberg wrote a popular account of his various expeditions in Borneo and Sumatra, originally in Swedish, entitled '*Tropikermas villande urskogar*' (Mjöberg 1928).

Mjöberg was succeeded by Edward Banks (1903–1988) in 1925, and his emphasis being on mammals, and apart from a 1931 paper on crocodiles and a 1937 paper on sea turtles, did not publish on herpetology. In the aftermath of World War II, in 1947, Tom Harnett Harrisson (1911–1976; obituaries and biographied in Smythies 1975; Medway 1976; Heimann 1997) was hired as Government Ethnologist and Curator of the Sarawak Museum. Apart from his ecclectic natural history and ethnographic interests, Harrisson wrote extensively on herpetological topics, notably a series of sea turtle papers in 18 parts in the *Sarawak Museum Journal* (Harrisson 1951; 1954; 1955; 1956a; 1956b; 1958a; 1958b; 1959; 1961b; 1962; 1963b; 1964; 1965; 1966; 1967) and also, papers reporting the rediscovery of *Lanthanotus borneensis* were published in notes authored by his then wife, Barbara Brünig Harrisson née Guttler (1922–) and a colleague, Neville Seymour Haile (1928–2004) (B. Harrisson 1961, 1962); T. Harrisson 1963a; Harrisson & Haile 1961a; 1961b). Haile (1958) also published a checklist of the snakes of Borneo. Harrisson also made the first herpetological collection from the remote Kelabit Highlands of Sarawak, incidental to his work on mammals there, which was described by Tweedie (1949).

Closer to the present time, several foreign contributors have dealt with the local herpetofauna (see below). During the Gunung Mulu Expedition in 1977–1978, organised by the Sarawak Government and the Royal Geographical Society, Julian Christopher Mark Dring (1951–) collected herpetofauna from this site, revising several amphibian groups and describing new species (e.g., Dring 1983a; 1983b; 1987).

Sabah

Known historically as British North Borneo during most of the Nineteenth Century, Sabah has had its fair share of explorers. Predictably, its highest mountain, Gunung Kinabalu, was subject to intense botanical and zoological interest. Between 1887 and 1888, John Whitehead (1860–1899), an ornithologist, organised expeditions to Gunung Kinabalu (described in his folio-format work entitled '*The exploration of Mount Kina Balu*'; Whitehead 1893). His herpetological specimens were donated to the British Museum (Natural History), London and the Muséum National d'Histoire Naturelle, Paris, and were described, sometimes simultaneously, by Boulenger (1887b) at the former collection, and Mocquard (1890) at the latter. Mocquard's paper presented an updated list of herpetofauna of Borneo, with 204 species, comprising 49 amphibians and 155 reptiles.

Another noteworthy expedition to this mountain was led in 1899 by Karl Richard Hanitsch (1860–1940), of the Raffles Museum, Singapore. The expedition was described by Hanitsch (1900), and Boulenger in London identified the herpetological specimens, in the process describing *Leptobrachium baluensis*, *Gecko rhacophorus* (at present *Ptychozoon rhacophorus*), *Stoliczkia borneensis* and *Oreocalamus hanitschi*. Two field associates of the Raffles Museum in Singapore, Frederick Nutter Chasen (1897–1942) and Henry Maurice Pendlebury (?–1945) collected on Kinabalu between April and May 1929 (Pendlebury & Chasen 1932), making their herpetological material available to Malcolm Smith, who wrote an account based on a collection of some 600 specimens, that are mostly extant in the Raffles Museum of Biodiversity Research, National University of Singapore (Smith 1931a). Boden Kloss's 1928 visit to Gunung Kinabalu was to select collecting stations for a survey of this mountainous area the following year, when the Kampung (= village) Kiau approach was taken. Consequently, it bears the label of a great many specimens, including a number of types.

Malaysia

Robert Frederick Inger (1920–) of the Field Museum of Natural History, Chicago, has been the most famous of the living scholars of Bornean herpetology. His contributions include monographs on systematics, field guides, papers on systematics, ecology and biogeography (e.g., Inger 1954; 1956; 1957; 1958a; 1958b; 1964; 1966; 1967; 1989; Inger & Frogner 1980; Inger & Gritis 1983; Inger & Haile 1959; Inger & Leviton 1961; Inger & Stuebing 1989; 1991; 1996); 1997; Inger *et al.* 1995; 1996); 2001; Inger & Tan 1996); Inger & Voris 2001), which continue to inspire the public, a most interesting tropical fauna. A second staff of the same institution, Harold Knight Voris (1940–), studied marine and freshwater snakes of the region, publishing ecological and taxonomic studies (e.g., Han *et al.* 1991; Voris 1964; 1985; Voris & Karns 1996). A collaborator of Inger and Voris is Robert Butler Stuebing (1946–) who conducted research on sea snakes and crocodilians (Engkamat *et al.* 1991; Stuebing 1985; Stuebing *et al.* 1985; Stuebing & Voris 1990; Stuebing *et al.* 2006), and also produced important accounts of several sites, new species descriptions (Stuebing 1994; Stuebing & Wong 2000) and an updated checklist of the snakes of Borneo (Stuebing 1991, with an update in 1994), culminating in a field guide to the snakes of Borneo, coauthored with Inger (Stuebing & Inger 1999). He also made a passionate plea for the continuation of systematic research in the region, and pointed out the need for continuing with systematic collections (Stuebing 1998). A number of Japanese colleagues have contributed to our knowledge of the Bornean herpetofauna. Foremost, for the study of the Amphibia, is Masafumi Matsui (1950–), who conducted field work in Sabah and Sarawak, describing new species as well as aspects of distribution and biology, especially acoustics (Matsui 1983; 1986; 1996); Matsui *et al.* 1985; 1996). His co-workers published significant works on reptiles–Tsutomu Hikida (1951–) and Hidetoshi Ota (1959–) published a number of papers on the distribution, genetics and systematics of lizards (e.g., Hikida 1979; 1980; 1982; 1990; Ota & Hikida 1988; 1989; 1991; 1996); Ota *et al.* 1989; 1990; 1991; 1992; 1996a; 1996b) The German contribution to the knowledge of Bornean herpetofauna have been significant, including the work of Rudolph Malkmus and Ulrich Manthey (1946–) throughout Borneo, and especially in Gunung Kinabalu, culminating in a volume on the herpetofauna of that massif (Malkmus *et al.* 2002).

Marine turtles of Malaysian Borneo have received attention in recent times by several workers. Nicolas James Pilcher (1965–) published on the situation in Sarawak and Sabah (Pilcher & Basintal 2000; Pilcher *et al.* 2000; Pilcher & Ali 1999; 2000), besides co-editing a book on sea turtle biology and conservation (Pilcher & Ismail 2000). G. Stanley de Silva (?–) an early staff member of Sabah Parks, contributed a number of papers on marine turtles of Sabah, addressing conservation issues (de Silva 1969a; 1969b; 1971; 1978; 1980). Ritchie & Jong (1993) published a popular account of man-eating crocodiles of the Batang Lupar region of central Sarawak, which was recently updated (Ritchie & Jong 2002).

A number of local herpetologists have commenced publication of research papers and notes, all useful for increasing our overall knowledge of the distribution and biology of a fascinating fauna, including Norhayati Ahmed (1968–) of Universiti Kebangsaan Malaysia, who has published regional checklists and inventories (e.g., Norhayati *et al.* 2004; 2005a; 2005b).

The work of the first author of this paper included the addition of a number of species to the Bornean fauna (e.g., Das & Bauer 1998; Das & Lim 2003) and of Peninsular Malaysia (e.g. Das & Lim 2000; Das & Norsham 2003), a historical account of herpetofaunal researches and explorations on Borneo (Das 2004b) and most recently, authored a book on the reptiles of Borneo (Das 2006). Collaboration with Alexander Haas (1964–) of Biozentrum Grindel und Zoologisches Museum, Universität Hamburg, on a project on the systematics and ecomorphology of amphibian larvae in Borneo is ongoing, and has resulted in several papers (e.g., Das & Haas 2005b; Haas *et al*. 2006). The second author contributed to the literature of Peninsular Malaysia, such as papers on distributional records, inventories and new species descriptions (e.g., Norsham & Abdul 2000; Norsham 2003; Norsham & Lim 2003).

TRENDS IN RESEARCH

Figures 1 and 2 present the rate of description of species of amphibians and reptiles known to occur in Malaysia to date. Analyses of the discoveries of the two groups are interesting. For amphibians, most new species were discovered in the 1890–1900s decade, coinciding with Boulenger, especially his British Museum catalogues, and also the various papers he wrote at the time based on material originating from the Malay Peninsula. Two other spikes are evident– the 1960–1970s and 1980–1990s decades, when a number of new species were described from Borneo by Inger and co-workers. A slump in species descriptions is evident thereafter. The most productive phase of discovery amongst the reptiles of Malaysia occurred in the 1830–1840s decade. Major monographs were published at this time from the museums of Paris and London, based on materials received from Malaysia and elsewhere, important contributors being John Edward Gray (1800–1875), Hermann Schlegel (1804–1884), Theodore Edward Cantor (1809–1860), André-Marie-Constant Duméril (1774–1860), Auguste-Henri-André Duméril (1812–1870) and Gabriel Bibron (1806–1848). The description of a large number of species since the beginning of the 21st Century thus heralds a new age of discovery of an interesting fauna.

The herpetofauna of Malaysia thus continues to be poorly known, as a result of incomplete sampling of the fauna. Much of the data available at present result from limited sampling done a century ago, and many species have not been collected since the original description. The

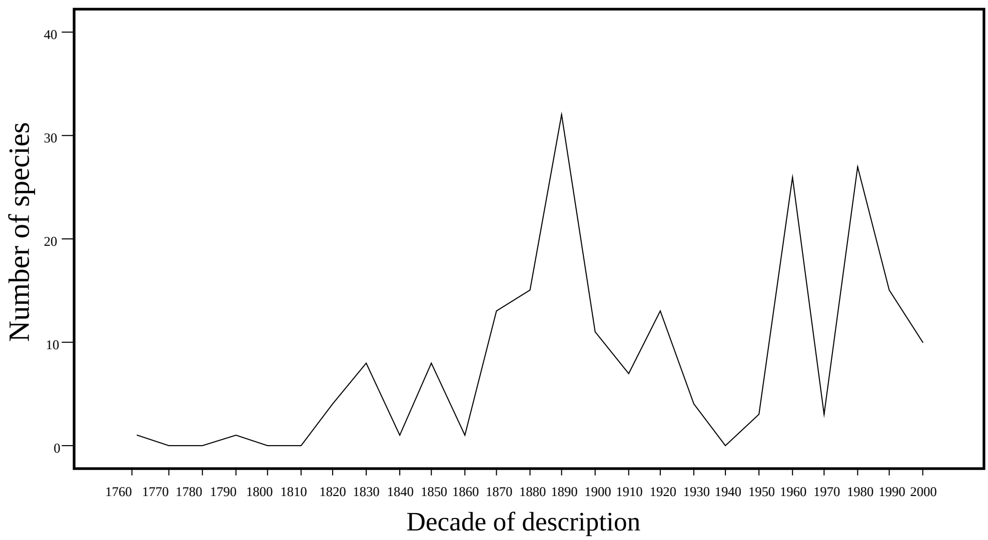

Fig. 1. Description of currently valid species of amphibians known from Malaysia, in 10 years interval.

Fig. 2. Description of currently valid species of reptiles known from Malaysia, in 10 years interval.

most recent compilation on the amphibian fauna of Peninsular Malaysia, that of Berry (1975), and of snakes by Tweedie (1983), are in need of revision, and carry no colour illustrations. There has been no modern synthesis of the rich lizard fauna, nor the crocodilians of Peninsular Malaysia. Lim & Das (1999) published a field guide to the turtles of Peninsular Malaysia (as well as Borneo). On the other hand, the herpetofauna of Borneo, is much better known, thanks to long-term researches conducted by Inger and his associates, resulting in field guides to anuran amphibians (Inger & Stuebing 1989; 1997 – reprinted 2005) and snakes (Stuebing & Inger 1999). A volume on lizards by the same publisher is available (Das 2004a), and most recently, a volume on the reptiles of the island (Das 2006). Given the relatively solid basis of systematics of the herpetofauna of Borneo (from where, nonetheless, new species continue to be described), an ecological and systematic comparison of the faunas of Peninsular Malaysia and Borneo is proposed. Because there have been little direct comparisons of the fauna of Peninsular Malaysia, with that of the much better known eastern part (Sarawak and Sabah in Borneo), several species at present thought to be conspecific are likely to be vicars or even possibly unrelated, as some research now underway with specific species complexes (e.g., *Rana chalconota*, *Limnonectes macrodon, Fejervarya limnocharis, Cosymbotus platyurus* and *Ophiophagus hannah*) suggest. Many of the new species discovered are cryptic species, which are very similar to known species, hence simply not recognised until a thorough revision of the entire group is undertaken, sometimes utilizing modern laboratory (including gene sequencing) and field (ecological and behavioural) methods. Hanken (1999) described the process of amphibian discovery in the recent past, attributing this to not only inventories of poorly known regions but also the use of genetic tools. Nonetheless, the new species discoveries for Malaysia are at present the result of relatively 'coarse-screening', suggesting that additional species that are taxonomically cryptic will be discovered in the future, with the use of DNA and other techniques.

Cryptic species are frequently localized, some restricted to patches of forests a few dozen hectares in extent or to one or two adjacent hill streams, making their discovery difficult, unless a concerted effort is made to conduct an exhaustive inventory. Non-recognition of cryptic species is known to have lead to their extinction (Daugherty *et al.* 1990). Other species may show populations with disjunctions, and structured into well defined phylogenetic assemblages or metapopulations, some with significant genetic variants, all requiring careful consideration for identification and conservation (see Sites & Crandall 1997). Supplying names to these "hidden" species, thus, is the first step towards their universal recognition and protection (Longino 1993; Wheeler 1995). True, the recognition of cryptic species is increasing the conservation burden; it also emphasizes the importance of moving away from taxon-based conservation to that emphasizing protection of the environment at the level of landscapes and ecosystems (Lovich & Gibbons 1997; Das 2002). Despite this knowledge, systematic research in the country is rather limited, and systematic collection small and scattered. The most significant one in Sarawak, the Sarawak Museum, has a small type collection (Das & Leh 2005), and none of historical significance exists elsewhere. New collections have now started in the Forest Research Institute Malaysia, Kepong, by the second author, at Universiti Kebangsaan Malaysia and Universiti Malaya, in Kuala Lumpur, and in Sabah, at the campus of Universiti Malaysia Sabah, Kota Kinabalu (the Borneensis collection), the Sabah State Museum, also at Kota Kinabalu, and at the Sabah Parks, Gunung Kinabalu National Park Headquarters.

CONSERVATION ISSUES AND THE FUTURE

Human impact on the rainforests in Malaysia predates 600 years before present (Maloney 1985). However, since the 1970s, large-scale conversion of forest areas for agricultural use has put great stress on the remaining tropical forests of the country (Aiken & Moss 1975; Appanah 1998). West Malaysia, on account of its peninsular geometry and faunal similarity to other large Sundaic islands, has an insular quality (Heaney 1991), potentially making species more vulnerable to extinction than in typical continental situations. The forests of Borneo are threatened primarily through conversion of forests to plantations and timber extraction (Primack & Hall 1992).

As a megadiversity country, much of Malaysia's biological diversity remains intimately associated with her tropical rainforests. However, regions of exceptional concentration of species within biodiversity hotspots are in montane regions, which are thus of great conservation importance in supporting species with small geographic ranges, including rare and endemic species. Other areas include poorly explored offshore islands, many of which continue to have unexplored biological diversity. Protection of small areas may be a relatively more efficient and cost-effective method for protecting regional biodiversity. A recent study in Amazonia, comparing collection-based data and those on qualitative study of regional biodiversity show little correspondence, emphasizing the need for more rigorous data collection and analysis to identify and subsequently protect biodiversity hotspot areas.

Besides overt threats to the fauna, caused by changing land-use patterns and habitat destruction, faunal decline in other parts of the world has also been reported from causes not completely understood at present, and may stem from a combination of factors, including ozone layer depletion, infection by virulent microorganisms, use of organochlorine pesticides and herbicides and habitat fragmentation. Lack of data on abundance make estimates of levels of imperilment of the Malaysian herpetofauna impossible, and serious attempts to remedy this may be needed to understand factors that potentially threaten species and populations. This gap is suspected to be a serious impediment to the conservation and management of an important component of the country's biodiversity.

The use of amphibians and reptiles to understand human impact on the environment is an active area of study (review in Parent 1992; see also Bury *et al.* 1980), although there has been little work done in tropical Asia. The systematic basis of these researches is of fundamental importance, and much work has been conducted in adjacent regions, such as Thailand, and in other Asian countries, such as Singapore, India, Sri Lanka and most recently, Vietnam. The work in Sri Lanka is particularly significant, in leading to the increase of the amphibian fauna from 53 to over 250 species (Pethiyagoda & Manamendra-Arachchi 1998; see also Manamendra-Arachchi & Pethiyagoda 2005; Meegaskumbura & Manamendra-Arachchi 2005). As many cryptic species have small ranges, non-detection of unique species has been linked to their extinctions (see Daugherty *et al.* 1990).

Nearly 600 species of amphibians and reptiles have been recorded from Malaysia, although this fauna is unequally distributed. An important challenge is to identify, at various spatial scales, areas of exceptional concentrations of species, or so-called "hotspots" of biodiversity of the herpetofauna (sensu Myers 1988; 1990). Important montane regions that hold promise include the Titiwangsa (or Main) Range of Peninsular Malaysia, that comprises Gunung Noring

(1,889 m), Gunung Chamah (2,171 m), Gunung Batu Putih (2,132 m), Cameron Highlands (1628 m) and Fraser's Hill (1,524 m), besides limestone areas of Gua Musang, Kelantan and the Kinta Valley area, Perak. Within Borneo, important montane regions requiring additional work include Gunung Mulu (2,377 m), Gunung Murud (2,423 m), Gunung Kinabalu (4,101 m) and Gunung Dulit (1,311 m). Specific ecological habitats inadequately sampled include peat swamps and kerangas.

One of the main goals of these studies should be to develop aid to the identification of the fauna, leading to a comprehensive (i.e., covering all nominal species and subspecies) monographs, field keys and field guides for the identification of amphibians and reptiles of Malaysia. Field guides are important in promoting conservation awareness and action, assisting capacity building, supporting environmental assessments (such as monitoring and evaluation) of development projects, encouraging ecotourism, building biodiversity databases, land-use planning through GIS applications and the production of regional and international Red Data Books of Threatened Species (Whitten 1996).

Contemporary conservation programmes derive substantial inputs from scientific databases on the distribution, ecology and systematics of regional biodiversity. Identification of hotspots, be these centres of high diversity or endemicity is critical for reserve selection and design (Lovich 1994), helping focus scarce conservation money on the areas with the highest priority. Myers (1988, 1990), utilizing plants as indicators, identified 18 areas of the Earth that support species disproportionately high for their combined area. Fortuitously, there is a concordence with the distribution of other taxa as well, and at least 19% of the world's herpetofauna are found in Myers' hotspots (Mittermeier *et al.* 1992). Biodiversity awareness is generating an increasing demand for basic information which systematics can provide (see Kottelat 1995). A priority of the systematist, in the face of rapid loss of habitats, has become the development of identification tools, critical for promoting environmental awareness and conservation, supporting environmental impact analyses and for other biodiversity studies.

The information base for amphibian and reptile systematics, taxonomy and field identification for Peninsular Malaysia continues to be the work of Boulenger (1912), with a substantial supplement by Smith (1930). The amphibian fauna of Borneo is somewhat better, with field guides available for the turtles, frogs and snakes (e.g., Inger 1966; Inger & Stuebing 1997; Stuebing & Inger 1999; Lim & Das 1999). Nonetheless, most of the field guides are not comprehensive in coverage. Several factors are responsible–the discovery of new species, reallocation of species to genera other than the ones originally allocated to, and in some instances, to different families, the synonymy of some names and the revival from synonymy of others, in addition to new distributional and natural history information. Monographs prepared in the early part of the last century contain terse descriptions, that would equally fit several closely related species (or "shoe-horning"), thereby potentially causing serious underestimation of biodiversity if assessments are made using these resources. Additionally, neither of the works mentioned carry colour photographs, often critical for field identification. Work conducted regionally, including in adjacent countries, has lead to a dramatic increase in the local fauna. For instance, fieldwork conducted in recent years in Vietnam has increased the number of known species of anuran amphibians by 40 species (N. B. Ananjeva, pers. comm. 1999).

We conclude by emphasizing the importance of basic sciences for both conservation biology and biotechnology. Herpetology as an integral part of biodiversity science needs to be

incorporated into the curricula of local schools and universities, in which students are exposed to the essentials of systematics, ecology, genetics, biogeography, anatomy and morphology, in training in field studies, acquisition and curation of biological specimens. And above all, what is needed is an encouragement of the appreciation of the great outdoors.
We summarise the primary activities for enhancing herpetological conservation as discussed above:

- Continue herpetofaunal inventories, particularly in species-rich zones and ecosystems, such as montane regions, lowland rainforests and offshore islands;
- Examine anthropogenic effects on the herpetofauna, including the role of land-use patterns, habitat fragmentation and destruction, use of organochlorine pesticides and herbicides;
- Establish and support systematic research, in addition to research on ecology, conservation biology, genetics, and related topics;
- Develop identification resources tools, such as monographs, field keys and field guides to the fauna;
- Promote local capacity building;
- Prioritize conservation action, through regional Red Data Books, etc;
- Promote conservation efforts that focus on the herpetofauna; and
- Include herpetology and herpetological field techniques in the curricula of local schools and universities.

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APPENDIX 1

Checklist of Amphibian Species of Malaysia

	Peninsular Malaysia	Sabah	Sarawak
Bufonidae			
Ansonia albomaculata Inger 1960			●
Ansonia anotis Inger Tan & Yambun 2001		●	
Ansonia fuliginea (Mocquard 1890)		●	
Ansonia guibei Inger 1966		●	
Ansonia hanitschi Inger 1960		●	●
Ansonia leptopus (Günther 1872)		●	●
Ansonia longidigita Inger 1960		●	●
Ansonia malayanus Inger 1960	●		
Ansonia minuta Inger 1960			●
Ansonia penangensis Stoliczka 1870	●		
Ansonia platysoma Inger 1960		●	●
Ansonia spinulifer (Mocquard 1890)		●	●
Ansonia tiomanicus Hendrickson 1966	●		
Ansonia torrentis Dring 1984			●
Bufo asper Gravenhorst 1829	●	●	●
Bufo divergens Peters 1871		●	●
Bufo juxtasper Inger 1964		●	●
Bufo kumquat Das & Lim 2001	●		
Bufo macrotis Boulenger 1887	●		
Bufo melanostictus Schneider 1799	●	●	●
Bufo parvus Boulenger 1887	●		
Bufo quadriporcatus Boulenger 1887	●	●	●
Leptophryne borbonica (Tschudi 1839)	●	●	●
Pedostibes everetti (Boulenger 1896)		●	
Pedostibes hosii (Boulenger 1892)	●	●	●
Pedostibes maculatus (Mocquard 1890)		●	
Pedostibes rugosus Inger 1958		●	●
Pelophryne api Dring 1984			●
Pelophryne exigua (Boettger 1901)			●
Pelophryne guentheri (Boulenger 1882)			●
Pelophryne macrotis (Boulenger 1895)			●
Pelophryne misera (Mocquard 1890)		●	
Pelophryne rhopophilus Inger & Stuebing 1996			●
Pelophryne signata (Boulenger 1895)	●		●
Pseudobufo subasper Tschudi 1839	●		
Megophryidae			
Leptobrachella baluensis Smith 1931		●	●
Leptobrachella brevicrus Dring 1984			●
Leptobrachella mjobergi Smith 1925			●
Leptobrachella palmata Inger & Stuebing 1991		●	
Leptobrachella parva Dring 1984		●	●
Leptobrachella sarasinae Dring 1984			●

Leptobrachium abbotti (Cochran 1926)		●	●
Leptobrachium gunungense Malkmus 1996		●	
Leptobrachium hendricksoni Taylor 1962	●		●
Leptobrachium montanum Fischer 1885		●	●
Leptobrachium nigrops Berry & Hendrickson 1963	●		●
Leptobrachium smithi Matsui *et al.* 1998	●		
Leptolalax arayai Matsui 1997		●	
Leptolalax dringi Dubois 1987		●	●
Leptolalax gracilis (Günther 1872)			●
Leptolalax hamidi Matsui 1997			●
Leptolalax heteropus Boulenger 1900	●		
Leptolalax kajangensis Grismer *et al.* 2004	●		
Leptolalax maurus Inger *et al*.1997		●	
Leptolalax pelodytoides (Boulenger 1893)	●		
Leptolalax pictus Malkmus 1992		●	
Megophrys baluensis (Boulenger 1899)		●	
Megophrys edwardinae Inger 1989		●	●
Megophrys kobayashii Malkmus & Matsui 1997		●	
Megophrys nasuta (Schlegel 1858)	●	●	●
Xenophrys aceras (Boulenger 1903)	●		
Xenophrys dringi (Inger, Stuebing & Tan 1995)			●
Xenophrys longipes (Boulenger 1885)	●		
Microhylidae			
Calluella brooksi (Boulenger 1904)			●
Calluella flava Kiew 1984			●
Calluella guttulata (Blyth 1856)	●		
Calluella minuta Das & Norsham 2004	●		
Calluella smithi (Barbour & Noble 1916)		●	●
Chaperina fusca Mocquard 1892	●	●	●
Gastrophrynoides borneensis (Boulenger 1890)			●
Kalophrynus baluensis Kiew 1984		●	
Kalophrynus eok Das & Haas 2003			●
Kalophrynus heterochirus Boulenger 1900		●	●
Kalophrynus intermedius Inger 1966			●
Kalophrynus nubicolus Dring 1984			●
Kalophrynus palmatissimus Kiew 1984	●		
Kalophrynus pleurostigma Tschudi 1838	●	●	●
Kalophrynus punctatus Peters 1871			●
Kalophrynus robinsoni Smith 1922	●		
Kalophrynus subterrestris Inger 1966		●	●
Kaloula baleata (Müller 1836)	●	●	●
Kaloula pulchra Gray 1831	●	●	
Metaphrynella pollicaris (Boulenger 1890)	●		
Metaphrynella sundana (Peters 1867)		●	●
Microhyla annectans Boulenger 1900	●		
Microhyla berdmorei (Blyth 1856)	●	●	●
Microhyla borneensis Parker 1926		●	●
Microhyla butleri Boulenger 1900	●		
Microhyla fissipes Boulenger 1884	●		
Microhyla heymonsi Vogt 1911	●		
Microhyla maculifera Inger 1989		●	
Microhyla palmipes Boulenger 1897	●		

Microhyla perparva Inger & Frogner 1979		●	●
Microhyla petrigena Inger & Frogner 1979		●	●
Microhyla superciliaris Parker 1928	●		
Micryletta inornata (Boulenger 1890)	●		
Phrynella pulchra Boulenger 1887	●		
Ranidae			
Amolops larutensis (Boulenger 1899)	●		
Fejerarya cancrivora (Gravenhorst 1829)	●	●	●
Fejervarya limnocharis (Gravenhorst 1829)	●	●	●
Fejervarya raja (Smith 1930)	●		
**Hoplobatrachus chinensis* (Osbeck 1765)		●	
Huia cavitympanum (Boulenger 1893)		●	●
Ingerana baluensis (Boulenger 1896)		●	●
Ingerana tenasserimensis (Sclater 1892)	●		
Limnonectes blythi (Boulenger 1920)	●		
Limnonectes finchi (Inger 1966)		●	
Limnonectes ibanorum (Inger 1964)			●
Limnonectes ingeri (Kiew 1978)		●	●
Limnonectes kenepaiensis (Inger 1966)			●
Limnonectes kuhlii (Tschudi 1838)	●	●	●
Limnonectes laticeps (Boulenger 1882)	●		●
Limnonectes leporinus (Andersson 1923)		●	●
Limnonectes macrognathus (Boulenger 1917)	●		
Limnonectes malesianus (Kiew 1984)	●		●
Limnonectes nitidus (Smedley 1931)	●		
Limnonectes palavanensis (Boulenger 1894)		●	●
Limnonectes paramacrodon (Inger 1966)	●		●
Limnonectes pileatus (Boulenger 1916)	●		
Limnonectes plicatellus (Stoliczka 1873)	●		
Limnonectes tweediei (Smith 1935)	●		
Meristogenys amoropalmus (Matsui 1986)		●	●
Meristogenys jerboa (Günther 1872)			●
Meristogenys kinabaluensis (Inger 1966)		●	●
Meristogenys macrophthalmus (Matsui 1986)			●
Meristogenys orphocnemis (Matsui 1986)		●	
Meristogenys phaeomerus (Inger & Gritis 1983)			●
Meristogenys poecilus (Inger & Gritis 1983)			●
Meristogenys whiteheadi (Boulenger 1887)		●	
Occidozyga baluensis (Boulenger 1896)		●	●
Occidozyga laevis (Günther 1858)	●	●	●
Occidozyga lima (Gravenhorst 1829)	●		
Rana banjarana Leong & Lim 2003	●		
Rana baramica Boettger 1901	●	●	●
Rana erythraea (Schlegel 1837)	●	●	●
Rana glandulosa Boulenger 1882	●	●	●
Rana hosii Boulenger 1891	●	●	●
Rana laterimaculata Barbour & Noble 1916	●	●	
Rana luctuosa (Peters 1871)	●	●	●
Rana miopus Boulenger 1918	●		
Rana nicobariensis (Stoliczka 1870)	●	●	●
Rana nigrovittata (Blyth 1856)	●		
Rana picturata Boulenger 1920		●	●

Rana raniceps (Peters 1871)	●	●	●
Rana signata (Günther 1872)	●	●	●
Staurois guttatus (Günther 1859)		●	●
Staurois latopalmatus (Boulenger 1887)		●	●
Staurois tuberilinguis Boulenger 1918		●	●
Taylorana hascheana (Stoliczka 1870)	●		
Rhacophoridae			
Chirixalus nongkhorensis (Cochran 1927)	●		
Nyctixalus pictus (Peters 1871)	●	●	●
Philautus acutus Dring 1987			●
Philautus amoeanus Smith 1931		●	
Philautus aurantium Inger 1989		●	
Philautus bunitus Inger *et al.* 1995		●	
Philautus disgregus Inger 1989		●	
Philautus erythropththalmus Stuebing & Wong 2000		●	
Philautus gunungensis Malkmus & Riede 1996		●	
Philautus hosii (Boulenger 1895)		●	●
Philautus ingeri Dring 1987		●	●
Philautus kerangae Dring 1987			●
Philautus longicrus (Boulenger 1894)		●	●
Philautus mjobergi Smith 1925		●	●
Philautus parvulus (Boulenger 1893)	●		
Philautus petersi (Boulenger 1900)	●	●	●
Philautus refugii Inger & Stuebing 1996			●
Philautus saueri Malkmus & Reide 1996		●	
Philautus tectus Dring 1987		●	●
Philautus umbra Dring 1987			●
Philautus vermiculatus (Boulenger 1900)	●		
Polypedates chlorophthalmus Das 2005			●
Polypedates colletti (Boulenger 1890)	●	●	●
Polypedates leucomystax Gravenhorst 1829	●	●	●
Polypedates macrotis (Boulenger 1894)	●	●	●
Polypedates otilophus Boulenger 1893		●	●
Rhacophorus angulirostris Ahl 1927		●	●
Rhacophorus appendiculatus (Günther 1859)	●	●	●
Rhacophorus baluensis Inger 1954		●	●
Rhacophorus bipunctatus Ahl 1927	●		
Rhacophorus cyanopunctatus Manthey & Steioff 1998	●	●	●
Rhacophorus dulitensis Boulenger 1892		●	●
Rhacophorus everetti Boulenger 1894		●	●
Rhacophorus fasciatus Boulenger 1895			●
Rhacophorus gadingensis Das & Haas 2005			●
Rhacophorus gauni Inger 1966		●	●
Rhacophorus harrissoni Inger & Haile 1959	●	●	●
Rhacophorus kajau Dring 1984		●	●
Rhacophorus nigropalmatus Boulenger 1895		●	●
Rhacophorus pardalis Günther 1858	●	●	●
Rhacophorus prominanus Smith 1924	●		
Rhacophorus reinwardtii (Schlegel 1840)	●	●	●
Rhacophorus robinsoni Boulenger 1903	●		
Rhacophorus rufipes Inger 1966		●	●
Rhacophorus tunkui Kiew 1987	●		

Theloderma asper (Boulenger 1886)	●		
Theloderma horridum (Boulenger 1903)	●	●	
Theloderma leprosa (Tschudi 1838)	●		
Ichthyophiidae			
Caudacaecilia asplenia (Taylor 1965)			●
Caudacaecilia larutensis (Taylor 1960)	●		
Caudacaecilia nigroflava (Taylor 1960)	●		
Ichthyophis biangularis Taylor 1965			●
Ichthyophis dulitensis Taylor 1960			●
Ichthyophis monochrous Bleeker 1858			●
Ichthyophis singaporensis Taylor 1960	●		

* introduced species.
Checklist of 15 April 2006.

APPENDIX II

Checklist of Reptile Species of Malaysia

	Peninsular Malaysia	Sabah	Sarawak
Acrochordidae			
Acrochordus granulatus (Schneider 1799)	●	●	●
Acrochordus javanicus Hornstedt 1787	●		●
Anomochilidae			
Anomochilus leonardi Smith 1940	●	●	
Anomochilus weberi van Lidth de Jeude 1890		●	
Boidae			
Python breitensteini Steindachner 1881		●	●
Python brongersmai Stull 1938	●		
Python molurus (Linnaeus 1758)	●		
Python reticulatus (Schneider 1801)	●	●	●
Colubridae			
Ahaetulla fasciolata (Fischer 1885)	●		●
Ahaetulla mycterizans (Linnaeus 1758)	●		
Ahaetulla prasina (Boie 1827)	●	●	●
Amphiesma flavifrons (Boulenger 1887)		●	●
Amphiesma frenatum (Dunn 1923)			●
Amphiesma inas (Laidlaw 1901)	●		
Amphiesma petersii (Boulenger 1893)	●	●	●
Amphiesma sanguineum (Smedley 1931)	●		
Amphiesma saravacense (Günther 1872)	●	●	●
Aplopeltura boa (Boie 1828)	●	●	●
Asthenodipsas laevis (Boie 1827)	●	●	●
Asthenodipsas malaccanus Peters 1864	●	●	●
Bitia hydroides Gray 1842	●		
Boiga cyanea (Duméril *et al.* 1854)	●		
Boiga cynodon (Boie 1827)	●	●	●
Boiga dendrophila (Boie 1827)	●	●	●
Boiga drapiezii (Boie 1827)	●	●	●
Boiga jaspidea (Duméril *et al.* 1854)	●	●	●
Boiga multomaculata (Boie 1827)	●		
Boiga nigriceps (Günther 1863)	●	●	●
Calamaria albiventer (Gray 1835)	●		
Calamaria bicolor Duméril *et al.* 1854		●	●
Calamaria borneensis (Bleeker 1860)		●	●
Calamaria everetti Boulenger 1893		●	●
Calamaria gervaisii Duméril *et al.* 1854		●	
Calamaria grabowskyi Fischer 1885		●	●
Calamaria gracillima Günther 1872			●
Calamaria griswoldi Loveridge 1938		●	
Calamaria hilleniuisi Inger & Marx 1965		●	●

Calamaria ingeri Grismer *et al.* 2004	●		
Calamaria lateralis Mocquard 1890		●	
Calamaria leucogaster Bleeker 1860		●	●
Calamaria lovii Boulenger 1887	●	●	●
Calamaria lumbricoidea Boie 1827	●	●	●
Calamaria melanota Jan 1862			●
Calamaria modesta Duméril *et al.* 1854		●	
Calamaria pavimentata Duméril *et al.* 1854	●		
Calamaria prakkei van Lidth de Jeude 1893		●	
Calamaria schlegeli Duméril *et al.* 1854	●	●	●
Calamaria schmidti Marx & Inger 1955		●	
Calamaria suluensis Taylor 1922		●	●
Calamaria virgulata Boie 1827		●	●
Cantoria violacea Girard 1857	●		
Cerberus rynchops (Schneider 1799)	●	●	●
Chrysopelea ornata (Shaw 1802)	●		
Chrysopelea paradisi Boie 1827	●	●	●
Chrysopelea pelias (Linnaeus 1758)	●	●	●
Coelognathus erythrurus (Duméril *et al.* 1854)		●	
Coelognathus flavolineatus (Schlegel 1837)	●	●	●
Coelognathus radiatus (Boie 1827)	●		
Collorhabdium williamsoni Smedley 1931	●		
Dendrelaphis caudolineatus (Gray 1834)	●	●	●
Dendrelaphis cyanochloris (Wall 1921)	●		
Dendrelaphis formosus (Boie 1827)	●	●	●
Dendrelaphis pictus (Gmelin 1789)	●	●	●
Dendrelaphis striatus (Cohn 1905)	●	●	
Dryocalamus subannulatus (Duméril *et al.* 1854)	●	●	
Dryocalamus tristrigatus (Günther 1858)		●	●
Dryophiops rubescens (Gray 1834)	●	●	●
Elaphe prasina (Blyth 1854)	●		
Elapoidis fuscus Boie 1827		●	
Enhydris alternans (Reuss 1834)			●
Enhydris bocourti (Jan 1865)	●		
Enhydris doriae (Peters 1871)		●	●
Enhydris enhydris (Schneider 1799)	●		●
Enhydris indica (Gray 1842)	●		
Enhydris pahangensis Tweedie 1946	●		
Enhydris plumbea (Boie 1827)	●	●	
Enhydris punctata (Gray 1849)	●		
Fordonia leucobalia (Schlegel 1837)	●		●
Gerarda prevostiana (Eydoux & Gervais 1837)	●		
Gongylosoma balodeirum (Boie 1827)	●	●	●
Gongylosoma longicauda (Peters 1871)	●	●	●
Gongylosoma mukutense Grismer *et al.* 2003	●		
Gonyophis margaritatus (Peters 1871)	●	●	●
Gonyosoma oxycephalum (Boie 1827)	●	●	●
Homalopsis buccata (Linnaeus 1758)	●	●	●
Hydrablabes periops (Günther 1872)		●	●
Hydrablabes praefrontalis (Mocquard 1890)		●	
Lepturophis borneensis Boulenger 1900	●	●	●
Liopeltis tricolor (Schlegel 1837)	●	●	●
Lycodon albofuscus (Duméril *et al.* 1854)	●	●	●

Lycodon butleri Boulenger 1900	●		
Lycodon capucinus Boie 1827	●	●	
Lycodon effraenis Cantor 1847	●		●
Lycodon laoensis Günther 1864	●		
Lycodon subcinctus Boie 1827	●	●	●
Macrocalamus chanardi David & Pauwels 2004	●		
Macrocalamus gentingensis Norsham & Lim 2003	●		
Macrocalamus jasoni Grandison 1972	●		
Macrocalamus lateralis Günther 1864	●		
Macrocalamus schulzi Vogel & David 1999	●		
Macrocalamus smithi David & Pauwels, 2004	●		
Macrocalamus tweediei Lim 1963	●		
Macrocalamus vogeli David & Pauwels 2004	●		
Macropisthodon flaviceps (Duméril *et al.* 1854)	●		●
Macropisthodon rhodomelas (Boie 1827)	●	●	●
Oligodon annulifer Boulenger 1893		●	
Oligodon booliati Leong & Grismer 2004	●		
Oligodon cf. *cinereus* (Günther 1864)		●	
Oligodon everetti Boulenger 1893		●	
Oligodon meyerinkii (Steindachner 1891)		●	
Oligodon octolineatus (Schneider 1801)	●	●	●
Oligodon purpurascens (Schlegel 1837)	●	●	●
Oligodon semicinctus (Peters 1862)		?	?
Oligodon subcarinatus (Günther 1872)		●	●
Oligodon vertebralis (Günther 1865)	●		
Opisthotropis typica (Mocquard 1890)		●	
Oreocalamus hanitschi Boulenger 1899	●	●	●
Oreophis porphyraceus (Cantor 1839)	●		
Orthriophis taeniurus (Cope 1861)	●	●	●
Pareas carinatus (Boie 1828)	●	●	
Pareas macularius Blyth in: Theobald 1868	●		
Pareas margaritophorus Jan in: Bocourt 1866	●		
Pareas nuchalis (Boulenger 1900)		●	●
Pareas vertebralis (Boulenger 1890)	●	●	
Psammodynastes pictus Günther 1858	●	●	●
Psammodynastes pulverulentus (Boie 1827)	●	●	●
Pseudorabdion albonuchalis (Günther 1896)		●	●
Pseudorabdion collaris (Mocquard 1892)		●	●
Pseudorabdion longiceps (Cantor 1847)	●		●
Pseudorabdion saravacensis (Shelford 1901)			●
Pseudoxenodon baramensis (Smith 1921)			●
Pseudoxenodon macrops (Blyth 1855)	●		
Ptyas carinata (Günther 1858)	●	●	●
Ptyas fusca (Günther 1858)	●	●	●
Ptyas korros (Schlegel 1837)	●		●
Ptyas mucosa (Linnaeus 1758)	●		
Rhabdophis chrysargos (Schlegel 1837)	●	●	●
Rhabdophis conspicillatus (Günther 1872)	●	●	●
Rhabdophis murudensis (Smith 1925)		●	●
Rhabdophis subminiatus (Schlegel 1837)	●		
Sibynophis collaris (Gray 1853)	●		
Sibynophis geminatus (Boie 1826)	●		
Sibynophis melanocephalus (Gray 1835)	●	●	●

Stegonotus borneensis Boulenger 1899		●	
Stoliczkia borneensis Boulenger 1899		●	●
Xenelaphis ellipsifer Boulenger 1900	●	●	●
Xenelaphis hexagonotus (Cantor 1847)	●	●	●
Xenochrophis flavipunctatus (Hallowell 1860)			●
Xenochrophis maculatus (Edeling 1864)		●	●
Xenochrophis trianguligerus (Boie 1827)	●	●	●
Xenochrophis vittatus (Linnaeus 1758)	●		
Xenodermus javanicus Reinhardt 1836	●	●	●
Cylindrophiidae			
Cylindrophis engkariensis Stuebing 1994			●
Cylindrophis lineatus Blanford 1881			●
Cylindrophis ruffus (Laurenti 1768)	●		●
Elapidae			
Bungarus candidus (Linnaeus 1758)	●		
Bungarus fasciatus (Schneider 1801)	●	●	●
Bungarus flaviceps Reinhardt 1843	●	●	●
Calliophis bivirgata (Boie 1827)	●	●	●
Calliophis gracilis Gray 1835	●		
Calliophis intestinalis (Laurenti 1768)	●	●	●
Calliophis maculiceps (Günther 1858)	●		
Naja kaouthia Lesson 1831	●		
Naja sumatrana Müller 1887	●	●	●
Ophiophagus hannah (Cantor 1836)	●	●	●
Hydrophiidae			
Aipysurus eydouxii (Gray 1849)	●	●	
Astrotia stokesii (Gray in: Stokes 1846)	●		
Enhydrina schistosa (Daudin 1803)	●	●	●
Hydrophis brookii Günther 1872	●		●
Hydrophis caerulescens (Shaw 1802)	●	●	●
Hydrophis cyanocinctus (Daudin 1803)	●	●	●
Hydrophis fasciatus (Schneider 1799)	●	●	●
Hydrophis gracilis (Shaw 1802)	●	?	?
Hydrophis klossi Boulenger 1912	●	●	
Hydrophis melanosoma Günther 1864	●	●	
Hydrophis ornatus (Gray 1842)	●	●	
Hydrophis spiralis (Shaw 1802)	●	●	●
Hydrophis torquatus Günther 1864	●		
Kerilia jerdoni Gray 1849	●	●	
Kolpophis annandalei Laidlaw 1901	●		
Lapemis curtus Shaw 1802	●	●	●
Laticauda colubrina (Schneider 1799)	●	●	●
Laticauda laticaudata (Linnaeus 1758)		●	
Pelamis platyura (Linnaeus 1766)	●	●	●
Praescutata viperina (Schmidt 1852)	●		●
Thalassophis anomalus Schmidt 1852	●	●	●
Typhlopidae			
Ramphotyphlops albiceps (Boulenger 1898)	●		
Ramphotyphlops braminus (Daudin 1803)	●	●	●

Ramphotyphlops lineatus (Schlegel 1839)	●	●	●
Ramphotyphlops olivaceus (Gray 1845)			●
Typhlops muelleri Schlegel 1839	●		
Viperidae			
Calloselasma rhodostoma (Boie 1827)	●		
Cryptelytrops purpureomaculatus (Gray 1832)	●		
Garthius chaseni (Smith 1931)		●	
Ovophis convictus (Stoliczka 1870)	●		
Parias hageni (van Lidth de Jeude 1886)	●		
Parias malcolmi (Loveridge 1938)		●	
Parias sumatranus (Boie 1827)	●	●	●
Popeia fucata (Vogel, David & Pauwels 2004)	●		
Popeia nebularis (Vogel, David & Pauwels, 2004)	●		
Popeia sabahi (Regenass & Kramer 1981)		●	●
Trimeresurus borneensis (Peters 1871)	●	●	●
Tropidolaemus wagleri (Boie 1827)	●	●	●
Xenopeltidae			
Xenopeltis unicolor Reinwardt 1827	●	●	●
Xenophidiidae			
Xenophidion acanthognathus Günther & Manthey 1995		●	
Xenophidion schaeferi Günther & Manthey 1995	●		
Agamidae			
Acanthosaura armata (Hardwicke & Gray 1827)	●		
Acanthosaura crucigera Boulenger 1885	●		
Aphaniotis fusca (Peters 1864)	●		●
Aphaniotis ornata (van Lidth de Jeude 1893)		●	
Bronchocela cristatella (Kuhl 1820)	●	●	●
Calotes emma Gray 1845	●		
Calotes versicolor (Daudin 1802)	●		
Complicitus nigrigularis (Ota & Hikida 1991)		●	
Draco blanfordii Boulenger 1885	●		
Draco cornutus Günther 1864		●	●
Draco cristatellus Günther 1872	●	●	●
Draco fimbriatus Kuhl 1820	●	●	●
Draco haematopogon Boie in: Gray 1831	●	●	●
Draco maculatus (Gray 1845)	●		
Draco maximus Boulenger 1893	●	●	●
Draco melanopogon Boulenger 1887	●	●	●
Draco obscurus Boulenger 1887	●	●	●
Draco quinquefasciatus Hardwicke & Gray 1827	●	●	●
Draco sumatranus Schlegel 1844	●	●	●
Gonocephalus belli (Duméril & Bibron 1837)	●		
Gonocephalus bornensis (Schlegel 1848)		●	●
Gonocephalus chamaeleontinus (Laurenti 1768)	●		
Gonocephalus doriae (Peters 1871)		●	●
Gonocephalus grandis (Gray 1845)	●	●	●
Gonocephalus liogaster (Günther 1872)		●	●
Gonocephalus mjobergi Smith 1925			●
Gonocephalus robinsoni Boulenger 1908	●		

Harpesaurus borneensis (Mertens 1924)			●
Hypsicalotes kinabaluensis (de Grijs 1937)		●	
Phoxophrys borneensis Inger 1960		●	●
Phoxophrys cephalum (Mocquard 1890)		●	●
Phoxophrys nigrilabris (Peters 1864)			●
Phoxophrys spiniceps Smith 1925		●	●
Pseudocalotes dringi Hallermann & Böhme 2000	●		
Pseudocalotes flavigula (Smith 1924)	●		
Pseudocalotes larutensis Hallerman & McGuire 2001	●		
Pseudocalotes sarawacensis Inger & Stuebing 1994			●
Anguidae			
Ophisaurus buettikoferi van Lidth de Jeude 1905		●	●
Eublepharidae			
Aeluroscalabotes felinus (Günther 1864)	●	●	●
Dibamidae			
Dibamus booliati Das & Norsham 2003	●		
Dibamus ingeri Das & Lim 2003		●	
Dibamus leucurus (Bleeker 1860)			●
Dibamus tiomanensis Diaz *et al*. 2004	●		
Dibamus vorisi Das & Lim 2003		●	
Gekkonidae			
Cnemaspis affinis (Stoliczka 1870)	●		
Cnemaspis argus Dring 1979	●		
Cnemaspis baueri Das & Grismer 2003	●		
Cnemaspis dringi Das & Bauer 1998			●
Cnemaspis flavolineata (Nicholls 1949)	●		
Cnemaspis kendallii (Gray 1845)	●		●
Cnemaspis kumpoli Taylor 1963	●		
Cnemaspis limi Das & Grismer 2003	●		
Cnemaspis nigridia (Smith 1925)			●
Cosymbotus craspedotus (Mocquard 1890)	●	●	●
Cosymbotus platyurus (Schneider 1792)	●	●	●
Cyrtodactylus aurensis Grismer 2005	●		
Cyrtodactylus baluensis (Mocquard 1890)		●	●
Cyrtodactylus brevipalmatus (Smith 1923)	●		
Cyrtodactylus cavernicolus Inger & King 1961			●
Cyrtodactylus consobrinus (Peters 1871)	●	●	●
Cyrtodactylus elok Dring 1979	●		
Cyrtodactylus ingeri Hikida 1990		●	
Cyrtodactylus malayanus (De Rooij 1915)			●
Cyrtodactylus matsuii Hikida 1990		●	
Cyrtodactylus peguensis (Boulenger 1893)	●		
Cyrtodactylus pubisulcus Inger 1957		●	●
Cyrtodactylus pulchellus Gray 1827	●		
Cyrtodactylus quadrivirgatus Taylor 1962	●		●
Cyrtodactylus semenanjungensis Grismer & Leong 2005	●		
Cyrtodactylus seribuatensis Youmans & Grismer 2005	●		
Cyrtodactylus sworderi (Smith 1925)	●		
Cyrtodactylus tiomanensis Das & Lim 2000	●		

Cyrtodactylus yoshii Hikida 1990		●	
Gehyra butleri Boulenger 1900	●		
Gehyra mutilata (Wiegmann 1834)	●	●	●
Gekko gecko Linnaeus 1758	●	●	?
Gekko monarchus (Duméril & Bibron 1836)	●	●	●
Gekko smithii (Gray 1842)	●	●	●
Hemidactylus brookii Gray 1845	●		●
Hemidactylus frenatus Duméril & Bibron 1836	●	●	●
Hemidactylus garnotii Duméril & Bibron 1836		●	
Hemiphyllodactylus harterti (Werner 1900)	●		
Hemiphyllodactylus typus Bleeker 1860	●	●	●
Lepidodactylus lugubris (Duméril & Bibron 1836)		●	
Lepidodactylus ranauensis Ota & Hikida 1988		●	
Luperosaurus browni Russell 1979	●		●
Ptychozoon horsfieldii (Gray 1827)		●	●
Ptychozoon kuhli Stejneger 1902	●	●	●
Ptychozoon lionotum Annandale 1905	●		
Ptychozoon rhacophorus (Boulenger 1899)		●	
Lacertidae			
Takydromus sexlineatus Daudin 1802	●		●
Lanthanotidae			
Lanthanotus borneensis Steindachner 1877			●
Scincidae			
Apterygodon vittatum Edeling 1864		●	●
Brachymeles apus Hikida 1982		●	●
Dasia grisea (Gray 1845)		●	●
Dasia olivacea Gray 1839	●	●	●
Dasia semicincta (Peters 1867)			●
Emoia atrocostata (Lesson 1830)	●	●	●
Emoia caeruleocauda (De Vis 1892)		●	
Lamprolepis nieuwenhuisii (van Lidth de Jeude 1905)		●	●
Lamprolepis vyneri (Shelford 1905)			●
Larutia larutensis (Boulenger 1900)	●		
Larutia miodactyla (Boulenger 1903)	●		
Larutia puehensis Grismer *et al.* 2003			●
Larutia seribuatensis Grismer *et al.* 2003	●		
Larutia trifasciata (Tweedie 1940)	●		
Lipinia nitens (Peters 1871)			●
Lipinia surda (Boulenger 1900)	●		
Lipinia vittigera (Boulenger 1894)	●	●	●
Lygosoma albopunctata Gray 1846	●		
Lygosoma bampfyldei Bartlett 1895	●	●	●
Lygosoma bowringii (Günther 1864)	●	●	●
Lygosoma quadrupes (Linnaeus 1766)	●		
Mabuya indeprensa (Brown & Alcala 1980)		●	
Mabuya longicauda (Hallowell 1856)	●		
Mabuya macularia (Blyth 1853)	●		
Mabuya multifasciata (Kuhl 1820)	●	●	●
Mabuya rudis Boulenger 1887		●	●
Mabuya rugifera (Stoliczka 1870)	●	●	●

Sphenomorphus aesculeticola Inger *et al.* 2002		●	
Sphenomorphus alfredi (Boulenger 1898)		●	
Sphenomorphus anomalopus (Boulenger 1890)	●		
Sphenomorphus butleri (Boulenger 1912)	●		
Sphenomorphus cameronicus Smith 1924	●		
Sphenomorphus cophias (Boulenger 1908)	●		
Sphenomorphus crassa Inger *et al.* 2002		●	
Sphenomorphus cyanolaemus Inger & Hosmer 1965		●	●
Sphenomorphus haasi Inger & Hosmer 1965		●	●
Sphenomorphus hallieri (van Lidth de Jeude 1905)		●	
Sphenomorphus indicus (Gray 1853)	●		
Sphenomorphus ishaki Grismer 2006	●		
Sphenomorphus kinabaluensis (Bartlett 1895)		●	
Sphenomorphus maculatus (Blyth 1845)	●		
Sphenomorphus maculicollus Bacon 1967		●	●
Sphenomorphus malayanus (Doria 1888)	●		
Sphenomorphus multisquamatus Inger 1958		●	●
Sphenomorphus murudensis Smith 1925			●
Sphenomorphus praesignis (Boulenger 1900)	●		
Sphenomorphus sabanus Inger 1958		●	
Sphenomorphus sanctus (Duméril & Bibron 1839)	●		
Sphenomorphus scotophilus (Boulenger 1900)	●		
Sphenomorphus shelfordi (Boulenger 1900)			●
Sphenomorphus sibuensis Grismer 2006	●		
Sphenomorphus stellatus (Boulenger 1900)	●		●?
Sphenomorphus tanahtinggi Inger *et al.* 2002		●	
Sphenomorphus tenuiculum (Mocquard 1890)		●	
Sphenomorphus tersus (Smith 1916)	●		
Tropidophorus beccarii Peters 1871		●	●
Tropidophorus brookei (Gray 1845)		●	●
Tropidophorus micropus an Lidth de Jeude 1905			●
Tropidophorus mocquardii Boulenger 1894		●	
Tropidophorus perplexus Barbour 1921			●
Uromastycidae			
Leiolepis belliana (Hardwicke & Gray 1827)	●		
Leiolepis triploida Peters 1971	●		
Varanidae			
Varanus dumerilii (Schlegel 1839)	●	●	●
Varanus nebulosus (Gray 1831)	●		
Varanus rudicollis Gray 1845	●	●	●
Varanus salvator (Laurenti 1768)	●	●	●
Crocodylidae			
Crocodylus porosus Schneider 1801	●	●	●
Crocodylus raninus Müller & Schlegel 1844			●
Crocodylus siamensis Schneider 1801	●?		
Tomistoma schlegelii (Müller 1838)	●	●	●
Dermochelyidae			
Dermochelys coriacea (Vandelli 1761)	●	●	●

Cheloniidae			
Caretta caretta (Linnaeus 1758)	●?		
Chelonia mydas (Linnaeus 1758)	●		●
Eretmochelys imbricata (Linnaeus 1766)	●	●	
Lepidochelys olivacea (Eschscholtz 1829)			●
Trionychidae			
Amyda cartilaginea (Boddaert 1770)	●	●	●
Chitra chitra Nutphand 1979	●		
Dogania subplana (Geoffroy Saint-Hillaire 1809)	●	●	●
Pelochelys cantorii Gray 1864	●	●	
**Pelodiscus sinensis* (Wiegmann 1834)	●		●
Geoemydidae			
Batagur baska (Gray 1831)	●		
Callagur borneoensis (Schlegel & Müller 1844)	●		●
Cuora amboinensis (Daudin 1801)	●	●	●
Cyclemys dentata (Gray 1831)	●		●
Cyclemys oldhami Gray 1863			
Heosemys annandalei (Boulenger 1903)	●		
Heosemys grandis (Gray 1860)	●		
Heosemys spinosa (Gray 1831)	●		●
Malayemys macrocephala (Gray 1859)	●		
Notochelys platynota (Gray 1834)	●	●	●
Orlitia borneensis Gray 1873	●		●
Siebenrockiella crassicollis (Gray 1831)	●		●
Emydidae			
**Trachemys scripta* (Schoepff 1792)	●	●	●
Testudinidae			
Indotestudo elongata (Blyth 1853)	●		
Manouria emys (Schlegel & Müller in: Temminck 1844)	●	●	●
Manouria impressa (Günther 1882)	●		

* refers to introduced species.
Checklist of 15 April 2006.

APPENDIX III

Websites Relevant to Malaysian Herpetology

1. *Amphibian Species of the World* (*Second Edition*) by D. R. Frost, American Museum of Natural History (www.research.amnh.org/herpetology/amphibia/index/html)
2. *Reptile Species of the World* by P. Uetz, European Molecular Biology Laboratory (www.embl-heidelberg.de-uetz/db-info/related.html).
3. *Frogs of the Malay Peninsula* by J. Sukumaran, University of Kansas (www.frogweb.org)
4. *Lizards of Borneo* by I. Das & G. Ismail, Universiti Malaysia Sarawak (www.arbec.com.my/lizards.)
5. *Turtles and Crocodiles of Borneo* by I. Das, Universiti Malaysia Sarawak (www.arbec.com.my/crocodilesturtles)
6. *Amphibia Web*, University of California (http://www.amphibiaweb.org)
7. *Amphibia Tree* (http://texas.amphibiatree.org)
8. *HerpNET* (http://herpnet.org)
9. *Aquatic Snakes of Southeast Asia* by Harold Voris, Field Museum of Natural History (http://www.fieldmuseum.org/aquaticsnakes)
10. *Bibliomania* by Breck Bartholomew (http://www.herplit.com). Includes a database of approximately 50,000 citations.

STATE OF KNOWLEDGE ON FRESHWATER FISHES OF MALAYSIA

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ABSTRACT

Freshwater fishes of Malaysia are diverse and inhabit a great variety of habitats ranging from small torrential streams to estuarine, highly acidic ecosystems and alkaline waters. Several species are endemic. Currently, there are about 280 species of freshwater fishes in Peninsular Malaysia, with more than 100 and 200 species reported from Sabah and Sarawak, respectively. The figures for Sabah and Sarawak are believed to be underestimates as the two states are poorly inventoried. In Peninsular Malaysia research on freshwater fishes is already established while in Sabah and Sarawak, the research is actively picking up in pace. Unlike Sabah, the fishes of Sarawak have never been the subject of any major research endeavor. Focus was given to major rivers in the state and many isolated and inland water bodies were left unexplored. In general, the fish diversity reported from Peninsular Malaysia reflects the peninsula's close similarity with mainland Asiatic icthyofauna and the Sundaic component. The lack of research coordination, funding and local variations in regulation hamper efforts to bring together all collections into one repository centre. This issue requires urgent attention.

INTRODUCTION

Land development has altered the landscape as well as the aquatic ecosystems in many parts of Malaysia. Conversion of an intact forest has resulted in a loss of fish habitats in the country. These losses are almost always permanent and recovery, if taking place, will probably take many years and even so, does not restore the original diversity. Freshwater fishes of Malaysia are diverse and interesting but the knowledge is rather unsatisfactory and varies greatly in Peninsular Malaysia, Sabah and Sarawak.

Freshwater fishes inhabit a great variety of habitats ranging from small torrential streams to estuarine habitats, with several species flourishing in highly acidic ecosystems of peat swamps and acid-water freshwater swamps. There are some species that thrive in both acidic and alkaline waters. Several species are endemic and their distribution are restricted to small areas,

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or confined to a particular drainage system, or if widely distributed, confined to an island or to a few localities.

The diversity of freshwater fishes in Peninsular Malaysia reflects a close similarity with mainland Asiatic icthyofauna and others are from Sundaic origin. These overlaps have been recognized by many researchers (e.g., Mohsin & Ambak 1983, Zakaria-Ismail, 1994). In Malaysia, there are various institutions engaged in the study of freshwater fish diversity. However, much of the research is driven on individual basis, rather than on a collective or collaborative effort, and this leads to a loss in information when focus and funding change directions. The lack of research coordination and local variation in enforcement hamper efforts to bring together all known specimens freshwater fishes of Malaysia into one holding institution.

The objective of this paper is to present the state of knowledge on the freshwater fish diversity in Malaysia. This information is gathered from past and recent publications. The need for a repository center is briefly discussed here. Brief information about the specialists and people working in the conservation and management of freshwater fishes as well as the possibilities for international collaboration are highlighted.

FRESHWATER FISHES OF PENINSULAR MALAYSIA

Freshwater fishes of Peninsular Malaysia have been receiving attention since 1800s. However, post-1990s may be regarded as the period where studies on the freshwater fishes are at its peak. Numerous works were published, particularly for Peninsular Malaysia (for details account of references, see Lim & Tan 2002). For the past 15 years, research on the freshwater fishes in Peninsular Malaysia has increased steadily and many new species and new records were reported. These were made possible by the surveys and inventories conducted in areas previously inaccessible and areas that were believed to harbor a lower diversity.

As of 2002, at least 278 species are recognized as native with at least 24 species introduced (Lim & Tan 2002). This number, at present, is around 290. Since 1990, 50 more native species have been added to the list and more than half are new to science (Lim & Tan 2002). To date, Peninsular Malaysia has probably one of the most extensively studied ichthyofauna diversity in the Southeast Asia region. This is due to the easy access to various inland habitats. Mohsin & Ambak (1983)'s publication on the diversity of freshwater fishes of Peninsular Malaysia is very extensive and considered a “classic” but, typically, it contains numerous nomenclature errors. In 1989, M. Zakaria-Ismail completed his doctorate on the systematics, zoogeography and conservation of freshwater fishes of Peninsular Malaysia (Zakaria-Ismail 1989). In his dissertation, he listed many species as new records. This list is now no longer the most updated checklist and furthermore, his dissertation is not widely available. Many new species have been subsequently added to the list, arising from inventories done at other areas such as the North Selangor Peat Swamp Forest (NSPSF) (Ng *et al.* 1992). The inventories, which began in 1989, resulted in the discovery and documentation of 65 species of fish. Following this, several other reports on the freshwater fish diversity are being prepared (Ahmad & Lim *in prep*). The species diversity in Peninsular Malaysia may not exceed 300 unless major taxonomic revisions on certain groups are dealt with, supplemented with the use of molecular approaches.

FRESHWATER FISHES OF SABAH AND SARAWAK

Sabah and Sarawak has perhaps over 100 and 200 species, respectively. It is difficult to provide a close estimate of the diversity as many studies are still in progress or about to begin. Therefore, the figures currently available for Sabah and Sarawak are poor estimates. The two states are believed to harbor more than what we currently know of their ichthyofauna diversity. This low number merely reflects the lack of inventory studies. For Sabah, Chin (1990) listed the number of freshwater fish species *ca.* 155, including 12 exotic species. Martin-Smith & Tan (1998) acknowledged that the true number of freshwater fishes in Sabah is probably much higher.

Sabah is probably better known for its freshwater fish diversity based on the work of Robert F. Inger & P. K. Chin, the Freshwater Fishes of North Borneo (1962) and a subsequent supplementary chapter in 1990 (Inger & Chin 1990). Apart from this, there were no other major taxonomical studies/revisions nor were there many comprehensive collections made—much of the research in the state were ecological in approach. Specialist collections at localized areas however, yielded interesting results (Chin & Samat 1992, Chin & Samat 1995). Work by Martin-Smith & Tan (1998) has significantly contributed to the understanding of ichthyofauna in eastern Sabah. Two new species of the genus *Gastromyzon* had been described recently (Tan & Martin-Smith 1998).

Unlike Sabah, the freshwater fishes of Sarawak have never been the subject of any major research endeavor. Scattered studies were conducted mainly on documenting the fish fauna that were affected by development as part of the requirement of Environmental Impact Assessment (EIA). Again, focus was given to major rivers in the state and many isolated and inland water bodies were left unexplored. Watson & Balon (1984) conducted a survey along the Baram River but much of the associated taxonomic work was ignored. The listing of species that occurred in the River drainage, including those that occurred in Brunei, can be found in Kottelat & Lim (1995). This listing is probably the only major publication for the state of Sarawak. Several new species including a *Rasbora*, a freshwater puffer fish and an anabantoids fish had been described in the last decade from the state.

AREAS WITH KNOWN DIVERSITY

Previous studies on the freshwater fishes of Peninsular Malaysia were mainly conducted at Taman Negara (King Edward's National Park) (Zakaria-Ismail 1984, Tan & Hamzah 1990). Following this, at least four major rivers were surveyed and among them, only Sungai Pahang can be regarded as being thoroughly surveyed (Khan *et al.* 1996) and the fish collection properly catalogued and identified to the taxon level!

Fish survey along a tributary of Sungai Terengganu was made prior to the construction of the Kenyir hydroelectric dam more than two decades ago. Cramphorn (1983) visited several sites and the materials collected might be available elsewhere. The fish diversity along Sungai Perak and Sungai Kelantan have been documented by T.I. Kvernevik but these are not complete. A major gap is recognized and a more thorough survey is urgently required.

As for Tasik Bera and Tasik Chini, the ichthyofauna diversity and it contributions to fisheries have been documented by Mizuno & Furtado (1982). This was followed ten years later by the study on the swamp ichthyofauna of North Selangor Peat Swamp Forest (NSPSF) (Ng *et al*. 1992, 1994). The study marks the beginning of a fresh era for the freshwater fish research in Malaysia, particularly for Peninsular Malaysia.

In the late 1990s, a study was initiated to document the fish diversity of a small pocket of peat and freshwater swamp forest in the Pondok Tanjung Forest Reserve, Perak. In the five months of short-period samplings (December 1997 to April 1998), 42 fish species were recorded (Mansor *et al*. 1999) and the number has now increased to 50 species (A. Ahmad *unpubl*.). More focus was given to document the freshwater fish fauna of peat swamp related ecosystems. Zakaria-Ismail (1999) reported about 33 species of freshwater fish in Nenasi Forest Reserve, Pahang. Another study recorded 46 species in Southeast Pahang Peat Swamp Forest (SEPPSF). The most recent survey in SEPPSF, conducted along Sungai Bebar and Sungai Serai, yielded approximately 58 species, thus bringing the total fish species known to SEPPSF to 65 species (Ahmad *et al*. 2005).

Studies on the freshwater fish species in several major islands in Peninsular Malaysia yielded surprising results. Penang Island's ichthyofauna was documented by Alfred (1963) in which *Neolissocheilus hendersoni* (previously known as *Acrossocheilus hendersoni* Herre) was described. The species is endemic to Penang and Langkawi Islands. The Tioman Island's ichthyofauna has been surveyed by several researchers and the latest results were published by Ng *et al.* (1999). Fourteen species were reported to inhabit the many streams and creeks on the island. Despite its relatively low diversity, two species occurring there: *Sundoreonectes tiomanensis* (loach) and *Clarias batu* (catfish) are not found elsewhere. While *Clarias batu* is common along streams (Lim & Ng 1999), the loach is confined to a single cave situated in the island's interior.

In 2002, Malayan Nature Society (MNS) together with several other institutions organized a scientific and heritage expedition to the island of Langkawi. Together with previous collections, a checklist of the freshwater fish was prepared. At least 24 species were recorded, while three others are additional to the ones already known for Peninsular Malaysia (Ahmad & Lim *in prep*).

Inventory studies were also conducted in states parks such as Endau-Rompin (Zakaria-Ismali 1987, Ng & Tan 1999), Perlis State Park (Ahmad *et al*. 2001, Samat *et al*. 2002, Ahmad & Samat 2005), Penang National Park (Ahmad *et al*. 2002, Ahmad *et al.* 2004), small streams and headwaters in Pahang (Zakaria-Ismail 1993) and Johor (Lim *et al.* 1990), small isolated swamps in Terengganu (Kottelat *et al*. 1992). Ng & Tan (1999) recorded two new catfish species from Sungai Kahang while several new species were described from the freshwater swamps at Kuala Berang, Terengganu (Kottelat & Lim 1993).

In Sabah, there were no other major studies except for the work of Inger & Chin (1962). Localised surveys were conducted while others were more ecological in approach. Samat & Chin (1996) produced a checklist of the balitorid fishes, comprising 19 species and briefly discussed the biogeography, taxonomy, species composition and ecomorphology. A study on the balitorid loach, *Gastromyzon* is currently on-going (K.K.P. Lim, pers. comm.). Studies conducted at Danum Valley (Martin-Smith 1998, Martin-Smith & Tan 1998) yielded several new species (Tan & Martin-Smith 1998). Inventories were also conducted at Sungai Segama in the Tabin Wildlfe Reserve, Crocker Range, Maliau Basin and Kinabalu Park (Goose 1972, Samat 1990).

In Sarawak, apart from the work of Watson & Balon (1984) and the compilation of a fish checklist by Kottelat & Lim (1995), several other studies were conducted, mainly focusing on small areas and lacking major taxonomic work. Inventories were conducted along the Rajang River, Lambir and Gunung Mulu National Parks, Batang Ai and Bario areas. Large areas of the peat swamp forest in the state are yet to be explored. A small pocket of peat swamp forest near University Malaysia Sarawak (UNIMAS) has about 16 species of freshwater fish (Khairul-Adha & Yuzine *in press*). Surveys in other areas were conducted but the results are preliminary (Ahmad & Khairul-Adha *in prep*.).

REPOSITORY CENTER

Malaysia does not have a national repository centre (Ng 2000). The collections in Peninsular Malaysia are currently deposited in the respective institutions where the research is conducted. The need for a national repository centre is necessary but until this is created, universities, research institutions and government agencies will continue to keep their respective collections. At present, the collection at University Malaya (BIRCUM) is probably the only one being actively used by researchers and taxonomists alike. The University College of Science and Technology Malaysia (KUSTEM), Kuala Terengganu and University Kebangsaan Malaysia (UKM), Bangi each holds a good collection of freshwater fishes. The collections at KUSTEM are mainly new collections and this does not include collections reported by Mohsin & Ambak (1983). Fisheries Research Institute (FRI), Malacca, holds a significant number of collections that includes materials from Sungai Pahang. Many of these collections may not have been accurately curated.

In Sabah and Sarawak, both the State Museums play a significant role in holding a large collection of fishes found in the states. Apart from that, University Malaysia Sabah (UMS), Kota Kinabalu and UNIMAS have their own collections. The number of collections may not be as great compared to the Museums' collections, but they are still considered significant from the viewpoint of research.

LOCAL EXPERTISE

Ng (2000) stated that taxonomic expertise is a greatly misused word. In Malaysia, the number of practising taxonomists is scarce. Many taxonomists are trained in the field of research but unfortunately, do not eventually practice active taxonomic research. The establishment of the national repository center may not materialize if there is insufficient number of taxonomists, ecologists and biologists. In addition, it is becoming increasingly difficult to encourage the younger generation to be involved in the research and development of freshwater fishes. Kottelat & Whitten (1996) and Ng (2000) commented on the pathetic number of practising taxonomists in Asia. In Malaysia, the figure (Table 2 in Ng 2000) showed that only a few are involved in this field, but the actual number practicing might be even less than what is reported! In addition, many senior researchers are not actively publishing their results. The collaboration between Malaysia and other external agencies such as the Raffles Museum of Biodiversity Research (RMBR), Singapore, plays a significant role in enhancing knowledge on the country's freshwater fishes.

External collaboration is needed but more importantly, the availability of sufficient research funding is crucial to enable inventory work and systematic research. The involvement of organisations such as the United Nation Development Program, (UNDP) through the Global Environmental Facility (GEF) in the research on the peat swamp forests in Southeast Pahang, Sarawak and Sabah is significant in contributing to the habitat conservation. Notwithstanding this, it is crucial that local researchers play a more active role to the research and conservation of these precious natural resources.

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Commercial and Exotic Fish Diversity in Marine Parks in the Straits of Malacca and South China Sea

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ABSTRACT

Inventory of species diversity in different marine ecosystems has been conducted in Peninsular Malaysia, Sabah and Sarawak since early 1900's. Much of the work in taxonomic identifications was made possible through integrated effort ranging from periodic national fish resource surveys initiated as early as 1926, fishing trials and statistical data collected at various landing points. These efforts were strengthened by regional cooperation mechanisms, international research initiatives and grants. These have contributed, directly and indirectly, to an increase in information on marine fish diversity. At present, there are 1751 species of marine and brackish water fish recorded in Malaysia. More than 400 species recorded in the coastal areas and river estuaries and more than 450 species recorded offshore in East Malaysia alone. The diversity in the coastal areas, estuaries and offshore for Peninsular Malaysia is lower.

Improvements in diving and photographic-videographic equipments have provided a superb documentation of information of biodiversity at specific sites especially in marine park islands for both coastal and offshore areas. The interest in underwater photography and videography has enhanced the work significantly. Significant findings on fish biodiversity in marine park islands especially on rare and exotic species have increased tremendously.

This paper provides an overall picture of the Global Taxonomic Initiative (GTI) in Malaysia's marine fish environment based on the information gathered through individual research and institutional efforts, including published and unpublished reports. Information specific to Pulau Payar in the Straits of Malacca, Pulau Redang Islands in Terengganu, Tioman Islands in Pahang and Tinggi Islands in Johor are selected for the review since extensive research and surveys had been conducted on these islands.

The paper also discusses issues and obstacles experienced in undertaking the Global Taxonomic Initiative and provide recommendations for more effective GTI efforts including repository and management of specific marine ecosystems and corridors.

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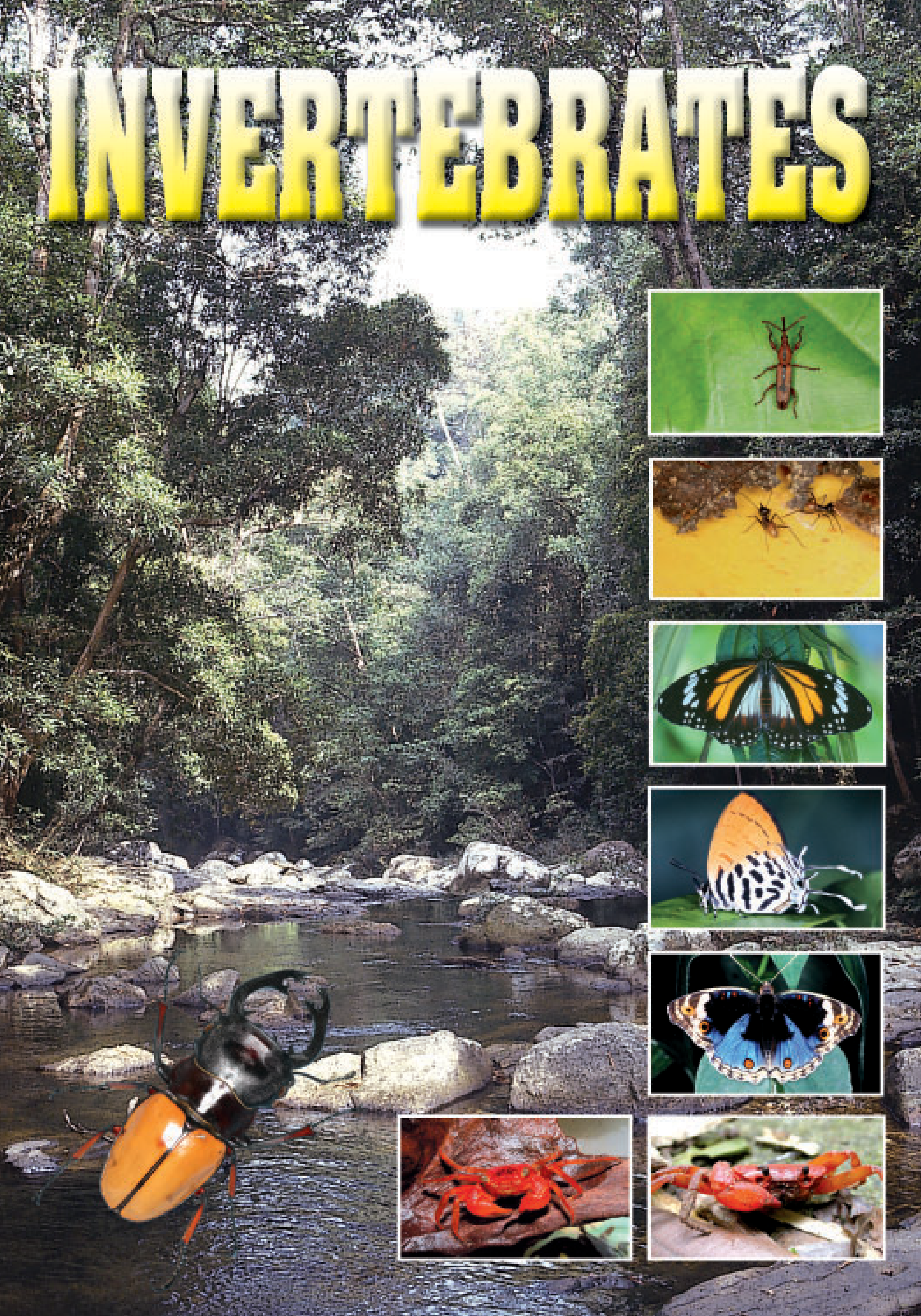
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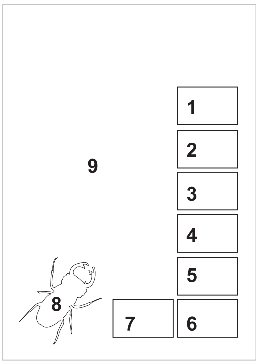

1. Cucurlionidae. Photo courtesy Shawn Cheng
2. *Hospitalitermes* sp. (Termitidae) Photo courtesy Shawn Cheng
3. *Danaus affinis* (Nymphalidae). Photo courtesy L.G. Kirton
4. *Drupadia ravindra moorei* (Lycaenidae). Photo courtesy L.G. Kirton
5. *Junonia orithya wallacei* (Nymphalidae). Photo courtesy L.G. Kirton
6. *Johora grallator* (Potamidae). Photo courtesy Lim Cheng Puay
7. *Geosesarma gracillimum* (Grapsidae). Photo courtesy P.K.L. Ng
8. *Odontolabis femoralis* (Lucanidae). Photo courtesy L.G. Kirton
9. Riverine vegetation in a tropical lowland dipterocarp forest. Photo courtesy L.G. Saw

MALAYSIAN FRESHWATER CRABS: CONSERVATION PROSPECTS AND CHALLENGES

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ABSTRACT

Of the over 150 species of true freshwater crab species now known from Sundaic Southeast Asia, more than half occur in Malaysia. Currently, 24 genera and 102 described species from four families; Potamidae, Gecarcinucidae, Parathelphusidae and Sesarmidae, are known. Many species of freshwater crabs, however, have very restricted geographic ranges, a consequence of their relative low fecundity cum direct development, poor dispersal abilities, and niche-specialisation. This makes freshwater crabs highly susceptible to anthropogenic activities. While there is no clear evidence that any one species has been made extinct as a result, the threats facing many known species are critical. The conservation status of Malaysian freshwater crabs are reviewed and assessed using the criteria established by the IUCN (2001), and the problems and challenges associated with these discussed. The report serves as a starting point for determining appropriate conservation strategies for these animals.

INTRODUCTION

Of the estimated 6,500 known species of brachyuran crabs, over 1,000 are known to be wholly freshwater in habit. Freshwater crabs are one of the most important organisms inhabiting Southeast Asian freshwaters, but are relatively poorly known because of their secretive habits. They are present in almost all clean freshwater bodies, from lowlands to high mountains. Some species have also become terrestrial and semi-terrestrial, moving about or burrowing into the forest floor. Their direct development and freshwater habit have resulted in rampant speciation, with a large number of species occurring in this part of the world. Malaysia alone has one of the highest densities of freshwater crab diversity in the world, with 24 genera and 102 known species from four families (Potamidae: 41 species; Parathelphusidae: 40 species; Gecarcinucidae: 3 species; and Sesarmidae: 18 species), many of them endemic, and more than half of them described between 1990 and 2000 (Ng 1988, 1990a, 2004; Cranbrook & Furtado 1988; Ng & Ambu 1998).

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Much of this diversity and endemism is owed to the complicated topography and equally diverse and heterogeneous habitats found in much of the country, ranging from rugged montane habitats with waterfalls and torrential streams to moist lowland forests to subterranean freshwaters; in both continental as well as insular landmasses. These provide plenty of opportunities not only for allopatric speciation to occur by geographic isolation, but also for sympatric speciation through niche specialization in the many ecological niches available. Naturally, these are coupled with the freshwater crab characteristics of possessing low fecundity, direct development and limited dispersal abilities.

The species distributions cover a wide gamut, from point endemics such as *Johora johorensis* (Gunung Pulai, Johor) to localized taxa like *Geosesarma nemesis* (Gunung Pulai and Gunung Panti, Johor, and Singapore) to wide ranging species such as *Parathelphusa maculata* (throughout Peninsular Malaysia, southernmost Thailand, Singapore and southern half of Sumatra).

The present paper aims to assess and discuss the conservation status of the 102 freshwater crab species now known from Malaysia.

MATERIALS AND METHODS

For purposes of reference and discussion, certain geographical terms have been used in this paper. These are defined below:

Sundaland/Sundaic - refers to the continental land masses and islands of the Sunda Shelf, i.e., Malay Peninsula, Borneo, Sumatra, Java and Lesser Sunda Islands. Palawan (including Balabac) is included but Sulawesi and the southern islands of the Philippines (e.g., Mindanao and Mindoro) are excluded.

Malay/Malayan - pertaining to Peninsular Malaysia, inclusive of southernmost Thailand (south of the Isthmus of Kra), and Singapore.

The terminology for morphological structure follows essentially that used by Ng (1988). Several genera and species are in the process of being described or the descriptions are in press. In such instances, no name has been applied. In this paper, the abbreviations G1 and G2 are used for the male first and second pleopods, respectively.

Although Ng (1988) previously recognised the taxon of subspecies, a reconsideration of the state of brachyuran systematics suggests that such a fine division is neither useful nor realistic, especially considering the poor understanding we have of their mechanisms of speciation. The phylogenetic species concept is utilised here as far as possible. Under this framework, all taxa previously regarded as subspecies are recognised here as species.

With regards to the threat status, the most recent (IUCN 2001) guidelines (Red List Categories & Criteria, version 3.1) were adopted for use in assessing the threat-levels of the various freshwater crab species considered. These categories are: Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), or Data Deficient (DD).

Although the criterion of population size is an important consideration in ascertaining a species' threat level, this is almost impossible to determine for the freshwater crab species treated here. The necessary quantifications simply have not been done. Many species are also very secretive in habits, and several have not been rediscovered since they were first collected. In particular, species, which are obligate cave dwellers, deep forest terrestrial species, tree-climbers or that otherwise have very specialised niches, cannot be effectively sampled. As such, the only objective data-sets of use are of the presence/absence type. Even so, when a species is supposedly absent from an area, this observation must be considered with regards to its known habits and behaviour. In many cases, the habitats and habits of a species can be predicted on the basis of its carapace physiognomy, leg structure and proportions, eye form as well as colour.

Nevertheless, in general, the presence/absence criterion at least allows the geographic range to be predicted using either the Extent of Occurrence (i.e. area contained within the shortest continuous imaginary boundary encompassing known sites of occurrence), or the Area of Occupancy (i.e. the area within its Extent of Occurrence which is actually occupied by the taxon). Given that most tropical habitats are very heterogeneous in structure, and aquatic habitats (including swamp forest structure and underground water-tables) fluctuate substantially depending on the time of the year; and that some species have small and highly localised populations; the Area of Occupancy (i.e. the available aquatic habitat particular to the species) criterion is too subjective to be very useful. The Extent of Occurrence is thus the preferred criterion for estimates used here for geographic range.

As such, the CR, EN and VU outcomes resulted from evaluation against criteria B1(a) and (b)(iii) in those categories. Continuing decline in Extent of Occurrence and/or quality of habitat was inferred if the habitat was not a protected area, or if it was a protected area subject to anthropogenic impacts such as pollution or encroachment.

A taxon is CR if its Extent of Occurrence is estimated to be less than 100 km^2 (B1) and its habitat is severely fragmented or it is known to exist at only one location (B1(a)); and there is a continuing decline in the area, extent and/or quality of its habitat (b)(iii).

It is EN if its Extent of Occurrence is estimated to be less than 5,000 km^2 (B1) and its habitat is severely fragmented *or* it is known to exist at no more than five locations (B1(a)); and there is a continuing decline in the area, extent and/or quality of its habitat (b)(iii).

It is VU if its Extent of Occurrence is estimated to be less than 20,000 km^2 (B1) and its habitat is severely fragmented *or* it is known to exist at no more than 10 locations (B1(a)); and there is a continuing decline in the area, extent and/or quality of its habitat (b)(iii). VU status was also applied to taxa that have an Area of Occupancy estimated to be less than 20 km^2; and are known from only a single population which is at least partly in a protected area, but is "prone to the effects of human activities or stochastic events within a very short time period in an uncertain future, and is thus capable of becoming Critically Endangered or even Extinct in a very short time period" (D2).

NT status was awarded to taxa that were evaluated against the criteria but did not qualify for CR, EN or VU at present, but likely to qualify for such a category in the near future.

LC status was awarded to taxa that were evaluated against the criteria and did not qualify for CR, EN, VU or NT; in general, these taxa are widespread (Extent of Occurrence greater than 20,000 km^2) and abundant.

RESULTS

The results are presented in Table 1, which is a checklist of the freshwater crabs of Malaysia, showing available data relevant to the IUCN (2001) Red List criteria together with the conservation outcomes. The assessment shows that of the 102 Malaysian species known, 16 taxa are Critically Endangered, 46 Endangered, 28 Vulnerable, 10 of Least Concern and 2 are Data Deficient. None of the species evaluated here qualified for the Near Threatened category as defined above.

DISCUSSION

Based on the conservation status assigned to the Malaysian freshwater crabs in the present study, a few patterns have emerged that should be noted. The restricted distributions of most of the freshwater crab species in Malaysia pose serious problems for conservation. It is somewhat fortunate that the species with the most restricted distributions are those which inhabit offshore islands or mountains (see later, however). These areas are generally less disturbed or not scheduled for development, at least for the moment. The serious loss of natural forest as a result of land development and agriculture has generally affected the lowlands more severely. The species which do occur in lowlands, e.g., *Parathelphusa maculata* and *Sayamia sexpunctata*, are still common in relatively unpolluted plantation waterways and ricefields. These lowland species also have relatively much wider distributions, and are least at risk. Ten species (e.g., *Perithelphusa borneensis*) reported here with an Extent of Occurrence of approximately 1,500 to 2,000 km^2 are categorized as Least Concern. Aquatic species (e.g., *Isolapotamon collinsi* and *Thelphusula baramensis*) in general appear to be faring better than their terrestrial kin, as only 22 out of 51 primarily aquatic species (43%) are categorized under Critically Endangered or Endangered. On the other hand, terrestrial or semi-terrestrial species like *Geosesarma katibas* and *Thelphusula granosa* seem to be under much greater threat, with 36 out of 47 such species (77%) being regarded as Critically Endangered or Endangered. Perhaps not surprisingly, the results also indicate that specialist species, e.g., the obligate cave-dwelling crab, *Cerberusa caeca*, are also more threatened, with most such taxa being Critically Endangered or Endangered. Interestingly, highland taxa, despite their relative inaccessibility, seem to also be at higher risk, with all 10 highland species in Peninsular Malaysia (e.g., *Johora grallator*) being Critically Endangered or Endangered. Many of the potamids and smaller parathelphusids are especially vulnerable to development and pollution. The limited distribution of most of these species with very restricted ranges is not an anomaly. *Johora johorensis* for example, is only known from Gunung Pulai, and despite much collecting around the hill and other areas, has not been recorded elsewhere. In neighbouring hills, it is replaced by two very different taxa: *J. intermedia* to the north and *J. murphyi* to the east. Any development of Gunung Pulai would thus have dire consequences for *J. johorensis*. Finally, the isolated nature of small islands also appears to put the island endemic species at a disadvantage, as illustrated by the eight species (five *Johora*, one *Parathelphusa*, two *Geosesarma*) known only from Pulau Tioman, all of which are regarded as Endangered.

Table 1. Checklist of the freshwater crabs of Malaysia (Potamidae, Parathelphusidae, Gecarcinucidae, Sesarmidae)

Species	Status	No. of sites	Extent of Occurrence	Range	Habitat/Ecology	Threats	Conservation measures
Johora aipooae (Ng, 1986)	EN	1	<500 km^2	Endemic to Taman Negara Park in Pahang, where it was first described from and has not been reported since it was first caught in the 1950s.	Almost certainly terrestrial to semi-terrestrial in habits due to its swollen carapace. No ecological notes associated with original capture.	No clear threat, as its precise range not known. That it was described from Taman Negara suggests it should be safe for the moment.	The retention of Taman Negara as a national park should ensure its survival.
Johora counsilmani (Ng, 1985)	EN	3	<500 km^2	Endemic to drainages in the central portion of Pulau Tioman, Pahang.	Primarily aquatic. Associated with clean, clear, flowing waters, hiding under rocks and vegetation during the day and emerging at night to forage in the water.	Potential water pollution and habitat loss/degradation in lower reaches of drainages. Uncontrolled tourism (viz. increased land use and over-exploitation of limited fresh-water resources) is a concern. No population impacts observed over last 20 years.	Conservation of Pulau Tioman hinterland and monitoring of water usage from lower reaches of streams.
Johora gapensis (Bott, 1966)	EN	2	<500 km^2	Endemic to Fraser's Hill, Pahang, and vicinity of high elevation. Described from specimens collected above 1,000 m above sea level (asl).	Primarily aquatic. Found under rocks and vegetation in and adjacent to forest streams.	Water pollution and habitat loss/degradation. The increased use of the area for tourists etc. is a concern. Over-use of freshwater resources and warming of surrounding forests may pose challenges. No population impacts observed over last 20 years.	Conservation of forests, water resources and monitoring of pollution levels in Fraser's Hill area.
Johora grallator Ng, 1988	EN	3	<500 km^2	Endemic to Gunung Kajang and immediately adjacent high elevation areas of Pulau Tioman, Pahang. Described from specimen collected at 792 m asl.	Terrestrial. Associated with higher elevation hill forests. Biology poorly known.	No clear immediate threat, as development of extremely rugged hilly hinterland of Pulau Tioman appears unlikely. Nevertheless, that it is a specialist and has a restricted range is a concern.	Conservation of Pulau Tioman hinterland.

Species	Status	No. of sites	Extent of Occurrence	Range	Habitat/Ecology	Threats	Conservation measures
Johora gua Yeo, 2001	EN	1	<500 km^2	Endemic to Pulau Tioman, Pahang. Described from single highland locality, Gua (cave) Tengkuk Ayer, on Gunung Kajang, 900 m asl.	Semi-terrestrial species found in caves and probably subterranean streams. Only obligate cavernicolous crab (troglobite) known from Peninsular Malaysia. Biology not well-known.	No clear immediate threat, as development of extremely rugged hilly hinterland of Pulau Tioman appears unlikely.	Conservation of Pulau Tioman hinterland.
Johora hoiseni Ng and Takeda, 1992	EN	2	<500 km^2	Endemic to Kelantan.	Primarily aquatic. Associated with clean, clear, flowing waters, hiding under rocks and vegetation during the day and emerging at night to forage in the water. Biology poorly known.	No immediate threat to populations within Taman Negara. Water pollution and habitat loss/degradation outside protected areas.	The retention of Taman Negara as a national park should ensure its survival. Conservation of forests and monitoring of pollution levels outside protected areas.
Johora johorensis (Roux, 1936)	CR	1	<10 km^2	Endemic to Gunung Pulai, Johore.	Primarily aquatic. Found under rocks and vegetation in and adjacent to upper stretches of forest streams.	No clear immediate threat, as locality is within designated Recreational Forest. However, potential disturbance/pollution from resulting to high levels of human activity coupled with the small range is a concern. Over the last 15 years, the species has become rare in the lower stretches of the drainage (where most human impacts are) but still relatively common in the higher areas.	Retention of Recreational Forest status or upgrading of protection status of Gunung Pulai area, especially for the headwaters. Restricting access to more pristine, sensitive sites within.

Species	Status	No. of sites	Extent of Occurrence	Range	Habitat/Ecology	Threats	Conservation measures
Johora intermedia Ng, 1986	LC	>20	<2,000 km^2	Endemic to highland forests of the lower half of the Main Range in Selangor, Pahang, Negri Sembilan and northwestern Johore.	Primarily aquatic. Found under rocks and vegetation in and adjacent to slow-flowing, shaded hill streams. One concern is that the species may prove to be part of a species complex and the range/threats will then need to be re-evaluated.	Habitat loss/degradation and pollution outside protected areas. No population impacts observed over last 20 years.	There are no specific conservation measures for this species.
Johora murphyi Ng, 1986	EN	2	<500 km^2	Endemic to Kota Tinggi and Gunung Panti, Johore, and adjacent areas in Johore and Pahang.	Primarily aquatic. Found under rocks and vegetation on the sides of waterfalls, streams or adjacent pools.	Habitat loss/degradation and pollution outside protected areas. No population impacts observed over last 20 years.	There are no specific conservation measures for this species. The Lombong area (Kota Tinggi waterworks) is a protected area and this will help ensure its survival. A larger area of protection is desirable.
Johora punicea (Ng, 1985)	EN	5	<500 km^2	Endemic to Pulau Tioman, Pahang.	Semi-terrestrial. Lives under rocks in damp areas near or adjacent to streams.	Water pollution and habitat loss/degradation in lower reaches of drainages. Uncontrolled tourism (viz. increased land use and over-exploitation of limited freshwater resources) is a concern. No population impacts observed over last 20 years.	Conservation of Pulau Tioman hinterland and monitoring of water usage from lower reaches of streams.

Species	Status	No. of sites	Extent of Occurrence	Range	Habitat/Ecology	Threats	Conservation measures
Johora tahanensis (Bott, 1966)	VU	3	<2,000 km^2	Endemic to a small range of mountains east of the Main Range in Pahang and western Terengganu.	Primarily aquatic. Associated with clean, clear, flowing waters, hiding under rocks and vegetation during the day and emerging at night to forage in the water.	No immediate threat to populations within Taman Negara. Water pollution and habitat loss/degradation outside protected areas. No population impacts observed over last 20 years.	The retention of Taman Negara as a national park should ensure its survival. Conservation of forests and monitoring of pollution levels outside protected areas.
Johora thoi Ng, 1990	EN	1	<500 km^2	Endemic to Pulau Redang, Terengganu.	Primarily aquatic. Associated with rocky streams with fast-flowing waters and adjacent small pools. Biology not well studied.	Water pollution and habitat loss/degradation. The development of Redang as a resort island will increase land-use threats and over-use of very limited freshwater supplies.	Conservation of Pulau Redang forests and monitoring of pollution levels as well as freshwater use.
Johora tiomanensis (Ng and Tan, 1984)	EN	5	<500 km^2	Endemic to drainages in the southern portion of Pulau Tioman, Pahang.	Primarily aquatic. Associated with clean, clear, flowing waters, hiding under rocks and vegetation during the day and emerging at night to forage in the water.	Water pollution and habitat loss/degradation in lower reaches of drainages. Uncontrolled tourism (viz. increased land use and over-exploitation of limited freshwater resources) is a concern.	Conservation of Pulau Tioman hinterland and monitoring of water usage from lower reaches of streams.
Stoliczia bella Ng and Ng, 1987	EN	1	<500 km^2	Endemic to highlands of Pulau Langkawi, Kedah.	Semi-terrestrial. Burrows under rocks in damp shaded areas adjacent to fast-flowing streams. Biology not well-known.	Water pollution and habitat loss/degradation.	Conservation of Pulau Langkawi highlands and monitoring of pollution levels.

Species	Status	No. of sites	Extent of Occurrence	Range	Habitat/Ecology	Threats	Conservation measures
Stoliczia changmanae Ng, 1988	CR	1	<10 km^2	Endemic to Gunung Padang, Terengganu.	Believed to be semi-terrestrial to aquatic. Biology not known.	Habitat loss/degradation. The isolated nature of the type locality should ensure survival in the near future.	Conservation of forests and monitoring of pollution levels in Gunung Padang area.
Stoliczia chaseni (Roux, 1934)	EN	1	<500 km^2	Endemic to Cameron Highlands, Pahang, and surrounding montane area exceeding 1,300 m asl.	Primarily aquatic. Associated with clean, clear, flowing waters, hiding under rocks and vegetation in shaded streams with sandy substrates.	Water pollution and habitat loss/degradation. The population has decreased in the last 15 years, and is believed to be due to the scale of developments in the Cameron Highlands.	Conservation of forests and monitoring of pollution levels in Cameron Highlands area.
Stoliczia cognata (Roux, 1936)	CR	1	<10 km^2	Endemic to area near Sungei Yum, Perak.	Semi-terrestrial. Lives under rocks in damp areas near or adjacent to streams. Biology not well-known.	Water pollution and habitat loss/degradation.	Conservation of forests and monitoring of pollution levels in Sungei Yum area.
Stoliczia goal Ng, 1993	CR	1	<10 km^2	Endemic to Gunung Goal, Sungei Siput, Perak.	Not known, presumably semi-terrestrial in habits.	Water pollution and habitat loss/degradation. The potential development of the areas, long "protected" due to insurgency problems, is a concern.	Conservation of forests and monitoring of pollution levels in Gunung Goal area.
Stoliczia karenae Ng, 1993	CR	1	<10 km^2	Endemic to Baling, Kedah.	Not known, presumably semi-terrestrial in habits.	Water pollution and habitat loss/degradation. The potential development of the areas, long "protected" due to insurgency problems, is a concern.	Conservation of forests and monitoring of pollution levels in Baling area.

Species	Status	No. of sites	Extent of Occurrence	Range	Habitat/Ecology	Threats	Conservation measures
Stoliczia kedahensis Ng, 1992	CR	1	<10 km^2	Endemic to Padang, Terap district, Kedah.	Primarily aquatic, likely to be similar to *S. stoliczkana*. Biology poorly known.	Water pollution and habitat loss/degradation.	Conservation of forests and monitoring of pollution levels in Terap district area.
Stoliczia leoi (Ng and Yang, 1985)	CR	1	<10 km^2	Endemic to Gunung Kledang, Perak above 700 m asl.	Primarily aquatic. Lives under rocks in damp areas near or adjacent to streams. Biology not known.	Water pollution and habitat loss/degradation. Its very narrow range is a major concern.	Conservation of forests and monitoring of pollution levels in Gunung Kledang area.
Stoliczia pahangensis (Roux, 1936)	CR	1	<10 km^2	Endemic to Gunung Brinchang, Cameron Highlands, Pahang, exceeding 1,900 m asl.	Semi-terrestrial. Lives under rocks in damp areas near or adjacent to streams. Biology not well-known.	Water pollution and habitat loss/degradation.	Conservation of forests and monitoring of pollution levels in Cameron Highlands area.
Stoliczia perlensis (Bott, 1966)	CR	1	<10 km^2	Endemic to Kaki Bukit, Perlis.	Primarily aquatic, biology probably similar to *S. stoliczkana*. Lives under rocks in damp areas near or adjacent to streams.	Water pollution and habitat loss/degradation.	Conservation of forests and monitoring of pollution levels in Kaki Bukit area.
Stoliczia rafflesi (Roux, 1936)	CR	1	<10 km^2	Endemic to Gunung Tahan, Taman Negara, Pahang, above 1,600 m asl.	Semi-terrestrial to aquatic. Not well studied.	No clear threat, as its range is restricted to Taman Negara.	The retention of Taman Negara as a national park should ensure its survival.
Stoliczia stoliczkana (Wood Mason, 1871)	VU	3	<2,000 km^2	Endemic to highlands of Penang island.	Primarily aquatic. Associated with clean, clear, flowing waters, hiding under rocks and vegetation.	Water pollution and habitat loss/degradation.	Conservation of highlands of Penang island and monitoring of pollution levels.

Species	Status	No. of sites	Extent of Occurrence	Range	Habitat/Ecology	Threats	Conservation measures
Stoliczia tweediei (Roux, 1934)	CR	1	<10 km^2	Endemic to Maxwell Hill (Bukit Larut), Perak, above 1,000 m asl.	Primarily aquatic. Associated with deep, fast-flowing waters of montane streams and waterfalls.	Water pollution and habitat loss/degradation. Its small range is a major concern.	Conservation of forests and monitoring of pollution levels in Maxwell Hill area.
Cerberusa caeca Holthuis, 1979	EN	2	<500 km^2	Endemic to Gunung Mulu National Park and adjacent limestone formations, Sarawak.	Primarily aquatic. An obligate cavernicolous species (troglobite) living in subterranean streams; and showing complete loss of cornea and body pigmentation.	No clear threat, as its range is within Gunung Mulu National Park.	The retention of Gunung Mulu area as a national park should ensure its survival.
Cerberusa tipula Holthuis, 1979	EN	2	<500 km^2	Endemic to Gunung Mulu National Park and adjacent limestone formations, Sarawak.	Semi-terrestrial to aquatic. An obligate cavernicolous species (troglobite) living in and around subterranean streams. Shows reduced cornea and body pigmentation.	No clear threat, as its range is within Gunung Mulu National Park.	The retention of Gunung Mulu area as a national park should ensure its survival.
Ibanum aethes Ng, 1995	VU	1	<2,000 km^2	Endemic to Lanjak-Entimau area, Sarawak.	Primarily aquatic. There are many more undescribed species in this genus known from Sarawak but have been missed due to their small size.	No clear threat, as its range is within Lanjak-Entimau Wildlife Sanctuary.	The retention of Lanjak-Entimau as a Wildlife Sanctuary should ensure its survival.
Ibanum pilimanus Ng and Jongkar, 2004	EN	1	<500 km^2	Endemic to the Bau limestone formations.	Primarily aquatic. Prefers lowland streams with rocky substrates and forest cover.	As the Bau area does not have long-term protection and the species occurs in low-lying areas, it is very vulnerable to anthropogenic effects.	The conservation of as many parts of Bau as possible is necessary.

Species	Status	No. of sites	Extent of Occurrence	Range	Habitat/Ecology	Threats	Conservation measures
Isolapotamon anomalum (Chace, 1938)	VU	4	<2,000 km^2	Endemic to Kinabalu area, Sabah above 1,000 m asl.	Primarily aquatic. Occurs in flowing streams with pristine waters and under forest cover.	No immediate threat to populations within Kinabalu National Park. Water pollution and habitat loss/degradation outside protected areas.	The retention of the protected status of Kinabalu National Park should ensure its survival.
Isolapotamon bauense Ng, 1987	VU	5	<2,000 km^2	Endemic to Bau district, Sarawak.	Primarily aquatic. Appears to be a facultative cavernicolous species (troglophile).	Water pollution and habitat loss/degradation.	Conservation of forests and caves, and monitoring of pollution levels in Bau district.
Isolapotamon borneensis Ng and Tan, 1998	Data Deficient nt (DD)	1	probably <500 km^2	Almost certainly endemic to Sarawak	Probably aquatic.	Not known. Species known only from old museum material.	Considering the physiognomy of the species, it is likely to be fully aquatic and probably occurs in clean mountain streams.
Isolapotamon collinsi Holthuis, 1979	VU	2	<2,000 km^2	Gunung Mulu National Park, Sarawak. Also found in Temburong, Brunei.	Primarily aquatic. Associated with fast-flowing streams.	No immediate threat to population within Gunung Mulu National Park.	The retention of Gunung Mulu area as a national park should ensure its survival.
Isolapotamon consobrinum (De Man, 1899)	LC	>16	>2,000 km^2	Western Sarawak including Gunung Matang (Serapi) in Kubah National Park. Also found in northwestern Kalimantan, Indonesia.	Primarily aquatic.	No immediate threat to populations within Kubah National Park. Water pollution and habitat loss/ degradation outside protected areas.	The retention of the protected status of Kubah National Park should ensure its survival.
Isolapotamon doriae (Nobili, 1900)	EN	1	<500 km^2	Endemic to Penrissen Mountains, Sarawak.	Aquatic to semi-terrestrial.	Water pollution and habitat loss/degradation.	Conservation of forests and monitoring of pollution levels in Penrissen Mountains area.

Species	Status	No. of sites	Extent of Occurrence	Range	Habitat/Ecology	Threats	Conservation measures
Isolapotamon griswoldi (Chace, 1938)	VU	3	<2,000 km^2	Endemic to Kinabalu area, Sabah.	Primarily aquatic.	No immediate threat, as range falls within Kinabalu National Park.	The retention of the protected status of Kinabalu National Park should ensure its survival.
Isolapotamon grusophallus Ng and Yang, 1986	Data Deficient (DD)	1	probably <500 km^2	Almost certainly endemic to Sarawak	Considering the physiognomy of the species, it is likely to be fully aquatic and probably occurs in clean mountain streams.	Not known. Species known only from old museum material.	Protection of highland drainages.
Isolapotamon ingeri Ng and Tan, 1998	VU	2	<2,000 km^2	Endemic to Tawau and Lahad Datu area in eastern Sabah, including Danum Valley Conservation Area.	Primarily aquatic.	No immediate threat to populations within Tawau Hills Park and Danum Valley Conservation Area. Water pollution and habitat loss/ degradation outside protected areas.	The retention of the protected status of Tawau Hills Park and Danum Valley Conservation Area should ensure its survival.
Isolapotamon kinabaluense (Rathbun, 1904)	VU	5	<2,000 km^2	Endemic to Kinabalu area, Sabah.	Primarily aquatic.	No immediate threat, as range falls within Kinabalu National Park.	The retention of the protected status of Kinabalu National Park should ensure its survival.
Isolapotamon nimboni Ng, 1987 (= *I. stuebingi* Ng, 1995)	VU	3	<2,000 km^2	South Sarawak including Lanjak Entimau Wildlife Sanctuary, and northwestern Kalimantan, Borneo, Indonesia.	Primarily aquatic.	No immediate threat to populations within Lanjak-Entimau Wildlife Sanctuary. Water pollution and habitat loss/degradation outside protected areas.	The retention of Lanjak-Entimau as a Wildlife Sanctuary should ensure its survival.

Species	Status	No. of sites	Extent of Occurrence	Range	Habitat/Ecology	Threats	Conservation measures
Phricotelphusa hockpingi Ng, 1986	CR	1	<10 km²	Endemic to Maxwell Hill (Bukit Larut), Perak, from 70 m to 850 m asl.	Semi-terrestrial to aquatic. Living under rocks and leaf litter in slower parts of streams and waterfalls.	Water pollution and habitat loss/degradation. Its small range is a major concern.	Conservation of forests and monitoring of pollution levels in Maxwell Hill area.
Phricotelphusa gracilipes Ng and Ng, 1987	EN	1	<500 km²	Endemic to highlands of Pulau Langkawi, Kedah.	Semi-terrestrial to aquatic. Living under rocks and leaf litter in slower parts of streams and waterfalls.	Water pollution and habitat loss/degradation.	Conservation of Pulau Langkawi highlands and monitoring of pollution levels.
Lepidothelphusa cognetti (Nobili, 1903)	EN	2	<500 km²	Endemic to Penrissen Mountains and Bau, Sarawak.	Semi-terrestrial to aquatic. Associated with sandstone areas. Biology not well-known, but has also been found in caves and near karst areas.	Water pollution and habitat loss/degradation.	Conservation of forests and monitoring of pollution levels in Penrissen Mountains and Bau areas.
Adeleana chapmani Holthuis, 1979	EN	1	<500 km²	Endemic to Gunung Mulu National Park, Sarawak.	Cavernicolous, mainly aquatic species. Demonstrating pale body pigmentation.	No clear threat, as its range is within Gunung Mulu National Park.	The retention of Gunung Mulu area as a national park should ensure its survival.
Coccusa cristicervix Ng and Jongkar, 2004	EN	1	<500 km²	Endemic to the Bau area of Sarawak.	Semi-terrestrial to terrestrial. Likely to be in the swampy areas between the limestone formations in Bau.	As the Bau area does not have long-term protection and the species occurs in low-lying areas, it is very vulnerable to anthropogenic and associated effects.	The conservation of as many parts of Bau as possible is necessary.
Thelphusula baramensis (De Man, 1902)	VU	4	<2,000 km²	Gunung Mulu National Park, Sarawak. Also found in Baram River and Temburong, Brunei.	Primarily aquatic. Associated with streams and heath and peat swamp forest.	No immediate threat to population within Gunung Mulu National Park.	The retention of Gunung Mulu area as a national park should ensure its survival.

Species	Status	No. of sites	Extent of Occurrence	Range	Habitat/Ecology	Threats	Conservation measures
Thelphusula dicerophilus Ng and Stuebing, 1990	VU	2	<2,000 km^2	Endemic to Tawau and Lahad Datu area in eastern Sabah, including Danum Valley Conservation Area.	Semi-terrestrial. Associated with puddles and temporary water bodies in muddy areas and swamps.	No immediate threat to population Danum Valley Conservation Area. Water pollution and habitat loss/degradation outside protected areas.	The retention of the protected status Danum Valley Conservation Area should ensure its survival.
Thelphusula granosa Holthuis, 1979	EN	1	<500 km^2	Endemic to Gunung Mulu National Park, Sarawak.	Semi-terrestrial.	No clear threat, as its range is within Gunung Mulu National Park.	The retention of Gunung Mulu area as a national park should ensure its survival.
Thelphusula hulu Tan and Ng, 1997	EN	2	<500 km^3	Endemic to Maliau Basin, Sabah.	Semi-terrestrial to aquatic. Associated with tea-coloured waters of fast-flowing streams.	No clear threat, due to the remoteness and inaccessibility of the Maliau Basin.	Conservation of the Maliau Basin area.
Thelphusula luidana (Chace, 1938)	VU		<500 km^2	Endemic to western Sabah, including Kinabalu area.	Aquatic. Occurs in highland streams.	No immediate threat to population within Kinabalu National Park. Water pollution and habitat loss/ degradation outside protected areas.	The retention of the protected status of Kinabalu National Park should ensure its survival.
Thelphusula sabana Tan and Ng, 1998	EN	1	<500 km^2	Endemic to Lahad Datu, Sabah.	Terrestrial to semi-terrestrial.	Habitat loss/degradation.	Conservation of forests and monitoring of pollution levels in Kaki Bukit area.
Thelphusula styx Ng, 1989	EN	1	<500 km^2	Endemic to Gunung Mulu National Park, Sarawak.	Cavernicolous, semi-terrestrial.	No clear threat, as its range is within Gunung Mulu National Park.	The retention of Gunung Mulu area as a national park should ensure its survival.

Species	Status	No. of sites	Extent of Occurrence	Range	Habitat/Ecology	Threats	Conservation measures
Thelphusula tawauensis Tan and Ng, 1998	EN	1	<500 km^2	Endemic to Tawau Hills Park, Sabah.	Semi-terrestrial.	No immediate threat, as its range falls within Tawau Hills Park.	The retention of the protected status of Tawau Hills Park should ensure its survival.
Bakousa sarawakensis Ng, 1995	EN	1	<500 km^2	Endemic to Bako National Park, Sarawak.	Primarily aquatic. Living under rocks and vegetation in waterfalls and streams.	No clear threat, as its range is within Bako National Park.	The retention of Bako area as a national park should ensure its survival.
Arachnothelphusa kadamaiana (Borradaile, 1900)	VU		<2,000 km^2	Endemic to Kinabalu area, Sabah.	Terrestrial. Has been known to climb trees.	No immediate threat, as range falls within Kinabalu National Park.	The retention of the protected status of Kinabalu National Park should ensure its survival.
Arachnothelphusa rhadamanthysi Ng and Goh, 1987	EN	1	<500 km^2	Endemic to Gomantong caves, Sabah.	Terrestrial. An obligate cavernicolous species (troglobite) living in and around subterranean streams.	Water pollution and habitat loss/degradation.	Conservation and monitoring of pollution levels in Gomantong caves area.
Arachnothelphusa terrapes Ng, 1991	EN	1	<500 km^2	Endemic Danum Valley Conservation Area, Sabah.	Terrestrial.	No immediate threat, as its range is within Danum Valley Conservation Area.	The retention of the protected status Danum Valley Conservation Area should ensure its survival.
Stygothelphusa bidiensis (Lanchester, 1900)	VU	3	<2,000 km^2	Endemic to Bau district, Sarawak.	Terrestrial to semi-terrestrial. A facultative cavernicolous species (troglophile) living in and around subterranean streams and epigeally, in limestone areas. The threats to this species are higher than stated as there are 2 species now regarded as this, and if split, their respective ranges are substantially reduced.	Water pollution and habitat loss/degradation.	Conservation of forests and caves monitoring of pollution levels in Bau district.

Species	Status	No. of sites	Extent of Occurrence	Range	Habitat/Ecology	Threats	Conservation measures
Stygothelphusa nobilii (Colosi, 1920)	CR	1	<10 km^2	Endemic to Mt Saribau, Sarawak, collected from "2,500 feet asl."	Associated with limestone areas, living in caves. Biology not known.	Water pollution and habitat loss/degradation.	Conservation of forests and monitoring of pollution levels in Mt Saribau area.
Terrathelphusa kuchingensis (Nobili, 1901)	CR	1	<10 km^2	Endemic to vicinity of Kuching, Sarawak, and possibly Bako National Park.	Terrestrial.	Habitat loss/degradation.	The retention of Bako area as a national park.
Terrathelphusa ovis Ng, 1997	EN	1	<500 km^2	Endemic to Gunung Mulu National Park, Sarawak.	Terrestrial. Living in burrows in forest floor.	No clear threat, as its range is within Gunung Mulu National Park.	The retention of Gunung Mulu area as a national park should ensure its survival.
Irmengardia didacta Ng and Tan, 1991	EN	1	<500 km^2	Endemic to the lowland swamps of southeastern Johore	Primarily aquatic. Living in slow-flowing waters with dense leaf litter and submerged vegetation, usually in freshwater swamp forests.	The increasing loss of the swamp forests of southeastern Johore poses a clear threat.	The selective protection of swamp forests is the only recourse.
Irmengardia pilosimana (Roux, 1936)	LC	3	<2,000 km^2	Widespread throughout Pahang, western Terengganu and Selangor.	Primarily aquatic. Living in slow-flowing waters with dense leaf litter and submerged vegetation.	No immediate threat to populations within protected areas throughout its range.	The retention of designated protected areas.
Perithelphusa borneensis (Von Martens, 1868)	LC	>10	>2,000 km^2	Widespread throughout Sarawak. Also found in western and northwestern Kalimantan.	Primarily aquatic in all types of water bodies, from stagnant pools to flowing peat swamp or clear-water streams and rivers.	No immediate threat to populations within protected areas throughout its range.	The retention of designated protected areas.
Perithelphusa lehi Ng, 1986	EN	1	<500 km^2	Endemic to Gunung Matang (Serapi) area in Kubah National Park.	Primarily aquatic. Living under rocks and vegetation in well-shaded forest streams.	No immediate threat, as range is within Kubah National Park.	The retention of the protected status of Kubah National Park should ensure its survival.

Species	Status	No. of sites	Extent of Occurrence	Range	Habitat/Ecology	Threats	Conservation measures
Sundathelphusa aspera Ng and Stuebing, 1989	EN	1	<500 km^2	Endemic to the hills around Kinabalu National Park in Sabah.	Primarily aquatic, lives under covered forest in small streams with clear water.	There are no clear threats but as its small range is mostly unprotected, it is very vulnerable.	Suitable areas need to be identified to ensure its survival.
Sundathelphusa tenebrosa Holthuis, 1979	EN	1	<500 km^2	Endemic to Gunung Mulu National Park, Sarawak.	Primarily aquatic, lives under covered forest in small streams with clear water. Facultative cavernicole.	No clear threat, as its range is within Gunung Mulu National Park.	The retention of Gunung Mulu area as a national park should ensure its survival.
Parathelphusa maculata De Man, 1879	LC	>30	>2,000 km^2	Widespread throughout Peninsular Malaysia. Also found in Singapore and southern half of Sumatra.	Primarily aquatic. Living in slow-flowing lowland streams under rocks, vegetation, leaf litter and debris. Also dig deep burrows in stream banks. High tolerance for anoxic water conditions.	No immediate threat, especially to populations within protected areas throughout its range.	The retention of designated protected areas.
Parathelphusa maindroni Rathbun, 1902	VU	5	<2,000 km^2	Widespread throughout Peninsular Malaysia. Also found in eastern Sumatra.	Primarily aquatic. Living in acidic freshwater swamps (pH 4.5-5.5) as well as blackwater peat swamps (pH 3.5).	Although widespread, restricted to freshwater and peat swamp habitats. Rapid loss and degradation of such habitats is a threat.	Conservation of freshwater and peat swamp habitats in its range.
Parathelphusa malaysiana Ng and Takeda, 1992	EN	1	<500 km^2	Endemic to Taman Negara, Pahang.	Primarily aquatic.	No clear threat, as its range is restricted to Taman Negara.	The retention of Taman Negara as a national park should ensure its survival.
Parathelphusa nagasakti Ng, 1988	EN	1	<500 km^2	Endemic to Pulau Tioman (probably in vicinity of Gunung Kajang).	Poorly known. Collected from "amongst forest leaf litter", but likely to be more aquatic like other members of the genus.	No clear threat at present, as development of extremely rugged hilly hinterland of Pulau Tioman appears unlikely.	Conservation of Pulau Tioman hinterland.

Species	Status	No. of sites	Extent of Occurrence	Range	Habitat/Ecology	Threats	Conservation measures
Parathelphusa ovum Ng, 1995	EN	1	<500 km^2	Endemic to Kinabatangan River area, Sabah.	Primarily aquatic. Living in slow-flowing lowland streams under rocks, vegetation, leaf litter and debris.	Water pollution and habitat loss/degradation.	Conservation of forests and monitoring of pollution levels along Kinabatangan River.
Parathelphusa oxygona Nobili, 1901	VU	4	<2,000 km^2	Western Sarawak.	Semi-terrestrial. Lives alongside lowland streams in many areas, often with covered or partially covered forests in primary and secondary forests; with leaf litter substrates.	Water pollution and habitat loss/degradation.	Conservation of sufficient drainages in its range.
Parathelphusa pulcherrima (De Man, 1902)	VU	5	<2,000 km^2	Eastern Sarawak to Brunei	Primarily aquatic. Living in slow-flowing lowland streams under rocks, vegetation, leaf litter and debris.	Water pollution and habitat loss/degradation.	Conservation of sufficient drainages in its range.
Parathelphusa sarawakensis Ng, 1986	VU	3	<2,000 km^2	Western Sarawak.	Primarily aquatic. Living in medium elevation fast-flowing, streams with gravel substrate, under rocks, vegetation, leaf litter and debris.	Water pollution and habitat loss/degradation.	Conservation of sufficient drainages in its range.
Parathelphusa valida Ng and Goh, 1987	VU	2	<500 km^2	Eastern Sabah.	Primarily aquatic. Living in slow-flowing lowland streams under rocks, vegetation, leaf litter and debris.	Water pollution and habitat loss/degradation.	Conservation of sufficient drainages in its range.
Siamthelphusa improvisa (Lanchester, 1901)	LC	>20	>2,000 km^2	Northern Peninsular Malaysia, reaching south to Perak. Also found throughout most of southern Thailand.	Primarily aquatic. Living in shallow, slow-flowing streams and rivers with clean water, under rocks, vegetation, leaf litter and debris.	Water pollution and habitat loss/degradation.	Conservation of forests and monitoring of pollution levels in its range.

Species	Status	No. of sites	Extent of Occurrence	Range	Habitat/Ecology	Threats	Conservation measures
Salangathelphusa brevicarinata (Hilgendorf, 1882)	VU	2	<2,000 km^2	Northern Peninsular Malaysia, Perlis. Also found in southern Thailand, including Phuket island.	Primarily aquatic. Living in shallow, slow-flowing streams and rivers with clean water, under rocks, vegetation, leaf litter and debris.	Water pollution and habitat loss/degradation.	Conservation of forests and monitoring of pollution levels in Perlis area.
Heterothelphusa fatum Ng, 1997	VU	1	<2,000 km^2	Endemic to northern Kelantan. Also found in immediately adjacent parts of southern Thailand.	Primarily aquatic. Living in slow-flowing lowland streams under rocks, vegetation, leaf litter and debris.	Water pollution and habitat loss/degradation.	Conservation of forests and monitoring of pollution levels in its range.
Heterothelphusa insolita Ng and Lim, 1986	VU	2	<2,000 km^2	Endemic to Kelantan and Terengganu.	Primarily aquatic. Living in slow-flowing lowland streams under rocks, vegetation, leaf litter and debris.	Water pollution and habitat loss/degradation.	Conservation of forests and monitoring of pollution levels in its range.
Sayamia sexpunctata (Lanchester, 1906)	LC	>30	>2,000 km^2	Northern Peninsular Malaysia, including Pulau Langkawi. Also found throughout most of southern Thailand.	Aquatic. Living in shallow, stagnant water bodies, including padi fields and ponds. Also dig deep burrows in stream banks. High tolerance for anoxic water conditions.	No immediate threat. One concern is that if there is over-use of pesticides in rice-cultivation etc., the species will be severely affected.	None needed for the immediate future.
Geithusa lentiginosa Ng, 1992	VU	2	<500 km^2	Endemic to Terengganu.	Primarily aquatic. Living in shallow, slow-flowing shaded forest streams among leaf litter and submerged debris.	Water pollution and habitat loss/degradation.	Conservation of forests and monitoring of pollution levels in its range.
Geithusa pulchra Ng, 1989	EN	1	<500 km^2	Endemic to Pulau Redang, Terengganu.	Primarily aquatic. Associated with rocky streams with clean, fast-flowing waters.	Water pollution and habitat loss/degradation. The development of Redang as a resort island will increase land-use threats and over-use of very limited fresh-water supplies.	Conservation of Pulau Redang forests and monitoring of pollution levels as well as freshwater use.

Species	Status	No. of sites	Extent of Occurrence	Range	Habitat/Ecology	Threats	Conservation measures
Geosesarma albomita Yeo and Ng, 1999	EN	1	<500 km^2	Endemic to Gunung Kajang and immediate vicinity above 900 m asl., of Pulau Tioman, Pahang.	Terrestrial. Associated with higher elevation hill forests.	No clear threat at present, as development of extremely rugged hilly hinterland of Pulau Tioman appears unlikely.	Conservation of Pulau Tioman hinterland.
Geosesarma aurantium Ng, 1995	EN	1	<500 km^2	Endemic to Lahad Datu, Sabah.	Terrestrial. Moist soil with thick leaf litter layer.	Habitat loss/degradation.	Conservation of forests and monitoring of pollution levels in Lahad Datu area.
Geosesarma bau Ng and Jongkar, 2004	EN	1	<500 km^2	Endemic to the Bau limestone formations.	Terrestrial. Prefers covered forest with dense leaf litter substrates.	As the Bau area does not have long-term protection and the species occurs in low-lying areas, it is very vulnerable to anthropogenic effects.	The conservation of as many parts of Bau as possible is necessary.
Geosesarma cataracta Ng, 1986	CR	1	<10 km^2	Endemic to Maxwell Hill (Bukit Larut), Perak, above 350 m asl.	Semi-terrestrial. Living in wet areas adjacent to streams and waterfalls.	Water pollution and habitat loss/degradation.	Conservation of forests and monitoring of pollution levels in Maxwell Hill area.
Geosesarma danumense Ng, 2003	EN	2	<500 km^2	Endemic to Danum Valley Conservation Area.	No immediate threat to populations within Danum Valley Conservation Area.	No immediate threat to populations within the Danum Valley Conservation Area.	The retention of the protected status of Danum Valley Conservation Area should ensure its survival.
Geosesarma foxi (Kemp, 1918)	EN	1	<500 km^2	Endemic to highlands of Pulau Langkawi, Kedah, above 600 m asl.	Terrestrial. Living in damp areas under rocks or rotting timber.	Habitat loss/degradation.	Conservation of Pulau Langkawi highlands and monitoring of pollution levels.

Species	Status	No. of sites	Extent of Occurrence	Range	Habitat/Ecology	Threats	Conservation measures
Geosesarma gracillimum (De Man, 1902)	LC	6	<2,000 km^2	Occurs in many parts of eastern Sarawak (including several national parks) and Brunei.	Terrestrial. Lives in thick clumps of moist vegetation and in covered forests with dense leaf litter.	Habitat loss/degradation.	As it occurs in many protected areas, it is not seriously threatened.
Geosesarma johnsoni (Serène, 1968)	VU	1	<500 km^2	Endemic to highlands of Penang island.	Semi-terrestrial to terrestrial.	Water pollution and habitat loss/degradation.	Conservation of highlands of Penang island and monitoring of pollution levels.
Geosesarma katibas Ng, 1995	VU	1	<2,000 km^2	Endemic to Sungei Katibas area, Lanjak-Entimau Wildlife Sanctuary area, Sarawak.	Terrestrial. Moves about forest floor under leaf litter.	No clear threat, as its range is within Lanjak-Entimau Wildlife Sanctuary.	The retention of Lanjak-Entimau as a Wildlife Sanctuary should ensure its survival.
Geosesarma malayanum Ng and Lim, 1986	LC	>10	<2,000 km^2	Highlands of northern Perak, Terengganu, Selangor, southern Pahang, northern Johore.	Semi-terrestrial. Occasionally found in pitcher plant cups.	Water pollution and habitat loss/degradation.	Conservation of highlands of and monitoring of pollution levels within its range.
Geosesarma nemesis Ng, 1986	EN	3	<500 km^2	Gunung Pulai and Gunung Panti, Johore. Also found in Singapore.	Semi-terrestrial. Found under rocks or digging burrows along stream banks.	Habitat loss/degradation and pollution outside protected areas.	Conservation of forest and monitoring of pollution levels within its range.
Geosesarma penangense (Tweedie, 1940)	VU	1	<500 km^2	Endemic to highlands of Penang island.	Semi-terrestrial. Found under rocks or digging burrows along stream banks.	Water pollution and habitat loss/degradation.	Conservation of highlands of Penang island and monitoring of pollution levels.
Geosesarma peraccae (Nobili, 1903)	LC	>10	<2,000 km^2	Lowlands of Johore and southern Pahang. Also found in Singapore.	Semi-terrestrial. Common in freshwater swamps and beside slow-flowing streams.	Water pollution and habitat loss/degradation.	Conservation of forest and monitoring of pollution levels within its range.

Species	Status	No. of sites	Extent of Occurrence	Range	Habitat/Ecology	Threats	Conservation measures
Geosesarma sabanus Ng, 1992	EN	1	<500 km^2	Endemic to Tawau Hills Park, Sabah.	Terrestrial.	No immediate threat, as its range falls within Tawau Hills Park.	The retention of the protected status of Tawau Hills Park should ensure its survival.
Geosesarma sarawakense (Serène, 1968)	VU	3	<500 km^2	Lowland freshwater and peat swamps of western Sarawak	Semi-terrestrial. Occurs in freshwater and peat swamps.	The gradual loss of fresh-water and peat swamps in Sarawak is a major concern and threatens the species.	Some areas of freshwater and peat swamps in western Sarawak must be retained to ensure its survival.
Geosesarma serenei Ng, 1986	CR	1	<10 km^2	Endemic to Maxwell Hill (Bukit Larut), Perak, above 1,000 m asl.	Semi-terrestrial.	Water pollution and habitat loss/degradation.	Conservation of forests and monitoring of pollution levels in Maxwell Hill area.
Geosesarma scandens Ng, 1986	EN	1	<500 km^2	Endemic to Fraser's Hill, Pahang, and vicinity of high elevation.	Terrestrial.	Habitat loss/degradation.	Conservation of forests and monitoring of pollution levels in Fraser's Hill area.
Geosesarma tiomanicum Ng, 1986	EN	2	<500 km^2	Endemic to Gunung Rokam and vicinity of Pulau Tioman, Pahang. Also found at lower elevation near Tekek-Juara trail.	Terrestrial. Associated with higher elevation hill forests.	No clear threats at present at higher elevation, but degradation or loss of habitat at lower elevation are a threat.	Conservation of Pulau Tioman hinterland and monitoring of development in lowlands.

Notes:
"Status" refers to conservation status derived using the IUCN (2001) Red List criteria. CR, Critically Endangered; EN, Endangered; VU, Vulnerable; LC, Least Concern.
"Number of sites" is the number of discontiguous sites from which collections of the species were made.
"Extent of Occurrence" is estimated based on overall area of distribution.
"Range" is the estimated geographical distribution based on published literature.
"Habitat/Ecology" refers to the habit and habitat type of the species.
"Threats" lists known and potential threats to the survival of the species.
"Conservation measures" lists the current and suggested conservation measures.

The conservation of freshwater crabs hinges almost entirely on preserving patches of natural forest large enough to maintain the good water quality of the original streams. Potamids are extremely sensitive to polluted or silted waters, and will not survive when exposed to these factors. In Singapore for example, the small patch of primary forest of Bukit Timah Hill (ca. 70 hectares) is quite sufficient to maintain a small but thriving population of the potamid *Johora singaporensis*. This species is known from only one other area in Singapore, which is threatened with development, and Bukit Timah is probably its last refuge (see Ng 1988, 1989, 1990b). The same is true for *Parathelphusa reticulata*, which is known to occur only in a small remnant patch of peat swamp forest patch of less than 50 hectares in the Central Catchment Area of Singapore (Ng 1989, 1990a, b). Similar patterns have been recorded for the freshwater crabs of Sri Lanka (Bahir *et al.* 2005).

Development, agriculture and exploitation of forest products probably cannot be halted, but compromises will have to be made if many freshwater crab species are not to be extirpated. It is likely that some species have already become extinct through extensive developments in some areas before their taxonomy can be better understood. Judicious and careful exploitation (e.g., controlled logging) is unlikely to cause extinctions as long as the water drainages are not polluted or redirected and the forest cover not completely stripped away. The recolonisation of many lowland plantations and estates by more adaptable species like *Parathelphusa maculata* is encouraging. How more montane taxa like potamids will cope is not known, but considering their fastidious habitat requirements, most species will not be able to adapt as readily as parathelphusids.

The subjectivity of threat levels assigned here must be emphasised, as some of the limitations of this study echo the challenges faced in conservation. Conservation challenges are often associated with the amount of knowledge available on the species. The freshwater crabs of Singapore and southern Peninsular Malaysia are better known, and their biology and distribution better understood, as are the potential threats. This, of course, stems from an inherent bias for conservation efforts to target the better studied species, which are better known simply because they are more easily caught by workers in more accessible areas, e.g., *Johora tiomanensis*, a large, locally common aquatic species found in the lower stretches of the forest streams of the southern half of Pulau Tioman, which are mostly in close proximity to villages. Conversely, hard-to-find species tend to be neglected as we simply do not know enough to initiate directed conservation efforts, e.g., *Geosesarma tiomanicum*, a tiny terrestrial species that dwells among the leaf litter of the forest floor in the rugged, hilly parts of Pulau Tioman, often some distance away from water sources – encountering this species in the middle of the forest is purely a matter of chance, subject to weather, seasons, and their own fluctuating populations (Ng 1988; Yeo *et al.* 1999).

Another aspect of our limited knowledge of some freshwater crabs that proves challenging for conservation, is the evolving taxonomy of some taxa. Some wide-ranging “species” that we might try to conserve (or worse, not see the need to conserve, presuming that they are widespread and common enough) may actually prove to be complexes of several distinct cryptic taxa, which could differ in various ways such as diets, habits, microhabitat preferences, ecological niches, local distribution, etc. One such possibility is *Johora intermedia*, which is here assigned the status of “Least Concern” primarily because it has been recorded from more than 20 sites throughout the lower half of the Main Range of Peninsular Malaysia (Selangor, Pahang, Negri Sembilan and northwestern Johor) in an estimated Extent of Occurrence of some 1,500 km^2. However, while the area it is known from appears to be relatively extensive, it must be noted that the distribution consists of many pockets of populations, and this species is known to show the greatest variation among the *Johora* species, facts that point to it probably being a species complex (Ng 1988). Another probable species complex is the troglophilic crab, *Stygothelphusa bidiensis*, which has an unlikely distribution of two disjunct cave systems in Sarawak (Bau and Gua Serian). The available evidence suggests that the populations in the two cave systems actually belong to two separate species (unpublished data). The same situation is true of *Lepidothelphusa cognetti*, which occurs in the sandstone streams of Bau and Penrissen.

Another point to consider is that for freshwater crabs in developing countries, the line separating a vulnerable or endangered species is a very fine one. This is mainly because of the very restricted distributions of many species and the speed of development projects; the time lapse between project conception and implementation, even for large scale ones, can be as short as a year.

Using Peninsular Malaysia and Singapore as an example, 42 species of potamids and parathelphusids are known at present. All the potamids (27 taxa) are found only in Peninsular Malaysia and Singapore. Of the 15 parathelphusids, 10 are endemic to Peninsular Malaysia and Singapore, the other five species also occurring in Sumatra or southern Thailand. The endemic taxa are almost always highland species, or occur on isolated islands. The conservation of this remarkable diversity is imperative (see also Ng 1988). There is thus, more than ever, a need to establish more nature reserves and national parks. And careful planning, co-ordination and supervision to minimise its destructive effects must temper development, inevitable though it may be. At the same time, other broader, long term issues, those of water-shed conservation, sufficient size of protected areas, and forest conditions (primary or secondary or disturbed) must be given due consideration. Such matters if dealt with properly would not just be for the benefit of freshwater crab diversity, but for the overall ecosystem as well.

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OVERVIEW OF INSECT BIODIVERSITY RESEARCH IN PENINSULAR MALAYSIA

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ABSTRACT

Malaysia's commitment to implement the Convention on Biological Diversity has provided fresh impetus for the documentation of the country's flora and fauna. Insects greatly outnumber other major lifegroups in terms of diversity and numbers, but an assessment of the degree to which the biodiversity and taxonomy of insects have been researched in Malaysia indicates that there are still great needs. In a survey of institutions in the vicinity of the capital city of Malaysia, 25% of 387 entomology dissertations and articles written over the last decade were on the subject of insect diversity, with many of the studies being of the numerical kind, while only 4% were on taxonomy and systematics – the science of describing biological diversity. In addition, the taxonomy and diversity of only a few major insect orders, such as Lepidoptera (butterflies and moths), Isoptera (termites) and Phasmida (stick insects), have been relatively well studied in Malaysia. Little is known of other important insect orders, such as Coleoptera (beetles), Hymenoptera (bees, wasps and ants), Diptera (flies) and Hemiptera (bugs). We argue that if any effective inventory of Malaysia's insect fauna is to take place, sustained interest and funding needs to be devoted to the study of their diversity and taxonomy.

INTRODUCTION

Biodiversity is often broadly defined as the different forms of plants, animals and microorganisms that exist, the levels at which they occur (e.g., species, population and ecosystem levels) and the different ways in which organisms, climate and geology combine to form functioning ecosystems. Approximately 1.8 million living species have been named and described and, of these, one million are insects (May 2002). It has also been estimated that invertebrates represent more than 90% of the planet's 10 million or so animal species (Erwin 1983, Wilson 1992).

Insects are ubiquitous in the environment and play important roles in maintaining the stability of ecosystems by being part of the food chain, mediating decomposition processes and through various ecological interactions, such as pollination, predation and herbivory. Large-scale anthropogenic activities such as forest clear-cutting extirpate insect species and destroy ecosystem dynamics and interactions that have been in place for millennia.

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In view of the rapid decline of forested areas in the world, world leaders agreed to promote the sustainable use and conservation of natural resources, at the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992. The Biodiversity Treaty, an important document stemming from the conference in Rio, emphasised the importance of countries accepting the responsibility for conserving biological diversity and promoting their use in a sustainable manner. Malaysia ratified the treaty in 1994, a year after the Treaty came into force. At the international conference, "Biodiversity: Science and Governance," held in Paris in 2005, the Malaysian premier, Dato Seri' Abdullah Ahmad Badawi, highlighted the government's efforts to protect and conserve the environment through the actions and coordination of the National Council on Biodiversity and Technology and the Natural Resources and Environment Ministry. A current project, initiated by the Prime Minister, aims to document Malaysia's biodiversity with the objective of producing a national 'red data book' on endangered animal and plant species in the country, their distributions and the levels of threat they face (Koh 2005; Cyranoski 2005).

In view of this plan to document Malaysia's biodiversity, there is a need to assess the current status of insect diversity research and the level of information available on major insect groups in Peninsular Malaysia. In this paper, we examine current trends in entomological research by analysing the undergraduate and postgraduate dissertation topics of students over the last decade in a few universities in and around the Klang Valley of Peninsular Malaysia, namely, University of Malaya, Universiti Kebangsaan Malaysia and Universiti Putra Malaysia. In addition, we examined both entomological dissertations and articles stemming from research by the Forest Research Institute Malaysia (FRIM) in the Pasoh Field Station from 1964 to 1999. FRIM was included in the survey because it is the primary research institution that conducts research on diversity and conservation in Peninsular Malaysia. Although there are limitations to the data obtained – for example, not all Malaysian universities or all years were included in the census – the results of this survey are still expected to give a good indication of the pattern of entomological research in Peninsular Malaysia. In addition to conducting this survey, we also examined the availability of taxonomic information on several well-known insect orders in Peninsular Malaysia.

TRENDS IN RELATION TO FIELDS OF RESEARCH

The number of entomological dissertations and articles from each of the institutions surveyed, and the number on insect diversity, is shown in Table 1. A total of 387 entomology dissertations and articles were examined. About 25% of these were on the subject of insect diversity; with Universiti Kebangsaan Malaysia contributing 75% of all studies on insect diversity.

Figure 1 shows the frequency of dissertations and articles on different topics of entomological research for the combined dataset of the survey, some of which covered more than one research area. Insect control was the most heavily researched area, and accounted for 31% of all entomological research. Insect diversity was the next most studied subject and accounted for close to 26% of all reported entomological work. Biological and ecological research, which was a popular area of research among undergraduates, contributed 37% of all documented work. Insect taxonomy, accounted for a mere 4% of all entomological studies. Although the survey did not cover taxonomic work published in local and international journals by staff of the various universities surveyed, this low figure is probably still reflective of the shortage of taxonomic research on insects in Malaysia.

Table 1. Numbers of research dissertations and articles on entomology and insect diversity (in parentheses) in the institutions surveyed.

Institutions	Faculties	Years examined	No. of dissertations / articles
***Universities:**			
Universiti Malaya	Institute of Biological Science	1995-2004	83 (21)
Universiti Putra Malaysia	Forestry & Agriculture Faculties	1991-2001	144 (2)
Universiti Kebangsaan Malaysia	School of Bioscience	1995-2004	128 (75)
Institutes:			
Forest Research Institute Malaysia†	–	1964-1999	32 (2)
		Total	387 (100)

* All counts for universities were based on dissertations. †For the Forest Research Institute Malaysia, counts were based on both dissertations and scientific articles from projects conducted in the Pasoh Field Station's 50-hectare plot (Soepadmo *et al*. 2000).

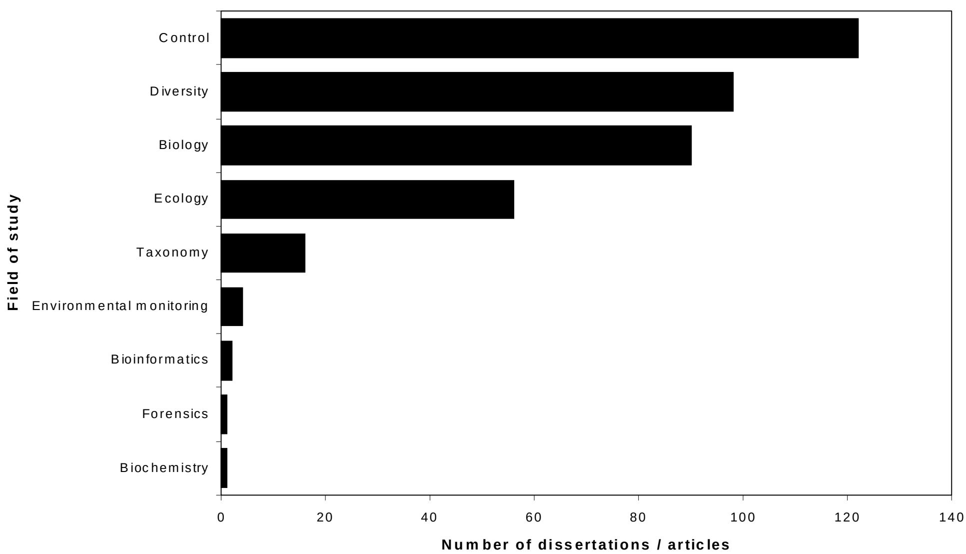

Fig. 1. Numbers of dissertations/articles written on different entomological research areas in the institutions surveyed.

In addition to the areas of entomological research mentioned above, there are also new and emerging areas of entomological research, such as environmental monitoring using insects as indicator species, bioinformatics, forensics and insect biochemistry. Together, they contributed to a very small number (eight) of the 387 dissertations, reports and articles written, among the four institutions surveyed.

TRENDS IN RELATION TO INSECT ORDERS STUDIED

Figure 2 shows the number of dissertations/articles written on the different insect groups in the four institutions surveyed. About 15 insect orders have been the subject of studies. They represent slightly less than half of all recognised insect orders. The most researched insect order was Lepidoptera (butterflies and moths), while Neuroptera, Plecoptera, Thysanura and Collembola were the least studied groups. Other orders that were the focus of much entomological research were Coleoptera, Hymenoptera, Homoptera, Diptera, Hemiptera, Orthoptera and Isoptera, in decreasing frequency. To some extent, the level of research on the different orders reflects the size of the order, for example, Coleoptera and Hymenoptera are the largest and second largest insect orders, respectively. It also reflects their economic importance in agriculture and forestry, as pests (e.g., many Coleoptera and Hemiptera) or as beneficial insects (e.g., Hymenoptera). There were also many entomological dissertations / articles written that were not on any specific insect order; many were comparative studies on the composition of invertebrate communities in natural and disturbed environments.

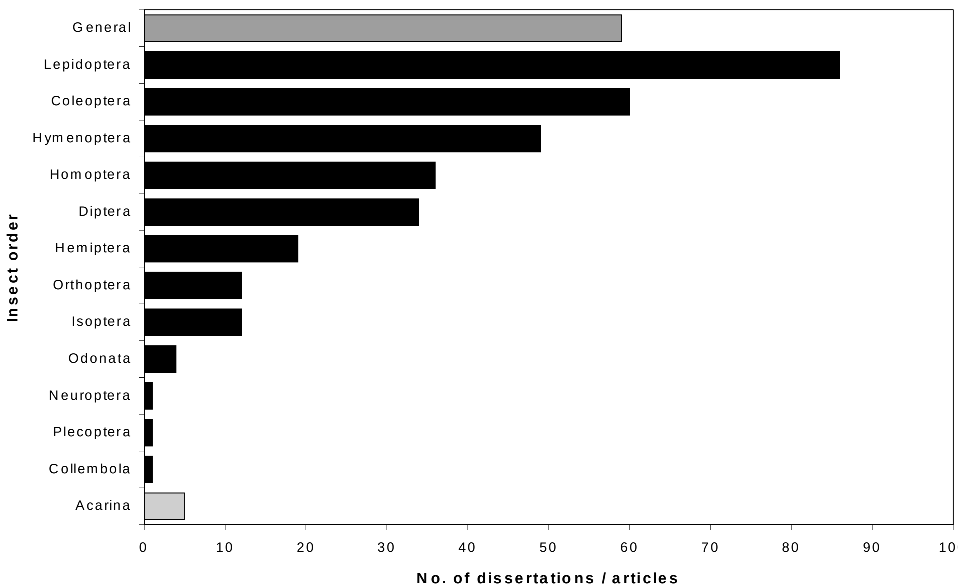

Fig. 2. Numbers of dissertations / articles written on different insect orders in the institutions surveyed. The category, 'General,' refers to dissertations / articles that did not specify a specific insect order, or that were about invertebrate or insect communities in general. Dissertations / articles on Acarina (mites) are included for comparison.

AVAILABILITY OF TAXONOMIC INFORMATION ON THE DIFFERENT INSECT ORDERS

The level of taxonomic information available on several insect orders in Peninsular Malaysia is compared against the size of the different orders in Table 2. The order Coleoptera (beetles) is well-known as the most diverse and numerous in the animal kingdom. However, there is a great void of information on Coleoptera in Malaysia. Although some groups have been relatively well-studied (e.g., Chrysomelidae), on the whole there is very little documentation of the taxonomy of most groups of beetles. Lepidoptera (butterflies and moths) is another vastly diverse group, but it has been relatively well-studied in Peninsular Malaysia. Moths are much more diverse than butterflies, and although there are several good monographs on them, much more work is needed to document their diversity in Peninsular Malaysia as well as in Sabah and Sarawak. The Isoptera (termites) and Phasmida (stick insects) are two other relatively well-studied groups in Peninsular Malaysia, although many unresolved taxonomic problems are recognised to exist the Isoptera (Tho 1992).

Table 2. Comparison of relative species diversity and the level of taxonomic information available for some insect orders occurring in Peninsular Malaysia.

Order	Relative size*	Availability of taxonomic information	Monographs available
1. Coleoptera	* * * * * * * * * *	Very low	-
2. Lepidoptera	* * * * * * * *	High	Butterflies: Fleming (1983), Corbet & Pendlebury (1992); Moths: Holloway (1976)†, Barlow (1982)
3. Hymenoptera	* * * * * *	Very low	-
4. Diptera	* * * * *	Very low	-
5. Hemiptera	* * * *	Very low	-
6. Homoptera	* * *	Very low	-
7. Orthoptera	* * *	Very low	-
8. Collembola	* *	Very low	-
9. Isoptera	* *	Moderate	Tho (1992)
10. Phasmida	*	High	Brock (1999), Seow-Choen (2000)
11. Thysanura	*	Very low	-

* Relative size of the order is based on figures given in Romoser & Stoffolano (1998).
† In addition, there is a further series of publications on the moths of Borneo by Holloway (1983, 1985, 1986, 1987, 1988, 1993, 1996, 1997, 1998, 1999, 2001). Many parts of this series are also available on the World Wide Web (http://www.mothsofborneo.com). Although based on specimens from Borneo, Holloway's work is a useful reference for Peninsular Malaysia as well.

Orders that have been relatively well studied are, to some extent, those that have attractive species (e.g., butterflies, moths and stick insects) or that have some importance in agriculture and forestry (e.g., termites). It is also worth noting that a number of monographs were authored by individuals who were not entomologists by profession, but who pursued the study of insects privately (e.g., the monographs on butterflies and stick insects).

In spite of its large number of species, many of which are beneficial insects, taxonomic information on the Hymenoptera (bees, wasps and ants) in Peninsular Malaysia is still very lacking. Other relatively large groups that have been little studied are the Diptera, Hemiptera, Homoptera, and Orthoptera. Many groups of insects for which taxonomic information is still lacking are important in ecosystem functions such as pollination, predation, phytophagy and the promotion of soil stability.

CURRENT AND FUTURE NEEDS FOR INSECT DIVERSITY RESEARCH IN MALAYSIA

As in most other countries, economically important insect pest species have been an important area of research in Malaysia. Research has often been driven by the need to develop management strategies for such pest species, thus, studies on insect control were highest in frequency in the institutions surveyed. Insect diversity studies ranked second in number. However, many utilised indices of diversity (e.g., Simpson's D & E and the Shannon diversity index) to measure biodiversity richness (or poorness). In many such studies, specimens are sorted based on phenotypes (termed "recognisable taxonomic units") to obtain diversity indices for different study areas. While this method allows for the comparison of animal or plant richness, it does little to enable the understanding of biological and ecological systems.

At the heart of understanding biological and ecological systems in an ecosystem is the understanding of the species that make up the diversity of the ecosystem, and the interactions of these species with other each other and with their environment. Such an understanding is only made possible through taxonomic work that enables us to identify species and provides a foundation upon which we can build on our knowledge of their biology, behaviour and ecological functions. In spite of this, taxonomic studies were poorly represented in the institutions surveyed, ranking last in number among mainstream areas of research such as diversity, ecology and biology.

The few studies on insect taxonomy that have been conducted in the country have primarily been on specific insect groups. Many insect groups have been poorly researched. The Hymenoptera, Diptera and Hemiptera, to name a few, are taxonomically diverse groups, yet there are no monographs on these insect groups in Malaysia. The Collembola and Thysanura are also poorly researched insect groups. Although small and rarely noticed, they are important in terrestrial ecosystems. Collembolans, for example, help in decomposition and nutrient cycling in the soil, while thrips are thought to be important pollinators of dipterocarp trees.

Taxonomists shoulder the responsibility of documenting organic diversity, and their skills are also needed in many ecological studies. In addition to their role in documenting species, taxonomists also usually ensure the proper curation and maintenance of valuable reference collections, as well as work on the systematics of the groups of organisms they study. The field of systematics, which is an extension of taxonomy, analyses relationships between organisms and discusses origins or causes of diversity. Research on systematics can often indirectly provide more information on the biological and ecological interactions of species than studies on diversity, yet it has rarely been pursued as a subject of research in the institutions surveyed. The dearth of taxonomic or systematic studies on insects is a serious cause for worry; our limited capacity to identify insects inadvertently limits our capacity to document at least three quarters of our country's biological diversity.

CONCLUSION

The dearth of taxonomic information on the majority of insect orders in Peninsular Malaysia is a matter of great concern, because one of the prerequisites in any effort to conserve species is that they need to be identified and described. Most insect orders remain poorly studied in

Peninsular Malaysia. There is a great need for taxonomic and systematic studies on insects in Malaysia, especially on many of the less popular insect groups. In addition, taxonomists and systematists need to be provided with adequate funds and incentives that will enable them to conduct their research, purchase relevant equipment and discuss and present their work. At the administrative and political level, there needs to be sustained interest and commitment to funding to ensure that insect diversity is properly documented and described. The success of Malaysia's initiative to inventorise its biodiversity greatly depends on sustained political will.

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RESEARCH ON THE DIVERSITY OF MOTHS AND BUTTERFLIES IN MALAYSIA AND THEIR USE AS BIODIVERSITY INDICATORS

Chey Vun Khen

ABSTRACT

The two geographical regions of Malaysia namely the Malay Peninsula and Sabah and Sarawak in Borneo, share a large proportion of their biodiversity including many moth and butterfly species. There are about 4,000 species of larger moths and 936 species of butterflies in Borneo. The Malay Peninsula has 1,031 species of butterflies, about 88 % of which are also found in Borneo. Their suitability as indicators of biodiversity is discussed: moths and butterflies are better known taxonomically in Malaysia, they respond rapidly to habitat change, their caterpillars being mainly phytophagous reflect the vegetation type being sampled, and moths especially are more speciose and easily sampled using a light-trap, which facilitates data analysis. The main biodiversity indices used are explained: for moth samples, Williams Alpha based on the log series is most appropriate, and for butterflies, which normally have smaller samples, non-parametric indices–e.g., the Shannon and Simpson indices – are commonly used. Research work on the diversity of moths and butterflies in Malaysia is also reviewed.

INTRODUCTION

Malaysia comprises two regions in Sundaland separated by the South China Sea, namely the Malay Peninsula and Sabah and Sarawak in the island of Borneo. Despite the geographical separation, the two regions share a large proportion of their biodiversity, including many species of moths and butterflies (Insecta: Lepidoptera), as they were joined by land when sea levels were lower in the last ice age.

Butterflies are the most glamorous insects, and they have been better studied worldwide compared to all other insect groups. In the Malay Peninsula, there are 1,031 species, with 21 endemics (Corbet & Pendlebury 1992), while the number of species is lower in the island of Borneo (936) but with a much higher number of endemics (94) (Ohtsuka 1996). About 88 % of the species in the Malay Peninsula are also found in Borneo. However, most of them occur as different subspecies in the two different regions. Half of the species are distributed in the

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lowlands below 750 m, and one-seventh of the species occur in the highlands. The rest are found in habitats at both elevations.

Moths are more speciose than butterflies, and taxonomically they have been better studied in Borneo than in the Malay Peninsula. They are commonly divided into the bigger macromoths and the smaller micromoths. According to Holloway (pers. comm.), there are just over 4,000 species of macromoths in Borneo. Most of them are also found in the Malay Peninsula. Robinson & Tuck (1993) estimated the number of species of the lesser-studied micromoths in South-East Asia to be more than 6,000, with most of the species occurring in Malaysia. Moths are more diverse between 500 metres and 1,000 metres above sea level (Chey 1998), where there is an overlap of both lowland and montane elements.

THREATENED SPECIES

CITES (2001) includes all the birdwing butterflies (*Troides* spp.) in Appendix II. This also covers the exceedingly beautiful Rajah Brooke's Birdwing, *Troides* (*Trogonoptera*) *brookiana*, found in Malaysia. In the IUCN Red Data Book on threatened swallowtail butterflies of the world (Collins & Morris 1985), three endemic species found in Malaysian Borneo are listed in the threatened categories, namely *Papilio acheron*, *Graphium procles*, and *Troides andromache*. They are mainly montane species. Another two species, *Papilio mahadeva* (in the Malay Peninsula) and *Papilio karna* (in Borneo), were said to require further monitoring and research. However, it is not only the sought-after, showy butterflies, which are threatened. As more lowland forests are being cleared, the families with a high proportion of lowland endemics with forest-restricted distribution, such as the lasiocampid and limacodid moths (Holloway & Barlow 1992) and the satyrid and amathusiid butterflies (Hamer *et al*. 2003), are losing much of their habitat. Paradoxically some species of limacodids may be able to persist (a few with pest status) in palm plantations such as oil palm and coconut.

TAXONOMY

The main taxonomic monograph on butterflies in the Malay Peninsula was written by Corbet & Pendlebury (4th edition, 1992, revised and enlarged by J.N. Eliot). Volumes written by Otsuka (1988) on the bigger butterflies (Papilionidae, Pieridae and Nymphalidae), Seki *et al*. (1991) on the Lycaenidae and Maruyama (1991) on the Hesperiidae form the primary monograph in Borneo. Revisions of some groups are also being carried out, e.g., the rattan-feeding hesperiid genus, *Zela* (Kirton & Eliot 2004). Abang *et al*. (2004) described 11 new subspecies of butterflies of the families Pieridae, Nymphalidae, and Lycaenidae found in Balambangan island, Borneo.

For moths, introductory monographs have been published by Barlow (1982), focusing mainly on macromoths, and Robinson *et al*. (1994), focusing on micromoths. A major taxonomic work on the macros is being published in the "Moths of Borneo" series by Holloway (1983, 1985, 1986, 1987, 1988, 1989a, 1993, 1996, 1997, 1998, 1999, 2001, 2003). A further volume, consisting of two more parts, is about to go to press at the time of writing.

Local collections of Lepidoptera are kept mainly in the forest research institutions of Peninsular Malaysia, Sabah and Sarawak. The Sabah Forest Insect Museum in Sepilok, for example, houses more than 2,400 species of macromoths with 18,000 pinned specimens. Various other collections are also maintained by universities and other research institutions. In addition, there are privately owned collections, such as that of Dato' Henry Barlow, who keeps an excellent collection of moths in his residence in Genting Sempah. By and large most of the collections with type specimens are housed in the major museums in developed countries, for example, the Natural History Museum in London.

INDICATORS OF BIODIVERSITY

Biodiversity on a global scale is estimated to be about 10 million species, and over 60 % are insects (Speight *et al*. 1999). Since the insect fauna is a major proportion of the biodiversity in a terrestrial ecosystem such as the tropical rain forest, human disturbance such as forest conversion will have a telling effect on it. The insect group that fulfils most criteria as effective indicators of changes in biodiversity is moths (Holloway & Stork 1991).

Taxonomy is the foundation of biodiversity, and its importance is underlined when insect groups are being used as bioindicators. To avoid confusion such as pooling of sibling species, which would adversely affect data, insect groups with better known taxonomy are preferred. Compared to other insect groups, moths (especially the macromoths) are the best known taxonomically after butterflies. Butterflies, however, are fewer in species and less readily sampled, which makes data analysis more difficult. Moths are easily sampled using a light-trap at night and, being more speciose, they provide a larger data set that is easier to analyse. Compared to vertebrates such as mammals or birds, which are less readily observed or sampled, moths, for the afore-mentioned reasons, are relatively easily sampled.

In their larval stage, moths and butterflies are mainly phytophagous leaf-feeders (Holloway *et al*. 2001; Robinson *et al*. 2001), but the caterpillars of some species of moths belong to other guilds such as detrivores of plant and animal material, flower, fruit, and seed predators, stem borers, lichen and algal browsers, fungal feeders and insectivores (Holloway & Stork 1991). Some of them are stenotopic species restricted to a certain habitat, some are specialists with limited ecological tolerance or are host-plant specific, while others are generalists indicative of disturbed habitat. Moths of the *Lophoptera* lineage (Noctuidae: Stictopterinae) have caterpillars that are known to be leaf-feeders of Dipterocarpaceae, and species in this group are likely to be absent in highly degraded forest sites (Chey 2002). Thus, abundance or absence of the moths will reflect on the composition of the vegetation in the area being sampled.

Rapid and sensitive response to environmental disturbance is a prerequisite for a bioindicator. Moths and butterflies generally have short life cycles and respond rapidly to changes in the environment. Species with limited ecological tolerance can only thrive in an undisturbed forest environment and will be the first to disappear after human disturbance. Most generalists or r-strategists, on the other hand, are opportunists distributed over a wide range of ecological gradients, and they rapidly increase in abundance as a result of disturbance. They particularly favour early successional stages in ecological regeneration, and many are pests of crops.

BIODIVERSITY INDICES

Species abundance models are commonly used to indicate the level of biodiversity in a habitat, with the log normal and the log series being the main models. They are based on an assumption that for a very large sample that closely reflects the population structure, it will result in a bell-shaped log normal curve. But a typical smaller annual sample is one-tailed and usually fits equally well to the log series and the log normal, with the rarer species having been missed. Species abundance curves usually have the log abundance plotted against species rank. A shallower curve means higher diversity while a steeper curve means lower diversity.

Moth samples are usually annual samples, which fit into the log series. Based on the log series, a diversity index known as Williams Alpha is derived (Fisher *et al*. 1943). This index is independent of sample size, which allows cross-comparison of most samples. The log series gives a diversity value less subject to the vagaries of the non-resident species, and is more dependent on the mid-range species resident at the site, and hence more representative (Taylor 1978). For these reasons, most moth samples are compared using Williams Alpha. A higher value means higher diversity.

For butterfly samples, which are normally smaller, non-parametric indices with no assumption on the underlying species abundance distribution are commonly used. These include the popular Shannon index, as well as Simpson's index (Magurran 1988). They are diversity indices based on the proportional abundances of species.

SIMILARITY COEFFICIENTS

Biodiversity indices alone may tell us the levels of diversity but they don't show the composition of the underlying species assemblages. The 'coefficient of association' is a R-mode measure of percentage dissimilarity showing the pattern in species distributions and, hence, species associations, among the sampling sites. Based on the percentage dissimilarity, numerical single-link dendrograms as well as linkage diagrams can be drawn in which species indicative of a habitat are clustered together. This technique has been applied in biodiversity studies in Malaysia, for example, by Chey (1994).

Similarity coefficients can also be used in the R-mode to identify associations of species of moths that show correlations with particular vegetation zones and altitude zones (e.g., Holloway 1989b; Chey *et al*. 1997; Intachat *et al*. 2005). These associations offer particularly good suites of indicator species.

Preston's coefficient of faunal resemblance (1962), a simpler Q-mode measure of similarity based on presence or absence of species, is commonly used. The number of species present in each of any two sites and the number of shared species between them are used to calculate the Preston's coefficient. Based on the coefficient values, single-link dendrograms can be drawn clustering similar sites together.

RESEARCH REVIEW

Apart from the taxonomic work mentioned earlier, most of the research work on diversity of moths and butterflies in Malaysia has focused on their use as bioindicators of habitat quality and habitat change.

The specialist of Bornean macromoths, Dr. Jeremy Holloway in London, started his association with Borneo back in 1965 when a Cambridge expedition to Mount Kinabalu was organised. A paper giving a numerical analysis of the Kinabalu moth samples was published (Holloway 1970), as well as a taxonomic monograph on the moths of Mount Kinabalu (Holloway 1976). Thereafter, he has been consistently publishing taxonomic monographs in his “Moths of Borneo” series. Apart from that, he also publishes papers on moth ecology, particularly on the use of moths as indicators in comparing forest habitats in Malaysia. His papers include one on the larger moths of Gunung Mulu in Sarawak (Holloway 1984), and the response of moths to forest conversion in Sabah (Holloway *et al*. 1992).

Dr. Holloway also trained up two Malaysian entomologists working on moths. One is the present author who used moths to compare the biodiversity between plantation and natural forests in Sabah (Chey 1994; Chey *et al*. 1997), and who later studied the moth diversity of Lanjak-Entimau in Sarawak (Chey 2000a; 2000b). Another is Dr. Jurie Intachat of FRIM, who assessed moth diversity in natural and managed forests in Peninsular Malaysia (Intachat 1995; Intachat *et al*. 1999a; 1999b; 2005). Chey worked on the whole spectrum of macromoths to inventory biodiversity, while Intachat focused on the geometroid moths specifically to monitor change.

Others who have worked on moth diversity in Borneo include the German researchers Schulze & Fiedler (1996, 1997) and Beck *et al*. (2002).

Research on butterflies as indicators of forest disturbance in Sabah has been carried out since the mid 1990s by Dr. Jane Hill of the UK and her colleagues. Their papers include species abundance models (Hill & Hamer 1998), comparison of butterflies in rain forest gaps and closed-canopy forests (Hill *et al*. 2001) as well as in natural and selectively logged forests (Hamer *et al*. 2003), and the effects of rainfall as opposed to logging on the abundance of a selected butterfly species (Hill *et al*. 2003). They used fruit-baited traps, which were also used to study vertical stratification of activity (Tangah *et al*. 2004), as well as walk-and-count ground-based surveys.

In addition to these studies, a lot of general information on moths and butterflies in Malaysia is provided in the handbook by Holloway *et al*. (2001) and in the hostplant book by Robinson *et al*. (2001).

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AN OVERVIEW OF RESEARCH ON BEETLE DIVERSITY & TAXONOMY IN MALAYSIA

Arthur Y.C. Chung

ABSTRACT

Beetles form the most diverse insect order, with an estimated 400,000 species worldwide representing two-fifths of all insect species. Although some research has been carried out on beetle diversity in Malaysia, because of their high diversity, our understanding of their taxonomy, diversity, species assemblages and ecology is still far from adequate. Even at the family level, there are 166 families worldwide, more than half of which are recorded in Malaysia. Diversity in the beetle order is not only observed in numbers. Size, shape, colour and occurrence in various habitat types are also diverse in beetles. The smallest, biggest and bulkiest insects are beetles. Many small beetles are found in leaf litter and soil, and these are relatively difficult to extract and study. Different methods have to be used to conduct a comprehensive survey of beetles because of their occurrence in various types of habitats. The number of researchers who are working on beetle diversity, however, is very low, making it difficult to achieve an adequate knowledge of this insect group. Basic information on beetle diversity is very important, as this can contribute valuable information that can guide the formulation of conservation measures. In addition, many beetles are essential from an ecological and economic point of view. For example, the pollinating weevil, *Elaeidobius kamerunicus*, has contributed significantly to increased yields in the palm oil industry in Malaysia. In view of this, there is a need to encourage more researchers to work on beetles, such as through the provision of adequate funding. Having good and well-managed collections of beetles is crucial in facilitating research on beetle diversity and taxonomy. In addition to this, the use of information technology, such as databasing and electronic imaging, will enhance such efforts. There is also a need for networking and collaboration within agencies in Malaysia, as well as with foreign institutions, as a platform for the sharing and exchange of information that will further contribute to our understanding of beetle diversity at the local, regional and global level.

INTRODUCTION

Biodiversity has emerged at the centre of one of the most contentious global debates of this century. The debate often focuses on tropical rainforests, which are extremely diverse. Insects are one of the most important and dominant inhabitants of the rainforest. Approximately three-quarters of all species worldwide are insects, and more than half are found in tropical rainforests.

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To date, a substantial amount of research has been carried out to investigate insect diversity in the tropics (e.g. Stork 1991; Davis *et al.* 1997; Chung 1999). However, the current level of understanding of the diversity of many insect groups is still deficient. The importance of good local species-richness data for a wide range of questions posed by evolutionary biology in general and ecology in particular, is evident (Hammond 1990). To assess habitats for their relevance for conservation, ecological and diversity inventories provide an essential tool for environmental management, and insects are a major component in every terrestrial habitat.

Beetles are extremely diverse and abundant (Stork 1991; Chung *et al.* 2000a), and they participate in a great variety of interactions with other organisms. This makes them an important group to study if we are to understand the assemblage structure and diversity of the insect fauna in various tropical habitats.

BASIC INFORMATION OF BEETLES

Beetles belong to the insect order Coleoptera, which is characterized by a pair of sheath wings known as elytra. This is believed to be the most important factor that has contributed to the evolutionary success of the beetles (Evans 1977). The body and the elytra (forewings) are usually heavily sclerotized, giving the beetle an armoured appearance, which also protect it from dehydration and ultraviolet radiation. The cuticle (outer skin and skeleton) consists of chitin and protein, which is tough and protects the soft, inner organs. Another typical characteristic feature of this group is the biting mouthparts, giving them great adaptability. The word 'beetle' actually comes from the Middle English word 'bityl' or 'betyll' and the Old English 'bitula' meaning 'little biter' (Lawrence & Britton 1994). Beetles are an endopterygote group, that is they exhibit complete metamorphosis (holometabolous development), with distinct larval and pupal stages. Other detailed characteristic features of beetles are explained in standard taxonomical and ecological references of this group, for example, Evans (1977), Lawrence and Britton (1994) and Crowson (1981).

Beetles are probably related to soft-bodied, weakly flying insects such as alder flies (Megaloptera) and lacewings (Neuroptera) (Evans 1977; Lawrence & Newton 1982). The ancestors of beetles probably evolved about 300 million years ago during the Upper Carboniferous or Lower Permian periods (Evans 1977). There are fossils showing that the primitive Coleoptera had megalopteran-like venation on the elytra. Some other fossils have been found in the Ural mountains, Russia and in Czechoslovakia, showing marked similarities to the recent archostematan Ommadidae (a primitive Coleoptera family). The evolutionary history and phylogeny of beetles are discussed in Crowson (1981), and Lawrence and Newton (1982).

DIVERSITY AND TAXONOMIC CLASSIFICATION OF BEETLES

With an estimated 400,000 species, beetles form the most diverse insect order, outnumbering the Lepidoptera and Hymenoptera (Hammond 1992; 1995). They encompass two-fifths of all insect species. In comparison, there are about 45,000 species of vertebrates and 250,000 species of plants. Beetles are not only diverse in species but also in structure and size: the largest of them (the cerambycids *Titanus giganteus* from South America and *Xixuthrus heros* from Fiji) attain a length of 200 mm, almost 800 times greater than that of the smallest ones (*Nanosella* and related genera in the family Ptiliidae), which fall well within the size range of larger protozoans, such as *Paramecium* (Lawrence & Britton 1994).

There are a few beetle classifications used worldwide (e.g. Crowson 1981; Lawrence 1982; 1991; Paulian 1988) since the first appearance of Crowson's major work in 1955. One of the latest and widely used was compiled by Lawrence and Newton (1995), in accordance to the International Code of Zoological Nomenclature (ICZN 1985). This classification listed 166 families, 453 subfamilies and approximately 3,300 genera placed within four suborders (Table 1).

The largest suborder of Coleoptera is Polyphaga, which is divided into five series and 16 superfamilies, covering more than 90% of all beetle species. Within the Polyphaga, the superfamilies Chrysomeloidea, Curculionoidea and Staphylinoidea are the most successful groups (Lawrence & Newton 1982). The Chrysomeloidea (Chrysomelidae-Bruchidae-Cerambycidae) and Curculionoidea (Anthribidae-Attelabidae-Brentidae-Apionidae-Curculionidae-Scolytidae-Platypodidae) are predominantly herbivorous with 70,000 and 60,000 described species, respectively. The superfamily Staphylinoidea (*c*. 40,000 described species) contains the predominantly predacious and saprophagous Staphylinidae (*c*. 30,000 described species), Pselaphidae, Scydmaenidae, Leodidae and Ptiliidae.

Table 1. The suborders of Coleoptera

Suborder	Remarks
Archostemata	3 families, rare and primitive beetles, several fossils up to 280 million years old.
Myxophaga	4 families, small and uncommon beetles, feeding on algae.
Adephaga	8 families including Carabidae and Cicindelidae, mainly carnivorous beetles.
Polyphaga	Majority of the families, vary greatly in form and habits, feeding on various types of food.

Taxonomic classification within the order is rather complicated, and it is important to realize that the higher level classification of Coleoptera is not stable. Some suborders and many families probably do not represent monophyletic groups. Cladistic hypotheses for the classification of the Coleoptera are, therefore, lacking (Mawdsley 1994; Gullan & Cranston 1998; Chung 2003). A comprehensive bibliography on beetle families can be obtained through the internet (Lawrence *et al.* 2005).

IMPORTANCE OF BEETLES IN THE TROPICAL ECOSYSTEM

Because of their high diversity, beetles are suitable insects to use as indicators of environmental change. They are found in numbers in most vegetation types and can be easily sampled using various techniques (Chung *et al.* 2000b). Beetles are widely used in studies on diversity and ecology (e.g. Davis *et al.* 1997; Chung 2004). Documentation of diverse and ecologically important insect groups, such as assemblages of beetles, can provide qualitative and quantitative measures of biodiversity that provide a basis for decision making in relation to conservation (Harper & Hawksworth 1995).

Many beetles attack living trees and, thus, reduce the commercial value of their timber (Booth *et al*. 1990). They also sometimes cause the death of the trees, either directly or by transmitting pathogens. Some scarab beetles attack and cause severe damage to oil palm (Wood 1968) and rattans (Chung 1995). The gold dust weevil, *Hypomeces squamosus*, is one of the commonest defoliators that attacks many tree species, including dipterocarps and fast-growing exotic tree species (Chey 1996). Many cerambycids beetles are stem-borers: their larvae can severely damage trees, resulting in devaluation of timber and, sometimes, tree mortality. Thapa (1974) reported attack by the cerambycid borer, *Cyriopalus wallacei*, on dipterocarps in Sabah. Ambrosia beetles (Scolytidae and Platypodidae) also cause damage to many species of forest trees and rattans (Anzai 1991; Chung 1995; Chey 1996).

Some beetles are beneficial to humans. The discovery of a weevil pollinator had a dramatic effect on production in Malaysian oil palm plantations. The weevil, *Elaeidobius kamerunicus*, was introduced into Malaysia in 1981 to replace the practice of assisted pollination (Syed *et al*. 1982; Yee *et al.* 1984). Sakai *et al.* (1997) also reported that beetles of the families Chrysomelidae and Curculionidae contributed to the pollination of *Shorea parvifolia* in Sarawak. In addition, dung beetles (Scarabaeidae) are important decomposers and nutrient recyclers in the rainforest.

More research needs to be carried out on beetles because, in spite of their economic importance, there is still a lack of taxonomic and ecological information on the order in South-east Asia. For example, Hammond (1990; 1992) estimated that about 75% of the 6,000 species of beetles collected from a lowland forest in Sulawesi were undescribed, and Mohamedsaid (1990, 1993a; 1993b, 1994, 1996a) described numerous new species of leaf beetles in Malaysia within a short period of time.

STUDIES ON BEETLE DIVERSITY AND TAXONOMY IN MALAYSIA & ADJACENT COUNTRIES

Chung (2003) recorded 106 families of beetles in Borneo, mainly from Sabah (Appendix 1). This number, however, does not include all the families known to occur in Borneo. In Peninsular Malaysia, at least 93 beetle families are known to occur (Tung 1983), this number being based on the beetle family list issued by the Commonwealth Institute of Entomology in England.

A few recent studies on beetle diversity have been conducted in Malaysia. Chung (1999) and Chung *et al.* (2000a & b) compared the beetle diversity in various habitat types in Sabah, that is, primary forest, logged-over forest, forest plantations and oil palm plantations. In Peninsular Malaysia, Fauziah (2003a; 2003b) conducted beetle surveys in Langkawi and Johore. Abang and Norashikin (submitted) investigated the diversity and distribution of night flying beetles in a lowland mixed dipterocarp forest site in Sabah using modified Pennsylvanian light traps. Burghouts *et al.* (1992) also compared Coleoptera with other invertebrates in their study on leaf-litter decomposition and litter invertebrates, in a Sabah lowland rainforest. A project on “Tools for monitoring soil biodiversity in the ASEAN Region,” with funding from the Darwin

Initiative, UK, was conducted in Sabah between the years 2000-2003, involving researchers from the Natural History Museum (London), Universiti Malaysia Sabah and the Sabah Forestry Department. One of the focal study groups was soil and leaf-litter inhabiting beetles, which have been little studied.

In the adjacent country of Brunei, Mawdsley (1994) investigated the spatial structure of the Coleoptera assemblage in the rainforest and explored ways in which biologists can scale up estimates of species richness from a local to a regional scale. He used a wide range of collecting methods to sample from ground to canopy levels and compared the importance of each sampling method. Stork (1987a; 1987b, 1991) studied the arthropod fauna of lowland rainforest trees, in the same area as Mawdsley, wherein he emphasized the composition, guild structure and faunal similarity between Coleoptera and other insect groups.

Other research on Coleoptera has focused on certain beetle groups, emphasizing their taxonomy or ecology. Much of the research has been conducted by foreign researchers. Abang (2001) provided a list of publications on insect taxonomy (including beetles) authored by foreign scientists in Malaysia. Despite high diversity in the order, only 11 papers were published on beetles in the Malayan Nature Journal and the Malayan Naturalist from 1940 to 1990 (Kiew & Lyons 1992). Mohamed Salleh Mohamedsaid is one of the very few Malaysian beetle taxonomists. His work focuses on the taxonomy of leaf beetles, Chrysomelidae (e.g., Mohamedsaid 1996a; 1997). A total of 1,073 species and 215 genera from 13 subfamilies were recorded in Malaysia and Borneo (Mohamedsaid 2004). In addition, Fatimah Abang of Universiti Malaysia Sarawak (UNIMAS) works on longhorn beetles (e.g. Abang & Vives 2004, Abang 2003, Vives & Abang 2003) and weevils (pers. comm.).

Davis (1993) and Davis *et al.* (1997) investigated the ecology and behaviour of rainforest dung beetles in south-eastern Sabah. Hammond (1984) published a checklist of Staphylinidae occurring in Borneo, but emphasized that this list is conservative and that the actual number of staphylinids could be many times more than the figure in the list. Stork (1986) published an inventory of the Carabidae from Borneo. Hlavac and Maruyama (2004) worked on Staphylinidae that exhibit mutualistic relationships with ants in Peninsular Malaysia. Fireflies were studied by Ballantyne and Menayah (2000), and Mahadimenakbar *et al.* (2003). The Forest Research Institure Malaysia (FRIM) has also conducted some ecological research on fireflies (Krishnakumari 2002) and has on-going research on their biology and habitat requirements (L.G. Kirton, pers. comm.).

Japanese researchers have also contributed significantly to research on beetle diversity and taxonomy in Malaysia. Mizunuma and Nagai (1994) published a comprehensive, illustrated account of the world's lucanids, and many of the species featured are found in this region, including Malaysia. Ohara *et al.* (2001) worked on Histeridae, Ochi and Kon (1994) on dung beetles, and Kon *et al.* (1995) on Passalidae, while Araya (1994) and Araya *et al.* (1994) worked on Lucanidae. Makihara (1999) studied the Cerambycidae of Kalimantan, and his illustrated publication is often used as a reference in Sabah and Sarawak because, biogeographically, they share a lot of similarities with Kalimantan. The on-going Bornean Biodiversity and Ecosystem Conservation (BBEC) Programme has provided opportunities for Japanese researchers to work on beetles in Malaysia, particularly in Sabah (Mustafa & Kusano 2004).

Much of the research work in the past focused only on certain beetle taxa and not on Coleoptera as a whole. It is important that more research is conducted to study and understand beetles as a group, in order to gain a more comprehensive picture of this order collectively.

BEETLE REFERENCE COLLECTIONS IN MALAYSIA

As with all animal or plant groups, a reference collection of beetles is important for the study of their systematics as well as their diversity and, ultimately, forms the basis for their conservation. It provides basic, salient information, and the primary evidence for existence of species. Besides being indispensable to taxonomic work, a good beetle collection is part of the local, national, regional and international natural heritage (Abang & Ghazally 2001, Chung & Chey 2001). Beetle collections are usually an integral part of insect collections in general, which are often housed by museums, Federal or State Departments of Forestry and Agriculture, research institutions and universities. A list of the depositories that house existing insect collections in Malaysia has been provided by Abang and Ghazally (2001).

To date, there are approximately 1,700 species of beetles from 89 families in the Coleoptera collection of the Forest Research Centre in Sepilok, Sandakan. Although some are morphospecies – that is, they are recognised as having different morphology even though it is uncertain if they are different species – this number still probably reflects a very high number of true species. At the Sarawak Forest Research Centre in Kuching, more than 350,000 specimens from 31 families have been recorded, but only about 10% are identified to genus level (Lucy Chong, pers. comm.). There is also a good collection of beetles at Universiti Kebangsaan Malaysia in Bangi, with more than 600 identified beetle species, mainly from the family Chrysomelidae (Anon. 1996, Mohamedsaid 1996b). However, after the retirement of Prof. Mohamed Salleh Mohamedsaid, there is no other beetle specialist working on this group (Azman S., pers. comm.). A total of 61 families have been recorded at the Forest Research Institute Malaysia (FRIM) in Kepong (S. Cheng, pers. comm.). Other prominent beetle collections are in the Sarawak Museum and Universiti Malaysia Sarawak (Abang *et al*., 1996), Universiti Malaya and Universiti Malaysia Sabah.

THE NEED FOR COOPERATION IN RESEARCH ON BEETLE DIVERSITY AND TAXONOMY IN MALAYSIA

The high diversity of beetles in Malaysia practically guarantees that one will always be encountering beetles that have never been collected before, thus, classifying and identifying them can be a daunting task. Unlike many other insect orders, the taxonomy of beetles is difficult and unstable. The status of some families is very uncertain, while the classification of some obscure families varies, subject to the different views of different beetle taxonomists. Many of the characters used to delineate families are very general, being applicable to various beetle families. Being very diverse, there are many exceptions in the characters used. For example, some tenebrionids look almost identical to erotylids or coccinellids. In view of these difficulties, experience, skill and time are important when working on beetle diversity. It is also essential for beetle specialists to cooperate and share information, in order to be more effective in advancing our understanding of beetle taxonomy and diversity.

There are very few researchers that work on beetles in Malaysia and it is, therefore, difficult to achieve an adequate knowledge of this insect group. Abang and Ghazally (2001) noted that there were only about 17 insect taxonomists in the entire country, a number that is far too small to provide the substantial effort needed to alleviate the problem of a shortage of taxonomic information on insects. Basic information on beetle taxonomy and diversity is very important, as this can contribute valuable information that can guide the formulation of measures to ensure sustainable environmental management. Furthermore, many beetles are important from an ecological and economic perspective. For example, the pollinating weevil, *Elaeidobius kamerunicus*, has contributed significantly to the palm oil industry in Malaysia.

In view of the immensity and importance of the task, there is a need to encourage more researchers to work on beetles. Adequate funds need to be channeled towards such research to encourage more work on beetle diversity and taxonomy. Having good and well-managed collections of beetles is crucial in enabling research on beetle diversity and taxonomy. In addition to this, the use of information technology, such as databasing and imaging (e.g., digital images of specimens), will enhance such efforts. There is also a need for networking and collaboration within agencies in Malaysia, as well as with foreign institutions, as a platform for the sharing and exchange of information that will further contribute to our understanding of beetle diversity at the local, regional and global level. Since many of the good collections of beetles are in the developed countries, it is important for local scientists to liaise with foreign counterparts and work together with them. ANeT, established under the DIWPA network for social insect collections, is a good example of networking of researchers who are working on ants, through meetings, seminars and via the Internet.

In summary, my recommendations to enhance research on beetle diversity in Malaysia are similar to those highlighted for the roles of collections in biodiversity conservation (Abang & Ghazally 2001, Chey 2001), and they can be summarized as follows:

- Increase the number of beetle specialists in Malaysia;
- Provide training on beetle diversity and taxonomy for inexperienced curators and auxiliary staff;
- Provide funding and other incentives to encourage research on beetle diversity and taxonomy;
- Encourage beetle specialists to publish identification manuals and monographs to benefit more para-taxonomists and students;
- Increase the use of information technology to enhance research on beetle diversity and taxonomy;
- Establish networking and collaborative work; and
- Establish a directory for researchers working on beetles in this region.

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APPENDIX 1

A list of beetle families, based on Chung (2003)

1 Acanthoceridae
2 Aderidae
3 Anobiidae
4 Anthicidae
5 Anthribidae
6 Apionidae
7 Attelabidae
8 Biphyllidae
9 Bostrychidae
10 Bothrideridae
11 Brentidae
12 Bruchidae
13 Buprestidae
14 Cantharidae
15 Carabidae
16 Cebrionidae
17 Cerambycidae
18 Cerylonidae
19 Chelonariidae
20 Chrysomelidae
21 Cicindelidae
22 Cisidae
23 Clambidae
24 Cleridae
25 Coccinellidae
26 Colydiidae
27 Corylophidae
28 Crytophagidae
29 Cucujidae
30 Curculionidae
31 Dermestidae
32 Discolomidae
33 Dryopidae
34 Dytiscidae
35 Elateridae
36 Elmidae
37 Endomychidae
38 Erotylidae
39 Eucinetidae
40 Eucnemidae
41 Eulichadidae
42 Georissidae
43 Geotrupidae
44 Gyrinidae
45 Histeridae
46 Hybosoridae
47 Hydraenidae
48 Hydrophilidae
49 Inopeplidae
50 Jacobsoniidae
51 Laemophloeidae
52 Lagriidae
53 Lampyridae
54 Languriidae
55 Lathridiidae
56 Leiodidae
57 Limnichidae
58 Lophocateridae
59 Lucanidae
60 Lycidae
61 Lyctidae
62 Lymexylidae
63 Melandryidae
64 Meloidae
65 Melyridae
66 Mordellidae
67 Mycetophagidae
68 Mycteridae
69 Nitidulidae
70 Nosodendridae
71 Noteridae
72 Oedemeridae
73 Othniidae
74 Passalidae
75 Passandridae
76 Paussidae
77 Pedilidae
78 Phalacridae
79 Phengodidae
80 Platypodidae
81 Propalticidae
82 Pselaphidae
83 Psephenidae
84 Pterogeniidae
85 Ptiliidae
86 Ptilodactylidae
87 Ptinidae
88 Rhipiceridae
89 Rhipiphoridae
90 Rhizophagidae
91 Rhysodidae
92 Salpingidae
93 Scaphidiidae
94 Scarabaeidae
95 Scirtidae
96 Scolytidae
97 Scraptiidae
98 Scydmaenidae
99 Silphidae
100 Silvanidae
101 Sphindidae
102 Staphylinidae
103 Tenebrionidae
104 Throscidae
105 Trogidae
106 Trogositidae

THE STATUS OF RESEARCH ON HYMENOPTERA IN MALAYSIA, WITH SPECIAL EMPHASIS ON ICHNEUMONIDAE

Idris A.B.

ABSTRACT

The insect order Hymenoptera (wasps, ants and bees) is the second most speciose and diverse order on earth after beetles. They are extremely important as biological control agents of insect pests. The number of species is unknown but more than 115,000 species have been described and 5 to 10 times more await discovery. Problems faced by researchers working on Hymenoptera include poor inventory data, unavailability of up-to-date identification keys, checklists, databases, reference books and catalogues, and the lack of taxonomic revision. The number of researchers working on Hymenoptera worldwide is declining at an alarming rate. To date, 1,200 ant species have been recorded in Malaysia while more than 20,000 ichneumonid specimens have been collected, viz., up from 300 specimens eight years ago. Many species have been recorded from Malaysia for the first time, and many new species have been identified. Research is being conducted on ant and ichneumonid wasp systematics, as well as on their diversity and ecology, particularly in relation to habitat change. Generally, ants and ichneumonids were negatively affected by habitat (forest) change and could be used as bioindicators of habitat disturbance. Few revisions and catalogues are available, and there are no checklists. Specimens are housed in museums and insect collection centers throughout the world. Major collection centres in Malaysia include the Center for Insect Systematics (UKM) and Institute for Tropical Biology and Conservation (ITBC) (UMS).

INTRODUCTION

Hymenoptera is derived from the Greek words *hymen*, which means ‘membrane’ (or *Hymeno*, the Greek god of marriage), and *ptera*, which means ‘wing’ (LaSalle & Gauld 1993). The order comprises two suborders—Symphyta and Apocrita. The Symphyta, or sawflies, are more primitive. They have complete wing venation and do not have the constricted ‘wasp’s-waist’ seen in the rest of the order (LaSalle & Gauld 1993). Most species have phytophagous larvae that resemble those of Lepidoptera in both appearance and behaviour. Sawflies are a relatively small group consisting of 14 families, which contain just over 5% of described species of Hymenoptera, with the majority in the family Tenthredinidae (Gaston 1993).

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The suborder Apocrita contains the vast majority of species of Hymenoptera. It is divided into two groups, the Parasitica and Aculeata. The aculeates represent the most diverse group of Hymenoptera, in which the ovipositor structure has been modified into a sting. This group contains the groups of Hymenoptera known to most people, such as bees, wasps, hornets and ants. Some species are quite large in size, having a wing span of up to 10 cm (eg. the Spider wasps, Pompilidae). The majority of species are predatory (eg. wasps and hornets) or pollen feeding (eg. bees), but parasitism is common, particularly in the lower aculeates (Chrysidoidea). There are 19 families in Aculeata, and together they account for over 45% of described Hymenoptera species (Gaston 1993), with the families Apidae (bees), Formicidae (ants) and Sphecidae containing the most species.

The Parasitica is the largest group of Hymenoptera, and includes all non-aculeate Apocrita. Members have a constricted waist, but in which the ovipositor has not been developed into a sting. The vast majority of the species are parasitoids. However, there are species which are phytophagous, gall-forming, or predatory. The Parasitica contains 48 families in 10 superfamilies, and encompasses almost half the described species of Hymenoptera, with most of the species in superfamilies Ichneumoniodea and Chalcidoidea (Gaston 1993). The majority of the species, especially the Chalcidoidea, are very small (eg. 0.18 mm in length for some species in the family Trichogrammatidae), and most people are not even aware of their existence and role.

The insect order Hymenoptera is one of the dominant life forms on earth, both in terms of the number of species as well as in the diversity of life styles that have evolved within the group. The Hymenoptera contain the vast majority of socially organized insects and parasitoids, as well as a great variety of specialist predators and herbivores. They have emerged as the most speciose group in many studies on terrestrial biodiversity and they are pre-eminent as biological control agents of insect pest species.

The number of species of Hymenoptera is unknown and, at present, is almost impossible to estimate with any accuracy. Even the number of described species has not been accurately documented, given that there are many families for which there are no checklists or catalogues available. Some good checklists or catalogues are those of Johnson (1992), Bolton (1995), Noyes (1998), Townes (1983), van Achterberg (1983, 1988, 1997), Quicke (1987) and Sharkey (1988). La Salle and Gauld (1993) and Gaston (1993) have estimated the number of described species of Hymenoptera at more than 115,000 species. However, the total number (including undescribed and uncollected species) could be 5–10 times more, given that this is often the proportion of new species that are discovered following taxonomic revision of highly speciose families (Austin 1999). Determining the number of species for the ‘megadiverse’ regions of the world is a major problem. These areas include tropical or subtropical countries such as Australia, India, Malaysia, Indonesia, China, Brazil, Equador, Peru, Columbia, Mexico, Zaire and Madagascar; with a few exceptions, they have generally been poorly surveyed (McNeely *et al.* 1990). The hymenopteran fauna of Costa Rica is particularly well-studied (Hanson & Gauld 1995), and this work serves as a useful foundation for future research on the fauna of Costa Rica itself, and for other regions. The extent of species richness and biological complexity within the Hymenoptera dictates that the group should be at the center of studies assessing arthropod diversity. The full extent of their diversity will only be revealed when detailed studies similar to those in Costa Rica are undertaken for other species-rich regions of the world. Limiting factors common to many countries are the unavailability of up-to-date identification keys, taxonomic revisions, checklists, databases and catalogues (these are either lacking, difficult to get or very expensive to buy), the lack of taxonomists, poor financial support and a lack of research facilities and training programs.

STUDIES ON HYMENOPTERA IN MALAYSIA

Out of 100 families of Hymenoptera listed in Goulet and Huber (1993), there are only four groups, namely the Formicidae (true ants), Apidae (bees) and two parasitic wasp families (Ichneumonidae and Braconidae) that have been given more attention by local entomologists. Unfortunately, none of the present-day local entomologists undertake full-time taxonomic research, and this has a negative impact on efforts to advance our knowledge of the taxonomy and diversity of even these better-studied groups of Hymenoptera.

A. Ants (Formicidae)

Ants are important decomposers of organic matter, and contribute to nutrient cycling and soil enrichment. They have a well-earned title as 'ecological engineers' in terrestrial ecosystems (LaSalle & Gauld 1993)—they serve as food for other animals, have roles to play in seed dispersal, are able to control parasitism and predation, and some species have evolved mutualistic relationships with plants and other insects. In view of this, studies on this particular group of insects are vital.

There are no checklists available for ants in Malaysia, but Bolton (1995) has catalogued the ants of the world. According to Maryati (pers. comm.), there are currently 1,200 species of ants recorded from Malaysia, an increase of 300 over the number of species reported 10 years ago (Maryati 1995). This increase in the number of species recorded is mainly a result of intensive study by her research team, supported by external grants, in collaboration with scientists from the United Kingdom (Natural History Museum), Japan, USA, and Europe. The interesting geological and evolutionary history of Borneo, and its high biodiversity, attracts research collaboration between local and foreign entomologists. Although most of the ant collections are kept at the Natural History Museum (NHM), London, some are also deposited at the new 'Borneonsis' Collection Center in the Institute for Tropical Biology and Conservation (ITBC) located in Universiti Malaysia Sabah (UMS), or in other museums or national collections in Japan, the United Kingdom and USA. A number of publications that are useful references for researchers working on ants, some of which are revisions or catalogues, are listed in Table 1.

Malaysian entomologists currently working on ants are Datin Professor Dr. Maryati Mohamed of Universiti Malaysia Sabah (UMS), Professor Dr. Ahmad Said Sajap of Universiti Putra Malaysia (UPM) and the author, Associate Professor Dr. Idris Abd. Ghani of Universiti Kebangsaan Malaysia (UKM). Foreign entomologists actively involved in ant research in Malaysia are Professor Dr. Kazuo Ogata (Osaka University), Professor Dr. Seiki Yamane (Kagoshima University), Dr. Y. Hashimoto (attached to University Malaysia Sabah) and Dr. Barry Bolton (Natural History Museum, London). Japanese researchers are currently involved in a project on 'Insect Inventory in Tropical Asia', funded the JSPS (Japan Society for the Promotion of Science).

Table 1. Selected Publications Dealing with Ants in Malaysia.

No	Title	Authors & Year
1	The Role of Three Insect Groups (Ants, Dung beetles and Geometrid Moths) as Biological Indicators in Three Type of Habitats (Primary, Secondary & Oil Palms). MSc Thesis, Universiti Malaysia Sabah.	Bakhtiar 2000
2	A revision of the Australian ant genus *Notoncus* Emery, with note on the genera of Melophorini.	Bolton 1955
3	The ant tribe Tetramoriini. The genus *Myr* in the Oriental and Indo-Australian Regions, and in Australia.	Bolton 1977
4	A New General Catalogue of the Ants of the World	Bolton 1995
5	A preliminary analysis of the ants of Pasoh Forest Reserve	Bolton 1996
6	Identification Guide to the Ant Genera of the World	Bolton 1997
7	Stratification of ants in a primary rainforest in Sabah, Borneo	Bruhl *et al.* 1998
8	Leaf litter ant communities in tropical lowland rainforest in Sabah, Malaysia: Effect of forest disturbance and fragmentation	Bruhl 2001
9	Fauna semut di Hutan Hujan Tropika (Primer Sekunder) di Lembah Danum	Chung 1993
10	Common Lowland Forest Ants of Sabah. Forest Department Sabah.	Chung 1995
11	The ants of Tabin Wildlife Reserve, Sabah	Hashimoto *et al.* 1999
12	Diversity of Ants along an Urbanisational Gradient. MSc. Thesis. Universiti Malaysia Sabah	Jimbau 2004
13	Semut, UBTP, Universiti Malaysia Sabah	Maryati 1995
14	Terrestrial Ants of Poring, Kinabalu Park, Sabah	Maryati *et al.* 1996
15	Terrestrial Ants of Sayap, Kinabalu Park, Sabah	Maryati 1998
16	Taburan Semut Mengikut Altitude di Gunung Kinabalu. MSc thesis. Universiti Malaysia Sabah.	Norhasiah 2000
17	Comparison of Ant & Termite Diversity Between Regenerating & Primary Forest in Danum Valley & their Relationship with Physical, Climatic and Biological Factors. MSc. Thesis. Universiti Malaysia Sabah.	Noel 2004
18	Ant composition along an elevation gradient in Mount Kinabalu, Sabah, Malaysia	Shanmuga 1996
19	Canopy ants diversity assessment in the fragmented rainforest of Sabah	Widodo *et al.* 2001
20	Ground ant fauna in a Bornean Dipterocarp Forest	Yamane *et al.* 1996

B. Bees (Apidae)

1. Honey bee group

Apart from providing us with honey, pollen and resin, honey bees are vitally important as pollinators. Seven species have, so far, been recorded in Malaysia. They are *Apis dorsata* (giant honey bee, believed to be native to Malaysia), *A. cerana* (oriental honey bee), *A. florea* (dwarf honey bee), *A. nuluensis* and *A. koschevnikovi* (two bee species that nest in cavities), *A. mellifera* (common honey bee, introduced from Australia for the bee keeping industry) and *A. andreniformis* (recently described from Tenum, Sabah).

There are few Malaysian entomologists working on bees; they are Prof. Dr. Mahadzir Mardan (Universiti Putra Malaysia), Mr. Hussan Abdul Kadir (Malaysian Agriculture Research and Development Institute) and Mr. Salim Tingek in the Tenom Agricultural Research Station, Sabah (TARSS). These entomologists are studying bee behavior, pollination or thermoregulation. TARSS is quickly becoming a center dedicated to research on bees. Bee specimens are kept at various academic institutions such as UKM, UM, UPM and UMS and government agencies such as MARDI and the Department of Agriculture (Crop Protection Division).

2. Stingless bee group

Like honey bees, the stingless bees also play an important role in pollination (e.g., *Trigonia thoracica*, the pollinator for starfruit), Stingless bees however, are not an important source of honey and they are not kept commercially in hives. Very little is known about these bees.

To date, there are no Malaysian entomologists actively working on this group, nor are there any international or regional funds to support such research. However, Dr. Khoo Soo Ghee (retired lecturer of the University of Malaya) had recorded at least 35 species of *Trigona* from Malaysia, and this confirms Malaysia's status as being the country with the highest diversity of *Trigona* species in tropical Asia (S.G. Khoo, pers. comm.). Much of the material stemming from his research (identification keys, checklists, literature and specimens) are currently kept at the Insect Collection of University of Malaya or in Dr. Khoo's personal collection.

Identification keys for both honey bees and stingless bees are available at University of Malaya, TARSS and UPM, as well as from related websites, e.g., Taxacom Listserv Archive for 1996 or http://www.taxapad.com.

C. Parasitic Wasps, with special emphasis on Ichneumoidea (Ichnemonidae and Braconidae)

The parasitic wasps (Parasitica; refer above) is the largest group of Hymenoptera, the two largest families, Ichneumonidae and Braconidae, respectively having 35 and 28 subfamilies worldwide (Goulet & Huber 1993). These two subfamilies have been studied more than the other families. In nature, these parasitic wasps, also known as parasitoids, regulate herbivore populations, thereby reducing damage to the leaves, stems, flowers, fruits and roots of plants. In view of this, Altieri & Nicholls (2004) suggested that these wasps indirectly promote global floral and faunal diversity. However, highly disturbed habitats such as agricultural ecosystems do not favor parasitoid survival.

1. Braconidae

The braconids of the Old World Tropics, in particular the Indo-Australian and Oriental species, have been studied primarily by Drs. C. van Achterberg (Leiden Museum), D.L.J. Quicke (Imperial College, London) and A.B. Idris (UKM, Malaysia). At least three recent revisions have been published (Quicke 1997, Simboloti & van Achterberg 1990a, 1990b). In addition, one illustrated book to the subfamilies was published in 1996 (van Achterberg 1996), and another publication, "Keys to the Genera of Braconidae of the World," is in press (van

Achterberg, pers. comm.). In Malaysia, inventory work has just begun on braconids and, to date, there are *c*. 7,000 braconid specimens from 22 subfamilies in the collection of the Centre for Insect Systematics (CIS), UKM. Postgraduate collaboration with the Natural History Museum in Leiden, Holland and the University of Leiden, is on-going.

2. Ichneumonidae

Ichneumonidae is the largest family in the order Hymenoptera and the second largest family in the Animal kingdom. The number of species in the family exceeds the total number of vertebrate species and is greater than the number of species from any other insect family, with the exception of the Cucurlionidae (weevils), which is the most speciose insect family in the world (LaSalle & Gauld 1993, Romoser & Stoffolano 1998). It is estimated that Ichneumonidae comprises 5–8% of the total number of described insect species on earth (Gaston 1993). In 1969, Townes reported that 16,032 ichneumonid species had been described worldwide and that, of these, 2,579 species were from the Indo-Australian region. Based on this, he estimated that the total number of ichneumonid species worldwide could be more than 60,464.

a. Systematics and Taxonomic Studies

The earliest studies on Ichneumonidae were conducted by Gravenhost in 1829. In Malaysia, studies were initiated by Smith (1858), who first described *Pimpla punctata* (Pimplinae), *Sketia croceipes* (Cryptinae) and *Enicospilus giganteus* (Ophininae) from Sarawak (East Malaysia). In 1903, Cameron (1903) described *Camptotypus rugosus* (Pimplinae) from Peninsular Malaysia. Since then, many species have been described or recorded from Malaysia. Despite this, there have been no concerted efforts to collect and inventorise or to work on the taxonomy, systematics, zoogeographical distribution and phylogenetic relationships of Malaysian ichneumonids. In view of this, a study on Malaysian ichneumonids was initiated by the author in late 1997. To begin with, the genera *Goryphus* (Cryptinae) and *Xanthopimpla* (Pimplinae) were extensively studied. New species were described and new records made. *Xanthopimpla* is a very large tropicopolitan genus, with most species occurring in the Indo-Papuan archipelago, while the genus *Goryphus* is one of the commonest genera of Cryptinae and is highly abundant in the tropical and subtropical parts of the Old World. Both groups are poorly known. Studies on the genera *Theronia* (Pimplinae) and *Enicospilus* (Ophininae) have just begun in early 2005.

Eight years ago, the CIS had about 300 specimens of Ichneumonidae. Today it has over 20,000 specimens, accumulated over a period of seven to eight years of study. Of these, 20 specimens are types or paratypes. A total of 28 out of the 35 ichneumonid subfamilies world-wide, and 21 out of the 22 ichneumonid subfamilies in the Indo-Australian region (Yu & Horstmann 1997a, 1997b, Goulet & Huber 1993), have been collected. Among the subfamilies collected were Agriotypinae, Tersilochinae, Cylloceriinae, Micropleptinae, Orthopelmatinae and Tatogastrinae, which are new records for tropical Asia. A total of 140 genera were identified and, of these, at least 20 genera were new records for Malaysia. For *Goryphus* (Cryptinae), 20 species were recorded for Malaysia (up from only 8 prior to this study), including six new records and five new species (Yu & Horstmann 1997a). A total of 58 species of the genus *Xanthopimpla* were also recorded, of which five species were new to science and nine species were new records for Malaysia. This represents a 40% increase in the number of species recorded from Malaysia. To date we have already successfully identified one species of *Enicospilus,* that is, *E. lietincki,* as a new record for Malaysia.

Molecular phylogenetic studies using 28S rRNA and CO1 genes are in progress. Our preliminary results indicate that the use of CO1 genes gives better resolution compared to 28S genes. In addition, phylogenies derived from molecular classification agreed with those derived from morphology, at the genus level (Idris *et al.* 2005).

b. Ecological Studies

Results from an ecological study conducted in several localities in Peninsular Malaysia, that is, Taman Negara Merapoh (TNM), Pasoh Forest Reserve (PFR), Kuala Lompat Forest Reserve (KLFR) in the Krau Wildlife Reserve, Bangi Forest Reserve (UKMFR), Kuala Langat South Forest (HKLS) and Kuala Langat North Forest (HKLU), showed that the abundance of *Xanthopimpla* spp. (Hymenoptera: Ichneumonidae) were significantly different between localities. Table 2 shows the ichneumonid species diversity (Shannon-Weiner diversity index, H') in the six different forest localities. The ichneumonid abundance in TNM, a primary forest, was not significantly different from that in HKLU, a forest that had been logged five years ago. In fact, both forests had somewhat similar species richness indices (Margalef's richness index, R') and evenness indices (Shannon-Weiner evenness index, E'). Interestingly, only 48% of species were common to both forests. The primary forest conditions of TNM help equilibrate the population of *Xanthopimpla* species within the resources available. HKLU, even though highly fragmented, has a high number of individuals and high species diversity. This suggests that H' will be high, irrespective of the degree of habitat disturbance, as long as the number of species (richness, R') and number of individuals of a species (evenness, E') are high (Magurran 1988). Disturbed forest fragments result in an increase in the abundance and diversity of arthropod species (Samways, 1994). Although some species may be lost as a result of disturbances, others may benefit from these same disturbances. The abundance and diversity of wasps in HKLU could be attributed to the EL-Nino effects or a difference in forest type. It could also be due to the heterogeneity of HKLU as compared to other forests as suggested by the habitat heterogeneity hypothesis (Price 1984, Gauld 1987, Huston 1994). In comparison with other forest fragments, HKLU is considerably more dynamic, as it was logged in 1993 and constitutes vegetation still under succession. HKLS was last logged in 1976, while PFR and KLFR were logged more than 50 years ago and would have achieved greater climax equilibrium. PFR is considered less disturbed (FRIM, 1995), while Kuala Lompat is adjacent to a large area of pristine forest. HKLS, Pasoh and Kuala Lompat had low wasp abundance and diversity and this is probably due to competitive equilibrium resulting from

Table 2. Shanon diversity indices (H'), evenness indices (E') and Margalef's indices (richness indices, R') for *Xanthopimpla* species in six different forest localities in Peninsular Malaysia.

Forests	[1]H'	E'	R'
Hutan Kuala Langat Utara (HKLU)[2]	2.62 a	0.95	4.93
Taman Negara, Merapoh (TNM)	2.55 a	0.94	4.47
Pasoh Forest Reserve (PFR)	1.99 b	0.96	2.73
Kuala Lompat Forest Reserve (KLFR)	1.98 b	0.95	2.82
Bangi Forest Reserve (UKMFR)	1.89 b	0.91	2.92
Hutan Kuala Langat Selatan (HKLS)[2]	1.70 b	0.95	2.17

[1] Values of H' with similar alphabets were not significantly different at $p < 0.05$ (paired t-test).
[2] HKLU and HKLS are peat swamp forests; the others are lowland dipterocarp forests.

competitive exclusion (Huston, 1994; Cox & Moore, 1993). For Bangi FR, the low wasp abundance and diversity are probably due to its isolated location and small fragment size (it is only 105 ha). Huston (1994) pointed out that in smaller areas, competition is high and this results in equilibrium between extinction and immigration; such areas are likely to have lower diversity compared with larger areas.

The study also showed that ichneumonid diversity was significantly higher in the understorey than in the middle-storey or canopy of the forest, based on traps placed on a canopy tower at 0 m, 8 m and 15 m above ground level. Species richness and species evenness followed the same trend (Idris & Kee 2002). These results agree with that of Gonzaga & Idris (2004), who studied the vertical abundance of *Xanthopimpla* species (Ichneumonidae) in Pasoh Forest Reserve. Idris & Kee (2002) found that ichneumonid diversity tended to increase from the forest fringe into the interior, but only up to between 400 to 600 m into the interior of the forest (Table 3). This indicates that there are more ichneumonid species in the interior of the forest than in the fringe, and that species that inhabit the interior of the forest may be sensitive to disturbance. However, this was not the case for some species of genus *Xanthopimpla* such as *X. gampsura*, *X.elegans elegans* and *X. stemator*, as their abundance and diversity tended to be higher in the fringe than in the interior of the forest (Gonzaga & Idris 2004). The percent species similarity between all ground level samples and the ground level samples at the base of the canopy tower was higher than the percent species similarity between ground level traps and traps placed at a height of 15 m on the canopy tower (Table 4).

In 1998, a series of studies were conducted at the Bangi Forest Reserve to compare the effectiveness of various collecting methods. Malaise traps, pitfall traps, yellow pan traps, light traps and sweep nets were used. The results indicated that Malaise traps were more effective. In Sulawesi, Indonesia, Noyes (1989) found that yellow pan traps and sweep nets

Table 3. Shannon diversity index (H’), species evenness (E), and species richness (R) for Ichneumonidae collected at the Sungkai Wildlife Forest Reserve, Perak, Malaysia from July till October 2000.

Trap location	Shannon’s Diversity Index (H’)[1]	Shannon’s Evenness (E)	Margalef’s index (Richness, R)
Horizontal distance from forest edge (m)[2]			
0	2.76 [b]	0.89	5.91
100	3.50 [c]	0.94	10.23
200	4.30 [d]	0.99	16.96
400	4.53 [d]	0.97	16.87
600	4.49 [d]	0.95	16.90
Vertical Height (m)[3]			
0	3.68 [b]	0.95	9.19
15	0.35 [a]	1.52	1.68

[1] Values of H’ with the same alphabet were not significantly different at alpha = 0.05.
[2] Malaise traps were installed on the ground or forest floor.
[3] Malaise traps were installed at the top and bottom of a canopy tower 400 m from the forest edge.

Table 4. Percent species similarity of Ichneumonid species between ground level and canopy samples at Sungkai Wildlife Forest Reserve, Perak, Malaysia (July to October 2000).

Sampling location	Species similarity (%)			
	Horizontal (total)	Horizontal (400 m)	Bottom of tower	Top of tower
Horizontal (total)[1]	100	-	-	-
Horizontal (400 m)[2]	75.4	100	-	-
Bottom of tower[3]	50	98.7	100	38.1
Top of tower[3]	33.3	45.4	38.1	100

[1] All species from all sites in the horizontal sampling with ground-level Malaise traps, viz. 0, 100, 200, 400 and 600 m from the forest edge.
[2] Data for horizontal sampling with ground-level Malaise traps at 400 m from the forest edge.
[3] Data for the canopy tower, 400 m from the forest edge (bottom = 0 m, top = 15 m from forest floor).

sometimes collected more ichneumonids in areas that are undulating. Although the Bangi forest is also undulating, the mean numbers of ichneumonids caught in yellow pan traps and sweep nets were significantly lower than in Malaise traps. However, for the nocturnal ichneumonid subfamily Ophioninae, light traps were more effective.

A study on the flight phenology of ichneumonids in the primary and regenerating forests of Pasoh F.R. was conducted from April 2002 to March 2003. Generally, in both forests, there were two peaks flight activities, viz., June-July and October-December 2002, with the highest activity recorded in July 2002. Based on the flight phenology of the different genera, parasitoids could be categorized into genera that (1) peaked twice a year, (2) peaked only in June-July, (3) peaked only in October-December and (4) peaked in March. However, the flight activity of most genera varied with locality. The results also showed that seasonal new leaf flushes of trees may influence flight activity of ichneumonids. More ichneumonids were caught during the dry season of May to August 2002 than during the wet season of October to December 2002. Additionally, the optimum number of samples needed to yield maximum species diversity (the asymptote or threshold level) was higher in primary forests than in secondary or disturbed forests.

c. Zoogeographical Distribution

A study on the zoogeographical distribution of the genus *Xanthopimpla* and *Goryphus* recorded 58 species and three subspecies of *Xanthopimpla* in Malaysia (Idris *et al.* 2005). Of these, 53 and 34 were from Malay Peninsular and East Malaysia (Sabah and Sarawak), respectively. Only 20 species of *Goryphus* have been recorded in Malaysia: 12 species from the Peninsula and eight species from Sabah (no species have been recorded from Sarawak yet). The lower number of species recorded from East Malaysia is due to lower sampling intensity as a consequence of a limited budget. Zoogeographical maps showing the distribution of each species in Peninsular Malaysia, Sabah and Sarawak are available (Idris *et al*. 2005).

d. Potential Biological Indicators

There was a significant difference between disturbed and undisturbed habitats in relation to body size class distribution of *Xanthopimpla* species (Table 5). Although medium- and small-sized *Xanthopimpla* species dominated both habitats, populations of larger-sized species (approximately 12 mm body length or larger) tended to be higher in disturbed areas. This could be an example of competitive exclusion, in which certain species are prevented from occupying an area by the presence of other species (Cox & Moore, 1993). *Xanthopimpla* species, as examples of pimpline wasps, lay eggs in suitable hosts, and larger species select hosts that enable the development of a larger wasp. (Gauld, 1984). Disturbed habitats may favor the existence of suitable hosts for large *Xanthopimpla* species, which compete with smaller species for the limited resources available. Certain large species like *X. gampsura* were abundant in disturbed habitats, while *X. nigritarsis nigritarsis* was found only in pristine habitats. Although the finding is preliminary and needs to be verified by replication at other locations, these two species of *Xanthopimpla* may have the potential to be used as biological indicators for habitat disturbance.

Table 5. Contingency table[1] for the body length of *Xanthopimpla* species collected in undisturbed and disturbed habitats.

Body length (mm)	Undisturbed	Disturbed
Small (5.30 - 8.66)	16	20
Medium (8.67 - 12.03)	30	11
Large (12.04 - 15.4)	2	11
Total	48	42

[1] Chi Square (2 degrees of freedom) = 15.15, $p < 0.001$.

PUBLICATIONS AND OTHER SOURCES OF INFORMATION ON ICHNEUMONIDAE AND OTHER PARASITIC HYMENOPTERA

There are many ways to access information on Hymenoptera, in particular the Ichneumonidae and other parasitic hymenopterans. Provided below is a list of relevant references, revisions, catalogues, CD-ROMs and electronic information-sources (websites, etc). Useful books for beginners are those written by LaSalle & Gauld (1993), Gauld & Bolton (1996), Austin & Dowton (2000), Quicke (1987), Morley (1913) and Goulet & Huber (1993). Books or catalogues specifically on Braconidae (braconid wasps) and Formicidae (ants) have been written by van Achterberg (1996), Shenefelt (1975), van der Vecht & Shenefelt (1969) and Bolton (1997). Many other books or catalogues provide information on Ichneumonid wasps (Hymenoptera: Ichneumonidae) but these are too numerous to list here. To date, few revisions on Ichneumonidae and Braconidae have been published; these are Townes (1983), Quicke (1997) and Simboloti & van Achterberg (1990a & 1990b). Bouèek (1988) and Huang & Noyes (1994) provide good revisions for Chalcidoidea and Encyrtidae, respectively.

There are several journals that frequently publish or are devoted to research on Hymenoptera (Table 7). The Oriental Insects Monograph, Pacific Insect Monograph and Ichneumonologia Orientalis commonly publish articles on Ichneumonidae and Braconidae of the Indo-Australian and Oriental Regions, while the Zoologische Mededelingen Leiden and Zoologische Verhandelingen usually publish articles on braconids. The Journal of Hymenoptera Research publishes research on any aspect of Hymenoptera. Other articles on Hymenoptera diversity and taxonomy can also sometimes be found in Serangga, Bulletin of Entomological Research, Biocontrol and various other entomological journals.

At least one Interactive Catalogue of World Ichneumonidae called 'Taxapad 1998' is available in the form of CD-ROM (Table 7). (http:/www.taxapad.com) The CD is available for purchase at over RM 2,000/-, inclusive of a guide book. A CD-ROM identification guide to the genera of Braconidae is almost ready (van Achterberg, pers. comm.). Information on Chalcidoidea is also available online (http://www.nhm.ac.uk/entomology/chalcidoids) and 'A Universal Chalcidoidea Database' on CD ROM is also available for purchase (RM 4,000/- each) (John Noyes, pers. comm.). The proceedings of the 'International Symposium on biological control of arthropods' is also available on CD ROM (van Driesche, pers. comm.).

Table 6. List of publications related to Ichneumonidae and other parasitic Hymenoptera

Type of References and Titles	Author (s) and Year
Books/Revisions/Catalogues	
1. Hymenoptera & Biodiversity	LaSalle & Gauld 1993
2. The Hymenoptera	Gauld & Bolton 1996
3. Hymenoptera: Evolution, Biodiversity & Biological Control	Austin & Dowton 2000
4. Parasitic wasps	Quicke 1997
5. Hymenoptera of the World: Identification to Subfamilies	Goulet & Huber 1993
6. Illustrated Key to Subfamilies Braconidae (Hymenoptera: Ichneumonoidea)	van Achterberg 1996
7. Identification Guide to the Ant Genera of the World	Bolton 1997
8. Fauna of British India. Vol 3: Hymenoptera	Morley 1913
9. Australasian Chalcidoidea	Bouèek 1988
10. An Introduction to the Ichneumonidae of Australia	Gauld 1984a
11. The Pimplinae, Xoridinae, Acaenitinae and Lycorininae (Hymenoptera: Ichneumonidae) of Australia	Gauld 1984b
12. The taxonomy, distribution & host preferences of African Parasitic Wasps of the Subfamily Ophioninae	Gauld & Mitchell 1978
13. The taxonomy, distribution & host preferences of Indo-Papuan Parasitic Wasps of the Subfamily Ophioninae (Hymenoptera: Ichneumonidae)	Gauld & Mitchell 1981
14. Studies on the Hymenoptera. A collection of articles on Hymenoptera commemorating the 70th Birthday of Henry Townes	Gupta 1993
15. Revision of genera *Gelini* (Ichneumonidae).	Townes 1983
16. A Catalogue and Reclassification of the Indo-Australian Ichneumoidae	Townes *et al.* 1961
17. A Catalogue of World Ichneumonidae (Parts 1 & 2)	Yu & Horstmann 1997a,1997b
18. The Indo-Australian species of *Xanthopimpla* (Ichneumonidae)	Townes & Chiu 1970a 1970b
19. Genera of Ichneumonidae, Part I	Townes 1969
20. A revision of the Indo-Pacific Species of *Ooencyrtus* (Hymenoptera: Encyrtidae)	Huang & Noyes 1994
21. Revision of the *Euagathis* species (Hymenoptera: Braconidae) from Sulawesi	Simboloti & van Achterberg 1990a
22. Revision of the *Euagathis* species (Hymenoptera: Braconidae) from the Sundaland	Simboloti & van Achterberg 1990b
23. Hymenopterorum Catalogus: Braconidae 8	Shenefelt 1975
24. Hymenoptera Catalogus: Braconidae 1	van der Vecht & Shenefelt 1969
25. The Old World Genera of Braconine Wasps (Hymenoptera: Braconidae)	Quicke 1987

Researchers working on Hymenoptera can stay in touch with each other by registering themselves in a discussion group (parahym@)nhm.ac.uk). Registration can be done online or by contacting John Noyes at the NHM (j.noyes@nhm.ac.uk). The 'International Hymenoptera Conference' is held every four years and enables researchers to present their research findings.

Table 7. Examples of some Journals, CD-ROM/VCD, Websites and Researchers Working on Hymenoptera Parasitica.

Journals

1. Journal of Hymenoptera Research
2. Journal Natural History
3. Zoologische Mededelingen Leiden.
4. Zoologische Verhandelingen.
5. Serangga
6. Oriental Insects Monograph
7. Pacific Insect Monograph
8. Ichneumonologia Orientalis
9. Bulletin Entomological Research

(Devoted to only systematics articles except for no.7 and 9)

CD-ROM/VCD

1. Interactive Catalogue of World Ichneumonidae. 1998.
   (Taxapad 1999) by Dicky, S. Yu. 1998.
   http://www.taxapad.com
2. Universal Chalcidoidea Database : CD-ROM by Noyes (1998).
   http://www.nhm.ac.uk/entomology/chalcidoids
3. International Symposium on biological control of arthropods.
   CD-ROM Delta-interkey CSIRO, Australia.

Available Websites

http:/www.nhm.ac.uk/entomology/chalcidoids	
http://www.nhm.ac.uk/entomolgy/hymcours	hymenopterans
http://www.insectconsultancy.nl	hymenopterans
http://www.sfu.ca/~carmean/tig/	stingless bees
http://www.tolweb.org	Apocrita
http://www.zoo.bio.ufpr.br/hymenoptera	hymenopoterans
http://www.hymenoptera.tamu.edu/	hymenopterans
http://hymenoptera.tamu.edu/ish/	chalcids
http://www.discoverlife.org	especially ants
http://www.royensoc.co.uk	insect parasitoids

RESEARCHERS

Currently, few researchers work on hymenopterans, and many of those that do work on this order work on bees, ants and larger-sized wasps (e.g., vespids and specids), which are not as diverse as ichneumonids, braconids and chalcids (Goulet & Huber 1993). Table 8 lists the researchers working on parasitic Hymenoptera.

Table 8. List of Researchers working on the specific groups of Hymenoptera, and Institution in which they are attached.

Hymenoptera Group	Researchers	Institute(s)
Ichneumonids	M. Fitton & I. D. Gauld	Natural History Museum, London
	V.K Gupta	University of Florida/ American Institute of Entomology, Florida
	D.K. Yu	Agriculture & Agri-Food Canada Research Center, Alberta, Canada
	D. Wahl	American Entomological Institute, Gainesville, Florida, USA
	K. Horstmann	Biozentrum, Zoologie III, Am Hubland, Germany
	H. Goulet, J.T Huber & M.J Sharkey	Center for Land & Biological Resources Research Ottawa, Canada
Braconids	D.L. Quicke	Imperial College of Science, Technology and Medicine, University of London
	C. van Achterberg	The Natural History Museum, Leiden, Holland
	A.D Austin	University of Adelaide, Australia
	R.A.Wharton	Department of Entomology, Texas A & M University, Texas, USA
	J.B. Whittfield	University of Illinois at Urbana Champaign, USA
Chalcids	J. Heraty	University of California, Riverside
	J. Noyes	Natural History Museum, London
	J. LaSalle	CSIRO, Australia

SOURCES OF FUNDS

Funds to conduct research on Hymenoptera can be sourced from the ASEAN Regional Centre for Biodiversity Conservation, the Japanese International Cooperation Agency (JICA), the Darwin Initiative, Asia-Link Projects (supported by the European Union) and the Japan Society for the Promotion of Science (JSPS). Locally, government and semi-government agencies such as the Ministry of Science, Technology and Innovation (under the Intensification of Research Priority Areas or IRPA grant system), Federal Land Development Authority (FELDA) and the Johor State Park are primary sources of funding. With sufficient funds, inventories and research into the taxonomy, and ecology of Malaysian Hymenoptera can be conducted.

Overseas funding agencies are also open avenues for collaboration between local taxonomists and foreign researchers.

DEPOSITORIES OF COLLECTIONS

Many collections of Hymenoptera are housed in various institutes of higher learning and museums overseas. The largest collections, with many type specimens, are in the Natural History Museum (United Kingdom), Oxford University Museum (United Kingdom), National Museum of Natural History (Leiden, Netherlands), American Institute of Entomology Insect Collection (Florida, USA) and other museums in Europe, Japan and the USA. The American Institute of Entomology Insect Collection in Florida has c. 800,000 of ichneumonid specimens. Museums and insect collection centers that have Malaysian specimens include:

- Bishop Museum, 1525 Bernice Street, Honolulu, HI 69817-0916 USA.
- Deutsches Entomologisches Institut Schicklerstrasse 5D-16225 Eberswalde, Germany.
- Hope Entomological Collections, The University Museum, Parks Road, Oxford OX1 3PW United Kingdom.
- Institut Royal des Sciences Naturelles de Belgique, Département d’Entomologie, Rue Vautier 29, B-1000 Bruxelles, Belgique.
- Muséum National d’Histoire, Laboratoire d’Entomologie, 45 rue de Buffon, F-75005 Paris, France.
- Museum Victoria Science Program, GPO BOX 666E, Melbourne, Victoria 3001 Australia.
- National Museum of Natural History, Naturalis, P.O. Box 9517, 2300 RA Leiden, The Netherlands.
- Naturhistorisches Museum Wien, Burgring 7, A-1014 Wien, Austria.
- Systematic Entomology, Faculty of Agriculture, Hokkaido University, 060-8589, Japan.
- The Natural History Museum, Cromwell Road, London SW7 5BD, United Kingdom.
- Universiteit van Amsterdam, Zoölogisch Museum Amsterdam, Afdeling Entomologie, Plantage Middenlaan 64, 1018 DH Amsterdam, the Netherland.
- Zoological Museum, University of Copenhagen, Universitetsparken 15 DK-2100 Copenhagen, Denmark.
- Zoologisches Museum an der Humboldt-Universität zu Berlin, 10115 Berlin, Invalidenstraβe 43, Germany.
- American Institute of Entomology Insect Collection, University of Florida, USA.

CONCLUSION

Hymenopterans are an important component of our national biodiversity heritage, and play a significant role in maintaining ecological balance in many natural and man-made ecosystems. Only two Malaysian researchers are currently working on the taxonomic diversity and species abundance of Hymenoptera in relation to habitat change. The difficulties in getting grants and reference materials and the lack of job vacancies for students trained in taxonomic research contribute to the dearth of researchers. Only few institutes have specimen holdings i.e., the Center for Insect Systematics of UKM, Borneansis Collection (University Malaysia Sabah), Forest Research Institute Malaysia (FRIM) and Sabah Forest Research Center (FRC). It would be very difficult to develop checklists, revisions or catalogues on Hymenoptera if the basic need for local expertise and resources are not met. While Malaysia may have adequate facilities for such research, a further problem is the insufficiency of annual funds to curate specimens on a long term basis.

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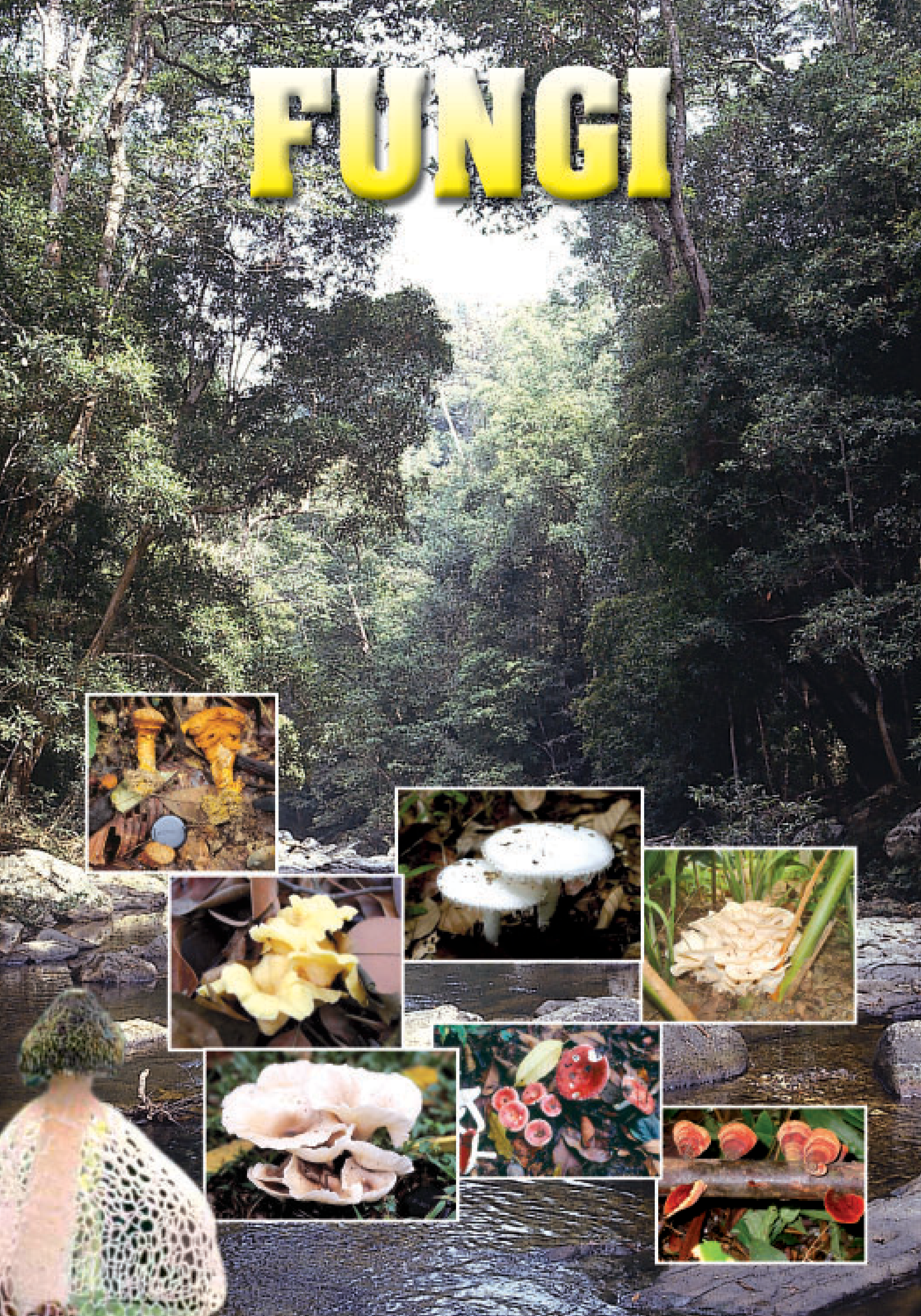
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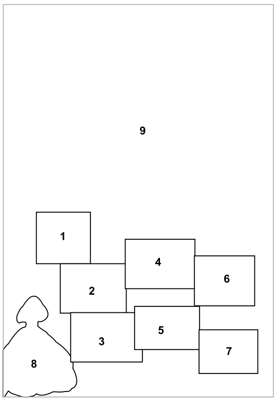

1. *Pisolithus aurantioscabrosus* (Pisolithaceae). Photo courtesy Lee S.S.
2. *Cantharellus* sp. (Cantharellaceae). Photo courtesy Lee S.S.
3. *Panus giganteus* (Polyporaceae). Photo courtesy Lee S.S.
4. *Amanita tjibodensis* (Amanitaceae). Photo courtesy Lee S.S.
5. *Russula* sp. (Russulaceae). Photo courtesy Lee S.S.
6. *Thelephora* sp. (Thelephoraceae). Photo courtesy Lee S.S.
7. *Stereum* sp. (Stereaceae). Photo courtesy Lee S.S.
8. *Dictyophora indusiata* (Phallaceae). Photo courtesy Lee S.S.
9. Canopy of a Malaysian lowland dipterocarp forest. Photo courtesy L.G. Saw

MACROFUNGAL DIVERSITY IN MALAYSIA

[1]Lee Su See & [2,3]Roy Watling

ABSTRACT

Macrofungi, also known as macromycetes or larger fungi, are fungi, which possess large (macroscopic) sporocarps or fruiting bodies. Many macrofungi are important as sources of food and medicine; some are symbionts in ectomycorrhizal associations with trees while others cause diseases and decay. It is estimated that up to about 70% of the fungi in Malaysia have yet to be discovered. This paper discusses the status of macrofungal diversity in Malaysia and shows that the existing figures for the number of species of Malaysian fungi are grossly underestimated. Much research still needs to be done before a clearer understanding of the status of macrofungal (and total fungal) diversity in Malaysia can be obtained and the resources needed for such an undertaking are discussed in the paper.

INTRODUCTION

Malaysia, one of the world's 12 most biologically diverse countries, is known to possess over 15,000 species of flowering plants, 286 species of mammals, more than 150,000 species of invertebrates, over 1,000 species of butterflies, 12,000 moth species, and more than 4,000 species of marine fishes (WCMC 1994). Yet amazingly, according to the Assessment of Biological Diversity in Malaysia (Anonymous 1997), there are only 400 species of fungi in the peninsula and 300 species in East Malaysia. The report does not mention whether any species are common to the two regions.

An assessment of all the fungi known to occur in Malaysia would be a monumental and time consuming task requiring access to numerous libraries and fungal collections around the world. As the time given for preparation of this paper was rather short, we restrict ourselves to a discussion of the diversity of only the basidiomycete macrofungi here, which still is a considerable task.

Macrofungi, also known as macromycetes or larger fungi, are fungi which possess large (macroscopic) sporocarps or fruiting bodies (Hawksworth *et al.* 1995) visible to the naked eye as opposed to the microfungi or micromycetes which possess microscopic sporomes. For the purpose of this paper Singapore is geographically considered part of Malaysia, thus reports

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of macrofungi from the former are also included as those being from Malaysia. Many macrofungi are important as sources of food and medicine, some are symbionts in ectomycorrhizal associations with trees while others cause diseases and decay.

A recent study of putative ectomycorrhizal fungi in a lowland rain forest at Pasoh, Malaysia clearly illustrates the large number of tropical fungi yet to be discovered (Lee *et al.* 2003). Of the 296 taxa of putative ectomycorrhizal fungi recorded, 66% are undescribed, reflecting the poor knowledge of macrofungi in the tropics. In another study also conducted at Pasoh, more than 200 species of polypores were found from a relatively small area of about 4 ha and along adjacent trails (Hattori & Lee 2003). The authors of this last study estimate that about 300 species of polypores might be expected from this single research site compared to only about 330 species recorded for the whole of Europe where most of the species have already been listed (Ryvarden & Gilbertson 1993, 1994). These examples are from only a few studies in Malaysia re-emphasising the late Prof. E.J.H. Corner's estimate that up to 70% of the fungi in Malaysia had yet to be discovered. From information obtained through personal communication, Jones and Hyde (2004) estimated that there are over 2,000 documented fungi in Malaysia. It would be safe to say that this figure is still an underestimate of the fungal diversity of Malaysia.

LITERATURE REVIEW

The first attempt to list Malayan fungi was made by Bancroft in 1913 (cited in Chipp 1921) in his "List of fungi identified in the Federated Malay States" in which 105 species were mentioned. An additional five species were listed by Sharples later that same year (Chipp 1921) and this was followed by a brief but important contribution on 16 boletes five years later by Patouillard and Baker (1918) (see Watling 2000). Subsequently, a general list of fungi for the Malay Peninsula was published by Chipp (1921) who, however, did not attempt to give a total number of species as many synonyms were evident and many of the early determinations still needed checking. Basidiomycetes make up the bulk of the collections described by Chipp (1921), with the earliest records being the collections of Beccari between 1865 and 1879 on his way to Sarawak and those of Rev. Father Scortechini in 1885. Other early collectors included Kunstler but the majority of the collections were the result of work by Ridley and Mrs. E. Burkill (Chipp 1921). The data contained in these early reports are now long out of date and the taxonomy considerably changed but there has been no other general listing of the fungi for the peninsula or Malaysia since. This lack of information was evident in Lim's (1972) short illustrated report on the more common macrofungi of Malaysia and Singapore, where the majority of the fungi were identified to genus level only and where surprisingly only one of the ten references listed was directly concerned with Malaysian fungi, despite extensive monographic work in the area.

Unlike other tropical countries, Malaysia and Singapore have been very well served for the macrofungi as many world monographs have been published centred around the macrofungi species found in the Malay Peninsula. This has been a result largely of the efforts and contributions of the late Prof. E.J.H. Corner who undoubtedly was the most prolific and authoritative mycologist in Malaysia (Watling 2001a). Of his 141 publications produced between 1929 until his death in 1996 (Watling 2001a), 97 concerned mycological topics, nearly all of them dealing with the macrofungi. His monographic treatments of the Boletaceae, Cantharellaceae, Clavariaceae, Thelephoraceae, Tricholomataceae and Polyporaceae are used worldwide and are highly significant contributions to the fungal flora of Malaysia. In 15 monographs covering just eight basidiomycete groupings, Corner described 621 new taxa of Malaysian fungi (Table 1). These new discoveries mainly resulted from his collecting trips to selected locations in the forests of Singapore, parts of Johor, Negeri Sembilan, Pahang and Mt. Kinabalu in Sabah. No doubt many more new taxa would have been discovered had the collecting trips been extended to more areas in each location and to other locations in the country. Considering that macrofungi are found in over 140 families in the basidiomycetes (and this excludes the many larger Ascomycota), it is quite awe-inspiring to imagine the numbers of new taxa that await discovery.

In addition to the monumental work of Corner, there are various publications on the macrofungal diversity of specific localities in Malaysia, such as Pulau Langkawi (Kuthubutheen 1981), the grounds of the Forest Research Institute Malaysia (FRIM), Kepong (Watling & Lee 1995, 1998), Sabah (Pegler 1997), selected forest reserves in Peninsular Malaysia (Lee *et al.* 1995, Watling & Lee 1999, Salmiah *et al.* 2002), and Pasoh Forest Reserve, Negeri Sembilan (Hattori & Lee 2003, Lee *et al.* 2002, 2003). There are also several publications on ascomycetes from Malaysia (e.g., Spooner 1991, Whalley 1993, Whalley *et al.* 1996, 1999) but these are not considered in the present paper.

Table 1. New taxa of Malaysian macrofungi described in selected monographs of the late Prof. E.J.H. Corner

Fungus Group	No. new taxa	Reference(s)
Amanita	30	Corner & Bas (1962)
Boletes	105	Corner (1972)
Cantharelloid fungi	24	Corner (1966)
Clavarioid fungi	9	Corner (1970)
Pleurotoid polypores	15	Corner (1981)
Polypores	172	Corner (1983, 1984a, 1984b, 1987, 1989a, 1989b, 1991a)
Thelephora and allies	18	Corner (1968)
Tricholomataceous agarics:		
Mycenoid and tricholomatoid components	103	Corner (1994)
Marasmioid components	93	Corner (1996)
Trogia	52	Corner (1991b)

Note: several species have varieties, which are not included here.

A recent study of polypores in East and South-East Asia (Hattori 2004) found that South-East Asia possesses a rich diversity of polypore fungi, many of which are possibly endemic. South-East Asia is considered a refugia during the Pleistocene and is the centre of distribution for several species (Table 2). Of the 208 species of polypore fungi found in Pasoh, Negeri Sembilan between 1992 and 1999, seven were temperate species, 33 pantropical, 24 paleotropical and 144 found only in South-East Asia showing that many were probably endemic (Hattori 2004).

Data on macrofungal diversity may also be obtained from publications dealing with other aspects of macrofungi, for example, those dealing with utilization, e.g., Burkill (1966), Sather (1978), Chin (1981, 1988) and Christensen (2002). However, data from some of the older

Table 2. Polypore fungi whose centre of distribution is considered to be in South-East Asia

Antrodiella aurantilaeta (Corner) T. Hatt. & Ryv.
Antrodiella brunneimontana (Corner) T. Hatt.
Elmerina holophaea Pat.
Elmerina ungulata Corner
Inonotus scaurus (Lloyd) T. Hatt.
Protodaedalea hispida Imazeki
Tyromyces incarnatus Imazeki

Source: Hattori 2004

publications need to be reexamined or re-evaluated and the fungal identifications confirmed but this may be impossible to carry out in the absence of voucher specimens. Information may also be obtained from assorted publications on macrofungal taxonomy from Malaysia (e.g., Baroni & Watling 1999; Hattori & Lee 1999; Pegler & VanHaecke 1994; Sims *et al.* 1995; Watling *et al.* 1995; Watling & Hollands 1990; Watling 1993a, 1993b, 1994a, 1997; Watling & Sims 2004; Turnbull 1995; Turnbull & Watling 1999) or South-East Asia (e.g., Jülich 1980, 1982, 1984a, 1984b; Watling 1994b, 1998, 2001b); ecology (e.g., Hong *et al.* 1984) and plant pathology (e.g., Hilton 1959, Singh 1973, Lee 1993, Lee & Noraini Sikin 1999). Although a listing of Malaysian macrofungi may be compiled by going through all the published literature, the veracity of much of the data cannot be confirmed unless voucher specimens exist.

SPECIMEN COLLECTIONS

Information on specimen collections of Malaysian fungi is scattered and not easily accessible. Fungal collections made before 1912 were sent to the Royal Botanic Gardens, Kew (Chipp 1921) with a small amount kept for comparison at the Singapore Botanic Gardens (SING). Collections made during the British colonial era in Malaya, including those from forestry and agriculture were also sent to Kew (K) for identification. Collections made by the Rev. M.J. Berkeley which were originally housed at the British Museum were transferred to Kew in 1979 under the Morton Agreement and material collected from Malaya and Singapore sent to the well known mycologists G.E. Massee, M.C. Cooke, E.M. Wakefield and R.W.G. Dennis were all deposited and available for examination at Kew. Some of the material collected on more recent expeditions to Borneo, e.g., to Mulu, are housed both at the Royal Botanic Garden Edinburgh (E) and at Kew (see Watling & Hollands 1990). Prof. Corner's extensive collection of Malaysian specimens, except those monographed before 1972, are now held in the Edinburgh Botanic Garden library and herbarium. Other materials are in the Botany School, Cambridge (CGE), although it is hoped that in the future these specimens will also be transferred to join the Edinburgh holdings. Some, many in rather poor condition, are held in the Singapore Botanic Gardens. Presently when time permits Evelyn Turnbull in Edinburgh is gradually databasing Corner's collections but this is a slow activity. However, many of the collections so-far catalogued have been examined and where necessary revised by visiting scientists, e.g., C. deCock, T. Hattori, U. Koljag, Y. Ota, E. Horak, S. Miller and R. Garcia-Sandoz. Other Corner's collections can also be found in the US Department of Agriculture's collections at Beltsville, Maryland, U.S.A. (BPI) as demonstrated on its website, whilst many of the collections of W. Jülich would most probably be deposited at the Rijksherbarium, Leiden, Netherlands (L).

Some collections of specific groups are also housed in Zurich, Switzerland (ZT) and Innsbruck, Austria resulting from collections made by Swiss and Austrian mycologists who visited Malaysia and South-East Asia in the 1970s and 1980s and exchange of specimens with Corner. None of these materials is supported by voucher cultures. Recent collections made by R. Watling & E. Turnbull of the Royal Botanic Garden Edinburgh under the auspices of collaborative projects with FRIM and featured in their papers noted above are deposited in the Edinburgh herbarium.

Several institutions in Malaysia maintain culture collections of macrofungi for research, teaching and commercial purposes. Apart from those at FRIM, most of the cultures are of non-indigenous species, comprising macrofungi cultivated in the country for food or medicinal purposes and whose original sources are largely undetermined (Tan & Lee 1999). However, specimen collections of macrofungi are rarer. Some universities such as Universiti Malaya (UM), Universiti Putra Malaysia (UPM) and Universiti Malaysia Sarawak (UNIMAS), hold some macrofungal collections, but information on the status and condition of the collections is not available. FRIM has a small collection of macrofungal specimens, mainly focused on the ectomycorrhizal and wood-inhabiting taxa. In order to obtain up-to-date information on the fungi of Malaysia, a survey of fungal collections, both of cultures and herbarium specimens held by both local and overseas institutions, needs to be carried out.

Early drawings of Malaysian macrofungi collected in Singapore made by C. de Alwis and Mrs. Burkill have been transferred from Edinburgh, where they formed part of the Corner bequest, to Singapore while Corner's field notes, commentaries and keys, line-drawings and numerous water colours accompany his material in Edinburgh.

SPECIALISTS/RESEARCHERS

In the early 1900s, specific scientists were assigned to study or specialize in particular fungal groups, for example, ascomycetes were under the purview of C.F. Baker who was a staff member of the Singapore Botanic Gardens in 1917, while the myxomycetes were the specialty of A.R. Sanderson (Chipp 1921). Corner's brief when he was appointed Assistant Director in Singapore included overseeing mycology and this led to him becoming involved in the study of butt-rot fungi of rubber, which in its turn led to the development of the mitic hyphal system for the classification of polypores. This tradition of specialization was upheld until very recently in most institutions dealing with fungal taxonomy, e.g., the International Mycological Institute in the U.K., the Rijksherbarium, Leiden, but unfortunately this practice ceased in the 1990s due to budget constraints. Several British experts well versed with the Malaysian mycota such as D.N. Pegler and R. Watling have retired and as a result of changing priorities in parallel with many countries in the western world, have not been replaced. However, there is hope yet in Japan and China where there are several young mycologists including fungal taxonomists who are interested in tropical fungal diversity. There has also been an upsurge of interest in the study of mycodiversity in neighbouring Thailand where many young researchers are being trained both locally and abroad in mycology and fungal taxonomy. Locally, researchers who work with Malaysian macrofungi are usually not trained as mycologists or taxonomists, their knowledge of macrofungal taxonomy being acquired through personal interest or necessity while working on plant pathology or other disciplines involving fungi. As in the west, mycology and fungal taxonomy are given little attention if any, in local university curricula as attention is focused more on the more glamorous and current topics of biotechnology and applied microbiology. The reasons for this are best discussed at another forum. There is a need to identify local researchers who are able to contribute the expertise needed to fully evaluate the fungal diversity of Malaysia.

Public appreciation of the fungi and their diversity needs to be encouraged through the organisation of interesting educational talks and regular fungal forays but the lack of sufficient experienced and knowledgeable leaders is a major stumbling block. One way to overcome this lack of expertise would be to invite some of the retired, experienced mycologists to conduct hands-on training courses and workshops on fungal taxonomy for local students, scientists and researchers. These experts could also be appointed visiting/honorary lecturers or professors at local universities to help strengthen the teaching of mycology and taxonomy as well as to assist in the supervision of student projects. Such experts could also be invited to participate in expeditions and other interdisciplinary projects where a fungal component exists, thereby in the process contributing to the evaluation and enumeration of our fungal diversity.

RELATED PROJECTS

At FRIM and other local educational and research institutions, various studies concerning macrofungi are being carried out, e.g., projects on selected plant pathogens, fungi utilized for food, medicine and industrial purposes, and those involved in ectomycorrhizal associations. However, there are few projects aimed directly at evaluating the macrofungal diversity of the country. One post-graduate project currently being undertaken at a local university aims to evaluate the biodiversity of polypore fungi using both classical and molecular techniques for *ex-situ* germplasm conservation and cultivation. A collaborative project between Universiti Sains Malaysia and some Japanese researchers has been underway for the last two years in the north of the country but details are sketchy. Between 1992 and 1998, FRIM collaborated with mycologists from the U.K. and Japan on the macrofungi of Pasoh Forest Reserve, Negeri Sembilan and this has resulted in the publication of several research papers, the discovery of many undescribed fungi of which some have already been published as new (Watling *et al.* 1995; Hattori & Lee 1999). Many of the collections made during the duration of these two projects still await further study and it is likely that several more new species, particularly in the Russulaceae and hypogeous fungi will be described when the taxonomists find the time to work on the collections. It is only through the joint efforts of such collaborative projects and with the help of foreign experts that we can hope to have a better understanding of our macrofungal diversity.

In the U.K. the British Mycological Society has been at the forefront of British mycology and its members have actively played a role in the enumeration of the British fungal flora. There is no equivalent organization in Malaysia but non-governmental organisations such as the Malaysian Nature Society (MNS), Worldwide Fund for Nature (WWF) and other organisations involved in nature conservation and education could assist in the evaluation of the Malaysian macrofungal diversity if such a project were to be implemented. Many members of the MNS are keen and expert nature photographers and have submitted photos of assorted fungi for identification. With a little education, interested members could be trained to properly collect and document the details of the fungi for further identification by the experts. This is where the stumbling block lies—there is a dearth of local expertise in the identification of the macrofungi. Some of the measures mentioned in the previous section could hopefully be implemented to overcome this problem.

RESOURCES REQUIRED

Information on macrofungal diversity in Malaysia is still far from satisfactory. As a first step, a thorough review of the literature on the topic needs to be conducted together with an assessment of the collections available not only in Malaysia but worldwide. This requires time, manpower and funding. Secondly, manpower and funding are needed for field visits to collect macrofungi from various locations and habitats throughout the country. This is a daunting and time consuming task as the collecting trips should coincide with the fungal fruiting seasons of the various locations. To ensure a proper representation of the flora of a particular area, collections need to be made over a continuous period of several years. Suitably trained manpower is needed not only to make the collections but also to describe and identify them. For the short-term, this could best be achieved either by inviting foreign experts to lead such collecting trips whilst providing on-the-job training to young, local researchers who could then continue the work later on, or by suitable candidates training with a mentor in Europe or North America, and in the case of Edinburgh, working with Corner's collections as the senior author and Tham Foong Yee from Singapore have been able to do. More importantly, researchers who have been trained in fungal taxonomy and inventory should continue to work in those fields and not be assigned to other projects so as not to lose the impetus gained from that training. Dedicated positions or time available in a particular job for macrofungal taxonomy must be assured. Otherwise, the benefits from the training would not be realized and no further progress would be made in macrofungal taxonomy. Facilities to store the specimens, such as proper storage cabinets and a herbarium are also needed, as are suitably trained curators for the collections. Molecular techniques are now routinely used for fungal identification; therefore equipment for such methods should also be available.

CONCLUSION

An up-to-date and accurate listing of the macrofungal diversity of Malaysia is a huge challenge that requires time, manpower, funding and expertise, not all of which are in place at the moment. Given the proper resources, dedication and commitment, it can be achieved, thereby not only providing us with a knowledge of our rich natural heritage but also open the doors for exploration and sustainable utilisation of our natural wealth for the welfare and benefit of humankind.

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WORLD CONSERVATION MONITORING CENTRe (WCMC) (1994) Species database. Downloaded from info@WCMC.org.uk

A CHECKLIST OF MANGLICOLOUS MARINE FUNGI FROM MALAYSIA

Siti Aisyah Alias

ABSTRACT

Mangrove forests occur in muddy shores, lagoons and estuaries of tidal rivers and provide a very unique habitat to many organisms including manglicolous marine fungi. Submerged parts of aerial roots, pneumatophores, subterranean roots, rhizomes, overhanging branches and twigs of mangrove trees and driftwood are the most common niches for marine fungi. The number of higher marine fungi species recorded from the mangrove areas has increased in recent years. Studies revealed that mangrove fungi are the second largest group among the marine fungi. A checklist of Malaysian higher marine fungi from the mangrove ecosystem is presented in this paper. The total number of fungi species recorded in Malaysia is 302 of which 234 species are identified and 68 species unidentified. The total number of species recorded in Malaysia is relatively high when compared to the total number of species recorded worldwide (444 species). The Ascomycota was the largest group encountered (275 species), followed by Deuteromycota (23 species) and Basidiomycota (2 species). The most commonly occurring species were *Lignincola leaves* (17.87%), followed by *Verruculina enalia* (13.92%), *Trichocladium achrasporum* (12.88%), *Savoryella lignincola* (12.35%), *Dictyosporum pelagicum* (11.86%), *Lulworthia grandispora* (11.53%), *Halocyphina villosa* (11.55%), *Periconia prolifica* (10.10%), *Leptosphaeria australiensis* (9.32%), *Halosarpheia marina* (8.93%), *Halosarpheia retorquens* (8.22%), *Lignincola longirostris* (8.16%), *Halosarpheia ratnagierensis* (7.40%), *Kallicroma tethys* (7.30%), *Dactylospora heliotrepha* (5.81%), *Trichocladium alopallonellum* (5.73%), *Trichocladium linderi* (5.40%), *Cirrenalia pygmea* (5.38%), *Savoryella paucispora* (5.36%) and *Marinosphaeria* sp. (5.07%). Percentage colonization was 84.8% and the average number of fungi per sample was 2.93.

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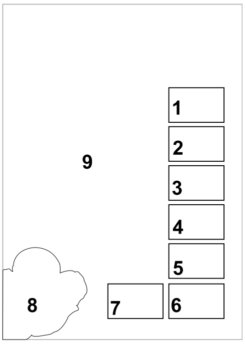
PLANTS



1. *Halymenia* sp. (Rhodophyta). Photo courtesy S.M. Phang.
2. A mixture of Phaeophyta. Photo courtesy S.M. Phang.
3. *Arytera littoralis* (Sapindaceae). Photo courtesy L.G. Saw.
4. *Etlingera elatior* (Zingiberaceae). Photo courtesy L.G. Saw.
5. *Nepenthes rajah* (Nepenthaceae). Photo courtesy L.G. Saw.
6. *Pinanga disticha* (Palmae). Photo courtesy L.G. Saw.
7. *Etlingera metriocheilos* (Zingiberaceae). Photo courtesy L.G. Saw.
8. *Rafflesia cantleyi* (Rafflesiaceae). Photo courtesy L.G. Saw.
9. *Alpinia malaccensis* (Zingiberaceae). Photo courtesy L.G. Saw.

SEAWEED DIVERSITY IN MALAYSIA

S. M. Phang, C. L. Wong, P. E. Lim, J. L. S. Ooi, S. Y. Gan, Melor Ismail, H. Y. Yeong & Emienour Muzalina Mustafa

ABSTRACT

Malaysia has an extensive coastline totaling 3432 km with 418,000 km^2 of continental shelf. Numerous islands form clusters along the coastlines. Rocky shores and sandy bays alternate with mudflats, while coral reefs fringe most islands. All these harbour niches for the variety of seaweed species found in Malaysian waters. The first checklist of the marine benthic algae in Malaysia was published in 1991 by Phang and Wee, together with a historical account of phycological research in this region. In 1998 Phang updated the checklist, including the first Malaysian new species (*Sargassum stolonifolium* Phang et Yoshida) published in the 'Seaweeds Resources of the World' by Critchley and Ohno. The present tally includes 386 taxa comprising Chlorophyta (13 families, 102 taxa), Rhodophyta (27 families, 182 taxa), Phaeophyta (8 families, 85 taxa) and Cyanophyta (8 families, 17 taxa). Many of the seaweeds have potential for commercialisation based on a variety of products and uses. The seaweed resources have to be protected against biodiversity losses due to habitat destruction, pollution, over-harvesting and biopiracy. The inventory of Malaysian seaweeds must continue together with more focused ecological studies. Biomass assessments of natural seaweed areas, productivity determination and phenological studies of important species, should be encouraged. Only then can the status of the seaweed flora of Malaysia be assessed and threatened species and habitats identified.

INTRODUCTION

Malaysia lies within the Indo-Malay-Philippine archipelago, which is part of the Indo-West Pacific region. With its extensive coastline totaling 4675 km with 418 000 km^2 of continental shelf, there exists high marine biodiversity as well as bioproductivity. Of the marine bioresources, the marine algae find niches in the various marine habitats (Phang, 1998). Algae are non-flowering photosynthetic organisms ranging from the microscopic phytoplankton to the macroscopic marine algae or seaweeds. In the present classification system, members of the Algae Kingdom are separately placed into three different phyla. The prokaryotic blue-green algae belong to the Prokaryota; the unicellular eukaryotic algae are placed in the Protista; while the macroscopic eukaryotic algae are placed in the Plantae. The seaweeds are thus part of the Plantae and may be grouped into three divisions namely the Chlorophyta (green

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seaweeds), Rhodophyta (red seaweeds) and the Phaeophyta (brown seaweeds). In this paper, the filamentous marine blue green algae (Cyanophyta) will also be considered seaweeds, as many of these species have both ecological and commercial importance just like the other seaweeds.

In Malaysia, these tropical seaweeds are subjected to the equatorial climate dominated by monsoon wind systems, with the Northeast Monsoon blowing between November and March, while the Southwest Monsoon brings rain from May to September (Phang 1998). Mangrove swamps dominate the west coast Peninsular Malaysia which is sheltered by Sumatra, Indonesia. On the east coast, rocky shores of post-Triassic granite are found in the north and Triassic quartzite and shale towards the south. Sandy and rocky beaches with coral reefs characterise the coastlines of Sabah and Sarawak. The salinity of Malaysian waters range between 28 and 34 ppt, while surface water temperature range between 27 and 29°C. Semi-diurnal tides occur on the west coast Peninsular Malaysia, while the east coast has a mixed tidal system. Mixed tidal regimes occur in Sabah and Sarawak.

SURVEY AND DOCUMENTATION OF SEAWEED RESOURCES IN MALAYSIA

The early records of seaweeds in the Southeast Asian region were contributed through the *Preussische Expedition nach Ost-Asien* (1860–1863) (Martens, 1866) and the Siboga Expedition (1899 – 1900) (Gepp & Gepp, 1911). Teo & Wee (1983) published the first guide to the seaweeds of Singapore. Seaweed research in Malaysia started in the 1980's when Phang (1984) published the first account of the seaweed resources of Malaysia. Using sources of information like Burkill's (1966) 'A Dictionary of the Economic Products of the Malay Peninsula' and publications without verification from deposited specimens, a list of Malaysian seaweeds and their uses was compiled. In 1991, Phang and Wee published the first checklist of the marine benthic algae in Malaysia together with a historical account of the study of marine algae in this region (Phang & Wee 1991). In 1998, Phang updated the checklist of Malaysian marine algae including additions from Phang (1994a, b, 1995) and a new species *Sargassum stolonifolium* described from Penang, west coast Peninsular Malaysia (Phang & Yoshida 1997). This checklist was published as part of the chapter on the seaweed resources of Malaysia in the 'Seaweed Resources of the World' (Critchley & Ohno 1998). Two hundred and sixty specific and infraspecific taxa (17 Cyanophyta, 92 Chlorophyta, 94 Rhodophyta and 57 Phaeophyta) were recorded (Phang 1998). Rhodophyta dominated as is expected of tropical seaweed flora. As we move towards the tropics, the ratio of red to brown seaweeds increases (Feldmann 1937). Many of the red algae are filamentous comprising mainly epiphytic species. These two checklists comprise many species that were reported in literature but were not verified due to absence of deposited material.

A survey conducted from 1995 to1999 by the University of Malaya in collaboration with Hokkaido University, Japan, resulted in many additions to the checklist and confirmation of some taxa, especially of the Rhodophyta. Thirty-eight new records (Kawaguchi *et al*. 2002, Masuda *et al.* 1997, 1999, 2000a, 2000b, 2001a, 2001b, 2002, 2003; Tani & Masuda 2003, Tani *et al.* 2003, Terada *et al*. 2000, Yamagishi *et al.* 2003), including one new species *Lomentaria gracillima* Masuda *et* Kogame were added to the checklist. Further additions included taxa previously recorded by Zanardini (1872), 35 species of Rhodophyta, 13 species of Phaeophyta and 16 species of Chlorophyta recorded by Ahmad Ismail (1995), Ajisaka (2002), Ajisaka *et al.* (1999) and Lim *et al.* (2001). In 2004, two new records of *Gracilaria*, *Gracilaria articulata* and *G. manilaensis* (Lim & Phang 2004) and 13 new records of *Sargassum* (Wong & Phang 2004), were published. Two expeditions to the northeast Langkawi resulted in a checklist for Langkawi Islands with 84 taxa identified (Phang *et al.* 2005). The seaweed flora of Langkawi is quite distinct from that of Peninsular Malaysia and East Malaysia. At the species level, the Sorenson's Coefficient of Similarity (S) between flora of Langkawi and west coast Peninsula Malaysia is 35.21%, although at the genus level, the S= 66.22%. The tally of Malaysian marine algae now stands at 388 specific and infraspecific taxa (17 taxa of Cyanophyta, 102 Chlorophyta, 182 Rhodophyta and 87 Phaeophyta) (Phang 2006). Table 1 gives the checklist of Malaysian marine algae. Most of the specimens are deposited at the Seaweeds and Seagrasses Herbarium established at the Institute of Biological Sciences, Faculty of Science, University of Malaya, which presently houses more than 7000 numbers of herbarium specimens collected from Malaysia, and the Herbarium of the Graduate School of Science, Hokkaido University, Japan.

Of the marine blue-green algae or Cyanophyta, species of *Oscillatoria* and *Lyngbya* dominate the mudflats while *Brachytrichia* grow abundantly over intertidal rocks and the sandy seabed. The Chlorophyta consists of the second highest number of taxa in Malaysian waters. Twelve species of *Caulerpa* have been recorded, mainly in coral reefs. Recent collections indicate that eight of these, namely *C. lentillifera*, *C. peltata, C. racemosa, C. scalpelliformis, C. serrulata, C. sertulariodes*, *C. taxifolia* and *C. verticillata* are still commonly found. The coral reefs are also dominated by species of *Halimeda* (*H. discoidea, H. opuntia, H. tuna*), the erect coralline algae which contribute towards reef building with the calcium carbonate retained in their cell walls. Several species of *Enteromorpha* and *Ulva* are found in the nutrient-rich shores and mudflats. *Enteromorpha intestinalis*, *E. chlathrata*, *Ulva lactuca* and *U. fasciata* are commonly seen covering small rocks, stones, driftwood and sandy patches along beaches. Many of these species are eaten by the coastal communities of the region.

The red seaweeds or Rhodophyta comprise the highest number of taxa. Species of *Halymenia* dominate the subtidal bedrock areas, while *Laurencia* and *Hypnea* species inhabit the bedrocks at the intertidal regions. These grow mainly in the cleaner deep waters. Four species of *Eucheuma* and two species of *Kappaphycus*, sources of carrageenan, have been collected from lower intertidal to upper sub-tidal areas in Sabah and around islands in Peninsular Malaysia. Except for the cultivated *Kappaphycus*, many of the *Eucheuma* species seem to have disappeared from Peninsular Malaysia. Twenty-two species of the agarophytic genus *Gracilaria* have been reported, many of which inhabit mangroves, sandy-mudflats and rocky shores. Erect coralline (*Amphiroa, Jania*) as well as crustose coralline (*Lithothamnion, Peyssonnelia*) Rhodophytes are commonly found in the coral reefs especially in the cleaner deep waters around the islands. In the mangroves small tufted thalli of *Bostrychia, Laurencia microcladia, Caloglossa adnata, Catenella* grow commonly with the green filaments of *Chaetomorpha linum* and *Cladophora*. Common epiphytic taxa include *Champia parvula, Centroceras, Ceramium, Spyridia, Polysiphonia*, *Heterosiphonia*, *Herposiphonia* and *Tolypiocladia glomerulata* (Phang 1989). Thirty-eight new records including one new species, were reported from the Malaysian-Japanese collaboration from 1995.

The brown seaweeds or Phaeophyta contribute high algal biomass (Phang & Maheswary 1989) on reefs. While *Sargassum* and *Dictyota* dominate in terms of species number, *Padina* are the most frequently found species. They inhabit a variety of substratum including mangroves,

Table 1. Checklist of Malaysian Marine Algae

TAXA	DISTRIBUTION	HABITAT
Division Cyanophyta		
Order Chroococcales		
Family Microcystaceae		
Merismopedia thermalis Kutzing [Syn: *Agmenellum thermale* (Kutzing) Drouet & Daily]	Sn	M
Microcystis zanardii (Hauck) P. Silva comb. nov [Syn: *Anacystis aeruginosa* (Zanardini) Drouet & Daily]	Sn	R, E
Family Entophysalidaceae		
Entophysalis Kutzing	Sn	Mg
Order Oscillatoriales		
Family Nostocaceae		
Anabaena licheniformis Bory de Saint-Vincent	Sn	E
Calothrix C. Agardh	E	R
Calothrix crustacea Schousboe & Thuret	W	C
Nostoc commune Vaucher	Sn	R, P
Family Scytonemataceae		
Scytonema hofman-bangii C. Agardh [*Scytonema hofmannii* C. Agardh nom. illeg.]	Sn	P
Family Oscillatoriaceae		
Lyngbya majuscula (Dillwyn) Harvey	W	M
Oscillatoria lutea C. Agardh	Sn	E
Family Phormidiaceae		
Pelagothrix clevei J. Schmidt	W	R
Spirulina subsalsa (Oersted)		
Family Schizotrichaceae		
Schizothrix arenaria (Berkeley) Gomont	Sn	E
Schizothrix calcicola (C. Agardh) Gomont	Sn	S, M
Schizothrix mexicana Gomont	Sn	R, C, S, M, E

Order Stigonematales		
Family Mastigocladaceae		
Brachytrichia quoyi (C. Agardh) Bornet & Flahault	W	R, C
Mastigocladus Cohn	Sn	Mg

Division Chlorophyta

Order Ulvales		
Family Ulvaceae		
Enteromorpha clathrata (Roth) Greville	E, Sn	C, R, M, E
Enteromorpha compressa (Linnaeus) Nees	W	-
Enteromorpha flexuosa (Wulfen) J. Agardh	W	-
Enteromorpha flexuosa (Wulfen) J. Agardh subsp. *flexuosa* [Syn: *Enteromorpha prolifera* (O.F. Muller) J. Agardh var. *tubulosa (*Kutzing)]	P	-
Enteromorpha flexuosa (Wulfen) J. Agardh subsp. *flexuosa* [Syn: *Enteromorpha tubulosa* (Kutzing) Kutzing]	Sn	R
Enteromorpha flexuosa (Wulfen) J. Agardh subsp. *paradoxa* (C. Agardh) Blidin	Sn	S
Enteromorpha intestinalis (Linnaeus) Nees	W, E, P	R, S
Enteromorpha ovata Thivy & Visalaksmi *ex* H. Joshi & V. Krishnamurthy	Sn	W
Ulva beytensis Thivy & Sharma	Sn	C
Ulva conglobata Kjellman	W	R
Ulva fasciata Delile	E, Sb, Sn	E, D, M, S
Ulva lactuca Linnaeus	W, Sn	D
Ulva latissima Linnaeus	P	-
Ulva pertusa Kjellman	P, Sn	D
Ulva reticulata Forsskaal	P, W, Sn	D
Family Sphaeropleaceae		
Sphaeroplea C. Agardh	Sn	M, S
Order Cladophorales		
Family Anadyomenaceae		
Anadyomene plicata C. Agardh	W, E, Sk	R, C, S
Anadyomene stellata (Wulfen) C. Agardh	Sb	-

Family Siphonocladaceae		
Boergesenia forbesii (Harvey) J. Feldmann	E	C, E, R
Boodlea coacta (Dickie) G. Murray & De Toni	E	S
Boodlea composita (Harvey) Brand [Syn: *Cladophora composita* Harvey]	W, E	-
Boodlea montagnei (Harvey *ex* J. Gray) Egerod [Syn: *Microdictyon montagnei* Harvey *ex* J. Gray]	W, Sn	C, E
Boodlea struveoides Howe	E	-
Cladophoropsis herpestica (Montagne) Howe	W	-
Cladophoropsis javanica (Kutzing) P. Silva comb. nov. [*Cladophoropsis zollingeri* (Kutzing) Reinbold]	Sn	C
Cladophoropsis membranaceae (Hofman Bang *ex* C. Agardh) Børgesen	E, Sn	E, M
Cladophoropsis sundanensis Reinbold	W, Sn	R
Dictyosphaeria cavernosa (Forsskal) Bøergesen [Syn: *Dictyosphaeria favulosa* (C. Agardh) Decaisne *ex* Endlicher]	W, E, Sn	C, R
Struvea anastomosans (Harvey) Piccone et Grunow ex Piccone [Syn: *Struvea deliculata* Kutzing]	W, E	C, E, R
Struvea ramosa Dickie	E	C, R
Family Valoniaceae		
Valonia aegagropila C. Agardh	W, E	C, R
Valonia fastigiata Harvey *ex* J. Agardh	W, P	R
Valonia utricularis (Roth) C. Agardh	W, E	C, R
Valoniopsis pachynema (G. Martens) Børgesen	W	R
Family Cladophoraceae		
Chaetomorpha aerea (Dillwyn) Kutzing	E	-
Chaetomorpha antennina (Bory de Saint-Vincent) Kutzing	W	R
Chaetomorpha crassa (C. Agardh) Kutzing	Sn	M
Chaetomorpha gracilis Kutzing	Sn	M
Chaetomorpha gracilis Kutzing [Syn: *Lola gracilis* (Kutzing) V. Chapman]	Sn	Mg
Chaetomorpha linum (O.F. Muller) Kutzing	W, E, Sn	C, E, M, R, S
Chaetomorpha minima Collins & Hervey	W, E	E
Chaetomorpha spiralis Okamura	W	-
Cladophora catenata (Linnaeus) Kutzing	E	C, E, R
Cladophora coelothrix Kutzing [Syn: *Cladophora repens* Harvey]	E	-
Cladophora forsskali (Kutzing) Bornet ex De Toni [Syn: *Siphonocladus forsskalii* (Kutzing) Bornet *ex* De Toni]	Sk	-

Cladophora inserta Dickie forma *inserta* [Syn: *Cladophora inserta* Dickie]	W	S
Cladophora patentiramea (Montagne) Kutzing	Sn	M
Cladophora prolifera (Roth) Kutzing	W	S
Cladophora prolifera (Roth) Kutzing [Syn: *Cladophora rugolosa* G. Martens]	W	S
Cladophora sericea (Hudson) Kutzing [Syn: *Cladophora nitida* Kutzing]	Sn	Mg
Cladophora stimpsonii Harvey	E	C
Cladophora vagabunda (Linnaeus) van den Hoek	E	E
Cladophora vagabunda (Linnaeus) van den Hoek [Syn: *Cladophora fascicularis* (Mertens *ex* C. Agardh) Kutzing]	W	C, R
Cladophora vagabunda (Linnaeus) van den Hoek [Syn: *Cladophora mauritiana* Kutzing]	Sn	E
Cladophoropsis javanica (Kutzing) P. Silva, comb. nov. [*Rhizoclonium grande* Børgesen]	W, Sn	R
Rhizoclonium hookeri Kutzing [Syn: *Rhizoclonium africanum* Kutzing]	E	-
Ventricaria ventricosa (J. Agardh) Olsen & J. West [*Valonia ventricosa* J. Agardh]	E, P	C
Order Bryopsidales		
Family Bryopsidaceae		
Bryopsis corymbosa J. Agardh	W, E, Sn	C, E, R
Bryopsis hypnoides Lamouroux	E	F
Bryopsis indica A.Gepp & E. Gepp	E, Sn	C, E
Bryopsis pennata Lamouroux	W, E	C, R
Bryopsis pennata Lamouroux var. *leprieurii* (Kutzing) Collins & Harvey	Sn	C, R, E
Bryopsis pennata Lamouroux var. *secunda* (Harvey) Collins & Hervey	Sn	C, R
Bryopsis plumosa (Hudson) C. Agardh	E, Sn	C, R
Derbesia fastigiata W. R. Taylor	Sn	Mg
Derbesia prolifica W. R. Taylor	E	C
Family Caulerpaceae		
Caulerpa fergusonii G. Murray	W	R
Caulerpa lentillifera J. Agardh	W, E, Sb, P, Sn	C, D, M, R, S
Caulerpa mexicana Sonder ex Kutzing [Syn: *Caulerpa crassifolia* (C. Agardh) J. Agardh]	P	-
Caulerpa microphysa (Weber van Bosse) J. Feldmann	W, E	R
Caulerpa peltata Lamouroux	W, E, Sn	C, R, S
Caulerpa peltata Lamouroux [Syn: *Caulerpa racemosa* (Forsskaal) J. Agardh var. *clavifera* (Turner) Weber-van Bosse]	P, Sn	C

Caulerpa peltata Lamouroux [Syn: *Caulerpa racemosa* (Forsskaal) J. Agardh var. *peltata* (Lamouroux) Eubank]	E	C
Caulerpa prolifera (Forsskaal) Lamouroux forma *zosterifolium* Børgesen	W	C
Caulerpa racemosa (Forsskaal) J. Agardh	W, E, Sb, Sn	C, M, S
Caulerpa racemosa (Forsskaal) J. Agardh var. *laetevirens* (Montagne) Weber-van Bosse	W	R
Caulerpa racemosa (Forsskaal) J. Agardh var. *macrophysa* (Sonder ex Kutzing) W. R. Taylor	W, E	R, S
Caulerpa racemosa (Forsskaal) J. Agardh var. *turbinata* (J. Agardh) Eubank	Sn	C
Caulerpa racemosa (Forsskaal) J. Agardh var. *turbinata* (J. Agardh) Eubank [Syn: *Caulerpa chemnitzia* (Esper) Lamouroux]	P	-
Caulerpa scalpelliformis (R. Brown ex Turner) C. Agardh	P	-
Caulerpa serrulata (Forsskaal) J. Agardh	W, E, Sb, Sn	C
Caulerpa serrulata (Forsskaal) J. Agardh var. *pectinata* Kutzing	W	R, S
Caulerpa sertulariodes (S. Gmelin) Howe	W, Sb, Sn	C, D, S
Caulerpa sertulariodes(S. Gmelin) Howe forma *longiseta* (Bory de Saint-Vincent) Svedelius	W	S
Caulerpa taxifolia (Vahl) C. Agardh	W, E, P, Sb, Sn	C, D, R
Caulerpa verticillata J. Agardh	W, E, Sb, Sn	C, R, E
Family Codiaceae		
Codium arabicum Kutzing	W, Sn	D
Codium geppiorum O. Schmidt	W, E, Sn	C, E, S
Codium tomentosum Stackhouse	E, P	C, R
Family Halimedaceae		
Halimeda discoidea Decaisne	Sb	R, S
Halimeda macroloba Decaisne	W, E	C, S
Halimeda opuntia (Linnaeus) Lamouroux	W, E, Sb, Sn	C, S
Halimeda opuntia (Linnaeus) Lamouroux var. *minor* Vickers	E	C, S
Halimeda simulans Howe	W, E	S
Halimeda tuna (Ellis & Solander) Lamouroux	W, E, Sb, Sn	C, S
Family Udoteaceae		
Avrainvillea erecta (Berkeley) A. Gepp & E. Gepp	W, E, Sn	C, E, S
Avrainvillea longicaulis (Kutzing) G. Murray & Boodle	W, E	C
Avrainvillea obscura (C. Agardh) J. Agardh	E	C, S

Tydemannia expeditionis Weber-van Bosse	E	R, S
Udotea argentea Zanardini var. *spumosa* A. Gepp & E. Gepp	W	C, S
Udotea cyathiformis Decaisne (Syn.: *Udotea sublittoralis* Taylor)	E	-
Udotea flabellum (Ellis & Solander) Howe	W	S
Rhipidosiphon javensis Montagne [Syn: *Udotea javensis* (Montagne) A. Gepp & E.Gepp]	W, E, Sn	C, S
Order Dasycladales		
Family Dasycladaceae		
Bornetella Munier-Chalmas	Sn	C
Neomeris annulata Dickie	P, E, Sn	C, R
Family Polyphysaceae		
Acetabularia acetabulum (Linnaeus) P. Silva [*Acetabularia mediterranea* Lamouroux nom. illeg.]	P	-
Acetabularia crenulata Lamouroux	Sb	-
Acetabularia major G. Martens	P	-
Acetabularia parvula Solms-Laubach	E	C
Acetabularia pusilla (Howe) Collins	E	-
Division Rhodophyta		
Order Erythropeltidales		
Family Erythrotrichiaceae		
Erythrotrichia carnea (Dillwyn) J. Agardh	Sn	E
Order Acrochaetiales		
Family Acrochaetiaceae		
Acrochaetium Nageli	E	C
Order Nemaliales		
Family Galaxauraceae		
Galaxaura rugosa (Ellis & Solander) Lamouroux [Syn: *Galaxaura squalida* Kjellman]	Sb	-
Tricleocarpa cylindrica (Ellis & Solander) Huisman & Borowitzka [Syn: *Galaxaura cylindrica* (Ellis & Solander) Lamouroux]	Sb	-

Family Liagoraceae		
Liagora ceranoides Lamouroux [Syn: *Liagora leprosa* J. Agardh]	E	-
Order Gelidiales		
Family Gelidiaceae		
Gelidium amansii Lamouroux	W	R
Gelidium pusillum (Stackhouse) Le Jolis	W	R
Gelidium spinosum (S. Gmelin) P. Silva, comb nov. [Syn: *Gelidium latifolium* Bornet ex Hauck]	P	-
Pterocladia caerulescens (Kutzing) Santelices	W	C, S
Pterocladia caloglossoides (Howe) Dawson [Syn: *Pterocladia parva* Dawson]	E	C, R
Family Gelidiellaceae		
Gelidiella acerosa (Forsskal) J. Feldmann & G. Hamel [Syn: *Gelidiopsis rigida* (C. Agardh) Weber-van Bosse]	E, P	C, R
Gelidiella lubria (Kutzing) J. Feldmann & G. Hamel [Syn: *Gelidiella bornetii* (Weber van Bosse) J. Feldmann & G. Hamel]		
*Gelidiella pannosa (*Feldmann) Feldmann et G. Hamel	W	R
Order Gracilariales		
Family Gracilariaceae		
Gracilaria articulata Chang et Xia	P	M
Gracilaria canaliculata Sonder	P	C, M, S
Gracilaria blodgetti Harvey [Syn: *Gracilaria cylindrica* Børgesen]	W	M
Gracilaria cacalia (J. Agardh) Dawson	Sn	C
Gracilaria changii (Xia et Abbott) Abbott, Zhang et Xia	W, E	Mg, M, R, S
Gracilaria coronopifolia J. Agardh	W, E, Sn	C, M
Gracilaria crassa Harvey ex J. Agardh	Sb, Sn	D
Gracilaria dura (C. Agardh) J. Agardh	Sb	-
Gracilaria edulis (G. Gmelin) P. Silva	W	R, S, M
Gracilaria edulis (S. Gmelin) P. Silva [*Gracilaria lichenoides* Greville nom. illeg.]	W, Sk, Sn	R
Gracilaria eucheumoides Harvey	P	-
Gracilaria firma Chang et Xia	W, Sb	R
Gracilaria foliifera (Forskaal) Børgesen	W	R
Gracilaria lichenoides Greville forma *taenoides* (J. Agardh) V. Hay [Syn: *Gracilaria taenoides* J. Agardh]	P	-

Gracilaria manilaensis Yamamoto et Trono	P, W	M
Gracilaria minor (Sonder) Durairatnam	P	-
Gracilaria multifurcata Børgesen	W	C, R
Gracilaria salicornia (C. Agardh) Dawson	W, E, Sb	Mg, M, R, S
Gracilaria subtilis (Xia et Abbott) Xia et Abbott	W	S, M
Gracilaria tenuistipitata Zhang et Xia	W	R
Gracilaria textorii (Suringar) De Toni	W	R
Gracilaria urvillei (Montagne) Abbott, Zhang et Xia	W, Sb, Sn	S, M
Gracilaria verrucosa (Hudson) Papenfuss [*Gracilaria confervoides* Greville nom. illeg.]	P, Sb	-
Gracilariopsis bailiniae Zhang et Xia	W, Sb	R
Order Bonnemaisoniales		
Family Pterocladiophilaceae		
Asparagopsis taxiformis (Delile) Trevisan	E	R, C, S
Family Halymeniaceae		
Cryptonemia crenulata (J. Agardh) J. Agardh	Sb	R
Cryptonemia yendoi Weber van Bosse	W	R
Grateloupia filicina (Lamouroux) C. Agardh	W, Sb	R, F
Halymenia dilatata Zanardini	E, Sb	C, R
Halymenia durvillei Bory de Saint-Vincent	W, E, Sb, P	C, R
Halymenia floresia (Clemente y Rubio) C. Agardh	E, Sn	C, R, S
Halymenia formosa Harvey ex Kutzing	E, Sn	C
Halymenia maculata J. Agardh	W, E, Sb, Sk	C, R
Halymenia microcarpa (Montagne) P. Silva [Syn: *Halymenia durvillei* Bory de Saint-Vincent var. *ceylanica* Kutzing (Harvey ex Kutzing)]	Sn	C
Family Kallymeniaceae		
Callophyllis heanophylla Setchell	E	R
Family Peyssonneliaceae		
Peyssonnelia inamoena Pilger	E	C, F
Family Rhizophyllidaceae		
Portieria hornemannii (Lyngbye) P. Silva	E	C

Order Hildenbrandiales		
Family Hildenbrandiaceae		
Hildenbrandia rubra (Sommerfelt) Meneghini	W	R
Order Corallinales		
Family Corallinaceae		
Amphiroa anceps (Lamarck) Decaisne	E	C, R
Amphiroa foliaceae Lamouroux	W, E, Sb	C, R
Amphiroa fragilissima (Linnaeus) Lamouroux	W, E, Sb, P, Sn	E
Amphiroa rigida Lamouroux	W, E, Sn	C, E, R
Amphiroa tribulus (Ellis et Solander) Lamouroux	E, Sb	-
Corallina Linnaeus	W, Sb	-
Fosliella dispar Foslie	E	-
Jania adhaerens Lamouroux	E	-
Jania capillacea Harvey	E	-
Jania decussate-dichotoma (Yendo) Yendo	E	C
Jania rubens (Linnaeus) Lamouroux	W, Sb	E
Melobesia membranacea (Esper) Lamouroux	Sk, P	E
Mesophyllum erubescens (Foslie) Lemoine [*Lithothamnion erubescens* Foslie]	W	R
Mesophyllum simulans (Foslie) Lemoine [*Lithothamnion simulans* (Foslie) Foslie]	W	R
Family Caulacanthaceae		
Catenella impudica (Montagne) J. Agardh	Sn	Mg
Catenella nipae Zanardini	W, Sk, Sn	Mg
Caulacanthus ustulatus (Turner) Kutzing	W, Sk	R
Order Gigartinales		
Family Gigartinaceae		
Chondracanthus acicularis (Roth) Fredericq [*Gigartina acicularis* (Roth) Lamouroux]	W	C
Chondracanthus intermedius (Suringar) Hommersand	W	R
Family Hypneaceae		
Hypnea charoides Lamouroux	W	R
Hypnea cenomyce J. Agardh	Borneo	-

Hypnea cornuta (Kutzing) J. Agardh	W	S, M
Hypnea esperi Grunow	Sn	C, E
Hypnea flexicaulis Yamagishi et Masuda	Sb	E
Hypnea musciformis (Wulfen) Lamouroux	P	-
Hypnea pannosa J. Agardh	W, E	C, R
Hypnea spinella (C. Agardh) Kutzing	E, Sn	C, E, R
Hypnea spinella (C. Agardh) Kutzing [Syn: *Hypnea cervicornis* J. Agardh]	E, Sb, Sn	C
Hypnea stellulifera (J. Agardh) Yamagishi et Masuda	W, Sb	F, M, R
Family Sarcodiaceae		
Sarcodia J. Agardh	W	R
Family Schizymeniaceae		
Titanophora (J. Agardh) J. Feldmann	W	C
Family Solieriaceae		
Agardhiella subulata (C. Agardh) Kraft & Wynne [Syn: *Agardhiella tenera* (J. Agardh) Schmitz]	P	-
Eucheuma serra (J. Agardh) J. Agardh	P	-
Eucheuma arnoldii Weber van-Bosse [Syn: *Eucheuma cuppressoideum* Weber-van Bosse]	P, Sn	-
Eucheuma denticulatum (Burman) Collins & Harvey [Syn: *Eucheuma muricatum* (S. Gmelin) Weber-van Bosse]	P	-
Eucheuma denticulatum (Burman) Collins & Harvey [Syn: *Eucheuma spinosum* J. Agardh]	P	-
Eucheuma horridum J. Agardh	P	-
Kappaphycus alvarezii (Doty) Doty ex P. Silva, comb. nov	Sb	S
Kappaphycus cottonii (Weber-van Bosse) Doty ex P. Silva	Sb	C, R
Solieria anastomosa P. Gabrielson et Kraft	Sb	C, R
Solieria robusta Greville (Kylin)	Sn	-
Order Rhodymeniales		
Family Champiaceae		
Champia compressa Harvey	E	C, F, R
Champia parvula (C. Agardh) Harvey	W, E	E
Champia vieillardii Kutzing	E	C
Gastroclonium compressum (Hollenberg) Chang & Xia	E	-

Family Lomentariaceae		
Lomentaria gracillima Masuda et Kogame	Sb	E
Lomentaria monochlamydea (J. Agardh) Kylin	E	C
Family Rhodymeniaceae		
Botryocladia leptopoda (J. Agardh) Kylin	W	Mn, C, S
Ceratodictyon spongiosum Zanardini	W, Sb	C, R
Chamaebotrys boergesenii (Weber-van Bosse) Huisman	E	C, E
Chrysymenia J. Agardh	Sb	-
Coelarthrum Børgesen	Sb	R
Gelidiopsis intricata (C. Agardh) Vickers	E	C
Order Ceramiales		
Family Ceramiaceae		
Anotrichium tenue (C. Agardh) Nageli (Syn: *Griffithsia tenuis* C. Agardh)	W, E, Sb	C, E, R
Antithamnionella elegans (Berthold) J. Price & D. John [Syn: *Antithamnionella breviramosa* (Dawson) Wallaston in Wolmsley & Bailey]	E	E
Callithamnion fellipponei Howe	E	-
Centroceras clavulatum(C. Agardh) Montagne	Sb	-
Centroceras minutum Yamada	E	C
Ceramium corniculatum Montagne	E	-
Ceramium diaphanum (Lightfoot) Roth [*Ceramium tenuissimum* (Roth) Areschoug nom. illeg.]	W, E	E
Ceramium fimbriatum Setchell & Gardner [Syn: *Ceramium gracillimum* (Kutzing) Griffiths & Harvey]	E	E
Ceramium flaccidum (Kutzing) Ardissone	E	E
Corrallophila huysmansii (Weber-van Bosse) R. Norris [Syn: *Ceramium huysmansii* Weber-van Bosse]	Sn	R
Griffithsia schousboei Montagne	W	E, R
Ptilothamnion codicolum (Dawson) Abbott	E	E
Spyridia filamentosa (Wulfen) Harvey	W, E	C, E, R, S,
Wrangelia argus (Monatgne) Montagne	E	E
Wrangelia bicuspidata Børgesen	W, E	Mn, C, S
Family Dasyaceae		
Dasya iyengarii Børgesen	W, E, Sb, Sk	E, F
Dasya longifila Masuda et Uwai	Sb	E
Dasya malaccensis Masuda et Uwai	W	F

Dasya pilosa (Weber-van Bosse) Millar	E, Sb	R
Heterosiphonia crispella (C. Agardh) Wynne	W, E, Sb, Sk	E, F
Heterosiphonia Montagne	W	E
Family Delesseriaceae		
Caloglossa adhaerens King & Puttock [Syn: *Caloglossa adnata* (Zanardini) De Toni]	Sk	-
Delesseria adnata Zanardini [Syn: *Caloglossa bengalensis* (Martens) King & Pullock]	Sk	-
Delesseria beccarii Zanardini [Syn: *Caloglossa beccarii* (Zanardini) De Toni]	Sk	-
Hypoglossum caloglossoides Wynne et Kraft	E	C, E
Hypoglossum rhizophorum Ballantine et Wynne	E	C
Hypoglossum simulans Wynne, I. Price & Ballantine	W	C
Martensia australis Harvey	Sb	E, R
Martensia fragilis Harvey	W, E	C, E, R
Taenioma dotyi Hollenberg	W	R
Taenioma perpusillum (J. Agardh) J. Agardh	Sb, Sk	E
Zellera tawallina Martens	Sb	R
Family Rhodomelaceae		
Acanthophora muscoides (Linnaeus) Bory de Saint-Vincent	Sn	C
Acanthophora spicifera (Vahl) Børgesen	W, E, Sn, P	C, D, R, S
Acanthophora spicifera (Vahl) Børgesen [Syn: *Acanthophora orientalis* J. Agardh]	W, Sn	C, E
Acanthophora spicifera (Vahl) Børgesen [Syn: *Acanthophora thierryi* Lamouroux]	Sk	-
Amansia rhodantha (Harvey) J. Agardh	Sb	R
Bostrychia moritziana (Sonder ex Kutzing) J.Agardh	Sn	Mg
Bostrychia tenella (Lamouroux) J. Agardh	W	Mg
Bostrychia tenella (Lamouroux) J. Agardh [Syn: *Bostrychia binderi* Harvey]	Sn	R
Chondria armata (Kutzing) Okamura	E, P	R
Chondria decidua Tani et Masuda	Sb	E
Chondria econstricta Tani & Masuda	Sb	E
Chondria xishaensis Zhang (Chang) & Xia	Sb	E
Herposiphonia pacifica Hollenberg	W, E	F, R
Herposiphonia secunda (C. Agardh) Ambronn	E	-
Herposiphonia vietnamica Pham	Sb	E
Laurencia articulata Tseng	E	C, R
Laurencia botryoides (C. Agardh) Gaillon	P	-

Laurencia caduciramulosa Masuda et Kawaguchi	E	R
Laurencia calliclada Masuda	E	R
Laurencia concreta Crib	W, Sb	C
Laurencia corymbosa J. Agardh	W, E	C, R
Laurencia decumbens Kutzing [Syn: *Laurencia pygmaea* Weber-van Bosse]	W	R
Laurencia flexilis Setchell	Sk	R
Laurencia glandulifera (Kutzing) Kutzing	W	R
Laurencia implicata J. Agardh	E	-
Laurencia intricata Lamouroux	W, E	-
Laurencia lageniformis Masuda	Sb, Sk	R
Laurencia majuscula (Harvey) Lucas	E, Sb, Sk	C, R
Laurencia microcladia Kutzing	Sn	Mg
Laurencia nangii Masuda	Sb	C, E
Laurencia obtusa (Hudson) Lamouroux	W	C
Laurencia pannosa Zanardini	Sk	-
Laurencia papillosa (C. Agardh) Greville, Setchell et Gardner	W, E, Sb, Sk	C, R, S
Laurencia parvipapillata Tseng	E	C
Laurencia perforata (Bory de Saint-Vincent) Montagne	E	C
Laurencia pinnata Yamada	W	R
Laurencia similis Nam et Saito	Sb	C, R
Leveillea junggermanniodes (Herling & G. Martens) Harvey	W, Sn	E, C
Murrayellopsis dawsonii Post	E	R
Neosiphonia apiculata (Hollenberg) Masuda et Kogame	E, Sb	E
Neosiphonia flaccidissima (Hollenberg) M.S.Kim et I.K.Lee	W	E
Neosiphonia savatieri (Hariot) M.S.Kim et I.K.Lee	E, Sb	E
Polysiphonia coacta Tseng	E	C, R
Polysiphonia decussata Hollenberg	E	E
Polysiphonia ferulaceae Suhr ex J. Agardh	Sn	E
Polysiphonia fucoides (Hudson) Greville [Syn: *Polysiphonia nigrescens* (Hudson) Greville in W. Hooker]	W, E	E, R
Polysiphonia platycarpa Børgesen	Sn	E
Polysiphonia scopulorum Harvey	W, E	C, E, F, R
Polysiphonia subtillisima Montagne	E	E, C
Polysiphonia violaceae Greville	E	E, R
Tolypiocladia calodictyon (Harvey ex Kutzing) P. Silva	E	E
Tolypiocladia glomerulata (C. Agardh) Schmitz	W, E	E

Division Phaeophyta		
Order Ectocarpales		
Family Ectocarpaceae		
Ectocarpus siliculosus (Dillwyn) Lyngbye [Misapplied name: *Ectocarpus confervoides* (Roth) Le Jolis]	W	-
Ectocarpus variabilis Vickers	W	-
Feldmannia enhali Hamel	W, E	E
Feldmannia indica (Sonder) Wolmsley & Bailey	W, E	D, E
Feldmannia simplex (Crouan & Crouan) Hamel [Syn.: *Ectocarpus cylindricus* Saunders]	E	-
Family Ralfsiaceae		
Ralfsia Berkeley	Sb	-
Order Sphacelariales		
Family Sphacelariaceae		
Sphacelaria caespitula Lyngbye	Sk, Sn	-
Sphacelaria rigidula Kutzing [Syn: *Sphacelaria furcigera* Kutzing]	W, Sb	R
Order Dictyotales		
Family Dictyoceae		
Dictyopteris acrostichoides (J. Agardh) Bornet	W	C, S
Dictyopteris deliculata Lamouroux	E	E
Dictyopteris woodwardia (R. Brown ex Turner) [Syn: *Haliseris woodwardia* (R. Brown ex Turner) C. Agardh]	Sk	-
Dictyota bartayresiana Lamouroux	W, E, Sn	C, R
Dictyota beccariana Zanardini	Sk, P	-
Dictyota cervicornis Kutzing	Sn	M
Dictyota cervicornis Kutzing [Syn: *Dictyota indica* Sonder ex Kutzing]	E, Sn	C
Dictyota cervicornis Kutzing [Syn: *Dictyota pardalis* Kutzing]	P	-
Dictyota cervicornis Kutzing forma *spiralis* Taylor	E	R
Dictyota ciliolata Kutzing	Sn	C
Dictyota dentata Lamouroux	Sb	-
Dictyota dichotoma (Hudson) Lamouroux	W, E, P, Sb, Sk	R
Dictyota dichotoma (Hudson) Lamouroux [Syn: *Dictyota apiculata* J. Agardh]	P	-
Dictyota divaricata Lamouroux	E	-
Dictyota friabilis Setchell	W, E	C, Mn, M, R

Dictyota hauckiana Nizamuddin [Syn: *Dictyota atomaria* Hauck]	Sb	-
Dictyota jamaicensis Taylor	E	S
Dictyota linearis (C. Agardh) Greville	W	-
Dictyota maxima Zanardini	Sk	-
Dictyota mertensii (Martius) Kutzing [Syn: *D. dentata* Lamouroux]	E	S
Dictyota submaritima Va Pham Hoang	E	R
*Lobophora variegata (*Lamouroux) Wolmsley ex Oliveira (Syn.: *Pocockiella variegata* (Lamouroux) Papenfuss)	W, E, Sb	C, S
Padina australis Hauck	W, E	C, R
Padina boergesenii Allender & Kraft	W, E	C
Padina boryana Thivy [Syn: *P. commersonii Bory de Saint-Vincent]*	W, E, Sn	R, C
Padina caulescens Thivy	E	-
Padina gymnospora (Kutzing) Sonder	Sb, Sn	C, S
Padina minor Yamada	E	C, S
Padina pavonia Lamouroux	Sk	-
Padina tetrastromatica Hauck	W, E, Sn	C, R
Spatoglossum vietnamense Pham	Sb	C
Stypopodium zonale (Lamouroux) Papenfuss	Sn	C
Order Scytosiphonales		
Family Chnoosporaceae		
Chnoospora minima (Hering) Papenfuss	W	R
Family Scytosiphonaceae		
Colpomenia sinuosa (Mertens ex Roth) Derbes & Solier	W, Sb	E, R
Hydroclathrus clathratus (C. Agardh) Howe [Syn: *Asperococcus clathratus* (C. Agardh) J. Agardh]	W, P, Sb	C, S
Rosenvingea fastigiata (Zanardini) Børgesen [Syn.: *Asperococcus fastigiatus* Zanardini]	Sk	-
Rosenvingea orientalis (J. Agardh) Børgesen	W	C, S
Order Fucales		
Family Cystoseiraceae		
Cystoseira trinodis (Forsskal) C. Agardh	E	C, R
Hormophysa cuneiformis (J. Gmelin) P. Silva	W, E, Sb	C, D, R
Hormophysa cuneiformis (J. Gmelin) P. Silva [Syn: *Cystoseira prolifera* J. Agardh]	W, Sk, Sn	C, D
Hormophysa cuneiformis (J. Gmelin) P. Silva [Syn: *Cystoseira triquetra* C. Agardh]	Sb, Sn	C

Family Sargassaceae

Sargassum abbottiae Trono	W	C
Sargassum acutifolium Greville	W, Sk	C
Sargassum angustifolium C. Agardh	Sk, Sn	-
Sargassum aquifolium (Turner) C. Agardh	Sn	-
Sargassum asperifolium Hering & G. Martens ex J. Agardh	Sn	D
Sargassum baccularia (Mertens) C. Agardh	W	C
Sargassum balingasayense Trono	Sb	C
Sargassum binderi Sonder ex J. Agardh	W	C
Sargassum cervicorne Greville	E	C
Sargassum cinereum J. Agardh	E, Sb, Sn	D
Sargassum crassifolium J. Agardh [Syn: *Sargassum feldmanii* Pham]		
Sargassum cristaefolium C. Agardh	W, E	C, R
Sargassum dotyi Trono	W	C, R
Sargassum duplicatum (J. Agardh) J. Agardh	Sb, Sn	R
Sargassum erumpens Tseng et Lu	E	C
Sargassum filipendula C. Agardh	Sb	-
Sargassum granuliferum C. Agardh	W, P	C
Sargassum grevillei J. Agardh	W	C
Sargassum heterocystum (kuetzing) Montagne	E	C, R
Sargassum hornschuchii C. Agardh	Sb	C
Sargassum ilicifolium (Turner) C. Agardh	W, E, Sn	R, C
Sargassum ilicifolium (Turner) C. Agardh [Syn: *Sargassum sandei* Reinbold]	W	R
Sargassum illicifolium (Turner) C. Agardh var *conduplicatum* Grunow	E	R
*Sargassum laxifolium*Tseng et Lu	Sb	C, R
Sargassum microcystum J. Agardh	Sb	C, R
Sargassum myriocystum J. Agardh	W, Sn	C
Sargassum oligocystum Montagne	Sb	R
Sargassum polycystum C. Agardh	W, E, Sb, Sn	D, C, R, S
Sargassum siliculosoides Tseng et Lu	E	C, R
Sargassum siliquosum J. Agardh	W, P, Sb, Sn	R
Sargassum spathulaefolium J. Agardh	W, Sn	D
Sargassum squarrosum Greville	W	C, R
Sargassum stolonifoium Phang et Yoshida	W	R

Sargassum swartzii C. Agardh	W	C
Sargassum tenerrimum J. Agardh	Sb	-
Sargassum torvum J. Agardh	Sn	R
Sargassum virgatum C. Agardh	W, Sn	C
Sargassum vulgare C. Agardh	Sb	C
Sargassum wightii Greville	W	C
Turbinaria conoides (J. Agardh) Kutzing	W, E, P, Sb, Sn	C, D, R
Turbinaria deccurrens Bory de Saint-Vincent	W, E	R
Turbinaria ornata (Turner) J. Agardh	W, E, P, Sn	C, S
Turbinaria ornata (Turner) J. Agardh var. *serrata* Jaasund	Sn	C
Turbinaria tricostata Barton	E	-

Abbreviation

Distribution:
P: Peninsular Malaysia; Sb: Sabah; Sk: Sarawak; Sn: Singapore; E: East Coast Peninsular Malaysia; W: West Coast Peninsular Malaysia

Habitat:
C: Coral; D: Driftweed; E: Epiphyte; M: Mud; Mg: Mangrove; P: Planktonic; R: Rock, Bedrock, Stones; S: Sand; W: Wood; F: Fish cage, fishing line and fish net

sandy areas, mudflats, coral reefs and rocky shores. *Turbinaria* and the encrusting *Lobophora variegata* often accompany the *Padina* on the intertidal coral reefs. The new species *Sargassum stolonifolium* Phang and Yoshida described from Penang Island, is the first in the genus to exhibit the phenomena of new plantlets derived from the first leaves (Phang & Yoshida 1997).

ECONOMIC IMPORTANCE OF SEAWEEDS IN MALAYSIA

Early records show that several seaweeds were utilised in Malaysia for food, animal feed, fertiliser and traditional medicine (Burkill 1966, Hooper 1960, Zaneveld 1959, Phang 1984). Seaweeds like *Gracilaria changii, G. edulis, G. salicornia, G. tenuispitata* and *Gelidium* spp. are used as salads and for the preparation of desserts such as *agar-agar*. *Sarer* which is a species of *Gracilaria* forms part of the food for the 'buka puasa' during the fasting months, especially along the east coast. In Sabah *Eucheuma* and *Caulerpa* are collected and eaten either raw or blanched in salads. In the Chinese medicine shops one can buy dried *Sargassum, Turbinaria* and *Ulva* of unknown origin, which is popularly used by the Chinese in a soup considered as a rich source of iodine and which 'cools' the body system. The nutritional value of Malaysian seaweeds is not known except for a short study reporting on the lipid and fatty-acid content of selected seaweeds (Norazmi 2001). Nine species of seaweeds were analysed for fatty acid composition, and *Dictyota dichotoma* was found to contain the highest (17.6% ash-free dry wt) amount of lipids. All the seaweeds contained eicosapentaenoic acid ranging from 2.4 to 10.7% total fatty acid, with *Gracilaria edulis* having the highest content.

Of the Malaysian seaweeds, only *Eucheuma (Kappaphycus*) is presently cultivated for the commercial production of carrageenan chips as well as semi-refined carrageenan in Tawau, Sabah. Fishing families around Semporna, east coast Sabah, are involved in the mariculture of the *Eucheuma* using the monofilament techniques in the reefs fringing the islands near Semporna. The average cultivation period is 45 days and continues for eight months of the year. The monthly production from Semporna was around 60 to 100 tonnes dry wt per month (Phang 1998). The harvested seaweed is sun dried on the platforms of houses built on the reefs and sold at RM 1.10 (US$1 = RM3.8) per kg dry wt (moisture content of 32 to 35%) to the carrageenan producers. There are three semi-refined carrageenan factories in Tawau. *Gracilaria changii*, a good source of high quality agar and agarose (Phang 1994b) has also been experimentally cultivated in shrimp ponds, mangrove ponds and irrigation canals (Phang *et al*. 1996). Unlike *Eucheuma, Gracilaria* farming has not gone large-scale, probably because there are no large agar factories in the region.

The search for novel bioactive compounds from marine algae has revealed tropical seaweeds to be a potentially important source (Masuda *et al.* 2002, Varaippan *et al.* 2004). Bioactive properties of seaweeds range from antiviral to antioxidant, immunostimulatory, anti-coagulant, anti-thrombic and anti-inflammatory. Traditionally coralline algae like *Corallina* and *Amphiroa* are crushed and fed to children to expel worms. *Halimeda opuntia, Acanthophora spicifera, Laurencia, Eucheuma spinosum, Gracilaria* sp., *Hypnea musciformis, Dictyopteris* sp., and *Sargassum* spp. contain antibiotic compounds.

These tropical seaweed resources have great potential for development as food, feed and sources of biopharmaceutical products in addition to industrial colloids. A potentially good culture system would be the integrated culture with shrimp, fish or abalone farming. *Gracilaria* can be cultured in shrimp ponds, where the seaweed removes dissolved nutrients from the excess feed of the shrimps, thereby cleaning up the water, and produce a useful biomass for extraction of agar and agarose or any other useful biochemicals (Phang *et al*. 1996). The seaweeds can also be used to feed aquaculture species like abalone. The young larvae find protection amongst the seaweeds from predators and the seaweeds also produce oxygen and remove carbon dioxide, thereby contributing to reduction in global warming simultaneously.

THREATS TO SEAWEED RESOURCES

There is little information on the ecology and biology of tropical seaweeds, more so of the Malaysian species (Phang 1988, 1989, 1995; Wong & Phang 2004). Information on standing biomass and productivity of natural populations is scarce, while none on the harvesting from any natural seaweed populations is available.

Threats to seaweed resources include land reclamation, construction of jetties, bridges and marinas, pollution, trawlers, destructive fishing methods, sand mining, overharvesting of commercial species, introduction of alien and invasive species, illegal bioprospecting and also natural phenomena like tropical storms, typhoons and global warming. Of these threats, development of islands and coastal areas into resorts and marinas is the greatest. Natural sandy habitats and fringing coral reefs have been silted over by clearing of mangroves (Phang 1988, 1995) as well as beach areas, for aquaculture and construction. Increased marine traffic adds oil and grease to the waters, while untreated discharges from sewage facilities, rubber and palm oil mills, electronic and electro-plating industries, bring organic and inorganic pollutants to the marine ecosystem (Ramachandran *et al*. 1995).

MANAGEMENT OF SEAWEED RESOURCES

Habitat destruction is an important issue related to the management of the seaweeds. Continued population concentration in coastal areas will lead to increased user conflicts, competition for ocean resources and habitat destruction. Aquaculture may replace wild fishing, resulting in impacts on the habitats of the seaweeds in the form of pollution and also habitat destruction. This issue may hopefully be addressed with the implementation of the National Coastal Zone Management Plan. The increase in bioprospecting would require laws to prevent biopiracy. Presently there are no specific legislations or policies to safeguard the seaweed resources. Marine Parks serve as refuges for seaweeds, but without increased manpower, funding and authority, even seaweed habitats in protected areas may be threatened. While about 14 ministries and 23 government agencies perform ocean related functions, there is no clear Federal-State relationship regarding biodiversity management. There is also lack of coordinated gathering, processing, storage and dissemination of biodiversity information. Recently the Marine Parks Division has been entrusted the task of documenting the marine resources of Malaysia. There is a lack of skilled human resources in implementing agencies as well as research institutions and universities for managing the resources, especially in the form of taxonomists. The important contribution of the general public to marine biodiversity conservation and management must not be neglected. Non-governmental organisations like the Malaysian Nature Society and the Malaysian Society of Marine Sciences regularly organise community awareness programmes to enlist public assistance in the protection of natural resources. An Environmental Education Curriculum should be introduced to schools to inculcate awareness in the younger population.

Strategies for the protection of seaweeds and other natural resources include the establishment of a National Biodiversity Directorate, National Ocean Council, National Biodiversity Database and more Marine Protected Areas. The practice of sustainable fisheries, sustainable mariculture and the control of invasive alien species must be enforced. Integrated marine and coastal area management should be practiced. Alternative livelihoods could be introduced for poverty alleviation in coastal communities. There should be increased funding for research in areas of distribution, abundance and ecology of seaweed resources, thus enabling the proper assessment of the sustainability of the seaweed resources in Malaysia.

CONCLUDING REMARKS

The last two decades have seen an increase in seaweeds as a potential economic resource in the Asia-Pacific region, including Malaysia. Two genera, *Eucheuma* (*Kappaphycus*) and *Gracilaria* were targeted for development in Malaysia. However *Gracilaria* cultivation has not gone beyond the experimental stage. *Eucheuma* culture in Sabah continues with the fishing community around Semporna and has spread to the Kudat area through initiatives from the state government. These resources cannot meet the demands of the three carrageenan factories. *Gracilaria* on the other hand does not demand clean waters as *Eucheuma*, and should in fact grow well in Peninsular Malaysian waters. Agar processing requires simpler technology than carrageenan, and in fact has a high domestic demand (Jahara & Phang 1990). Of the other seaweeds, *Caulerpa* species are easy to culture but would require good marketing to sell its use as a delicacy in restaurants. *Acanthophora, Gracilaria* and *Hypnea* can be grown as feed for abalone.

The inventory of Malaysian seaweeds continues. Presently 386 taxa are recorded. Many scientifically interesting as well as commercially important species have been identified. Ecological information is scarce. Biomass assessments of natural seaweed areas, productivity determination and phenological studies of important species, should be encouraged. Only then can the status of the seaweed flora of Malaysia be assessed, and threatened species and habitats identified. The use of new approaches like molecular taxonomy should be encouraged to enhance species identification and possibly provide a fingerprinting technique to monitor and prevent biodiversity loss.

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TOWARDS THE FLORA OF MALAYSIA

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ABSTRACT

Malaysia has an estimated 15,000 species of vascular plants (angiosperms, gymnosperms and pteridophytes). Although located in the Malesian region, its affinity is Sundaic, having common elements with Sumatra, Java and Palawan. The two halves of Malaysia, Peninsular Malaysia extending from mainland Asia and East Malaysian states of Sabah and Sarawak on the island of Borneo have their own distinct floristic components. Peninsular Malaysia has about 8,300 species of vascular plants and Sabah and Sarawak have an estimated 12,000 species. The Flora of Sabah and Sarawak is generally richer than that of Peninsular Malaysia. For trees, on the average, Sabah and Sarawak have about 44% more species than Peninsular Malaysia. The flora of Peninsular Malaysia is better documented that of Sabah and Sarawak. The Flora of Malaysia project is planned in a phased approach, the approach is taken due to historical reasons, the different flora affinities between Peninsular Malaysia and Sabah and Sarawak and perceived resources available for such an endeavour. Peninsular Malaysia has recent revisions on a number of large families and families of tree species. Until recently, Sabah and Sarawak do not have specific accounts for the region. The Tree Flora of Sabah and Sarawak project, initiated in 1991, represents the first systematic modern attempt to document some of the important plant families of these two states. This project is expected to continue for another 10 years to complete the revision of about 4,000 estimated tree species found in the two states. The Flora of Peninsular Malaysia project began in 2005 with initial funds from the Malaysian government for at least the next five years. Upon completion of the Tree Flora of Sabah and Sarawak project, it is envisage the Flora of Sabah and Sarawak project will only start in about 2015. It is estimated that the Flora of Peninsular Malaysia project will take at least 20 years to complete (at revision rates of about 400-500 species a year). To achieve such rates, there must be substantial increase in manpower involvement and fund allocation.

INTRODUCTION

The two geographical halves of Malaysia pose interesting challenges towards documenting the flora of Malaysia. Peninsular Malaysia or the Malay Peninsula (here includes Singapore and Peninsular Thailand) contains the floristic elements of the Sunda Self and also of the mainland Asiatic species from seasonal climates (Wong 1998). Borneo, with its greater isolation from Malaya, has a flora of Sundaic element; however its flora is quite distinct. Historically,

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the two regions followed quite different botanical past. A very brief historical perspective is provided here, highlighting only the major works that are significance to the flora of these two regions. A more detail account of the historical works relating to the flora of both Borneo and Malaya can be obtained from the introductory volumes of the Flora Malesiana volumes (de Wit 1949, van Steenis-Kruseman 1950, van Steenis 1955). Wong (1987, 1995a) and Soepadmo (1999) also provided reviews with additional updates from de Wit, van Steenis and van Steenis-Kruseman of the botanical collection and documentation of the flora of both Peninsular Malaysia and Borneo.

BOTANICAL HISTORY OF PENINSULAR MALAYSIA

Botanical Collections

Peninsular Malaysia with a more direct former British Colonial rule had a longer and more sustained period of botanical exploration and enumeration. Its botanical history dates back to the first British settlement in the early 1800's in the Malay Peninsula in Penang where the island was important for the spice trade. Among the very important collectors during this period include that of N. Wallich whose collection, arranged in a catalogue (Wallich's catalogue), included contributions from G. Porter, W. Jack and G. Finlayson. Numbering about 8,000 species, Wallich's catalogue became the basis of many plant names for Penang and Singapore in Malaya, and India. W. Griffith, Wallich's predecessor, collected large numbers of specimens particularly from Malacca also form the basis of the foundation of botanical work in Malaya. Many collectors followed included L. Wray Jr., Father Scortechini, H. Kunstler (often labelled as King's Collector), A.C. Maingay, C. Curtis, C.B. Kloss, R. Derry, T. Oxley, J.S. Goodenough, I.H. Burkill, Mohamad Haniff, N. Cantley, F.W. Foxworthy and etc. A full listing of these collectors has been summarised by Burkill (1927) with some details of their background and their collection itineraries can be obtained from van Steenis-Kruseman (1950).

H.N. Ridley's arrival into Malaya is very significant to Malayan botany. Between 1888 and 1900, he was appointed as Director of Gardens and Forests, Straits Settlements and in 1901-1912, Director of Gardens, Singapore. Ridley was a man of great ability and he contributed most significantly towards the botany of Peninsular Malaysia. In his career, he described over 4,200 plant species. He amassed a huge collection amounting to about 50,000 numbers, of which the main set is in Kew with duplicates in Singapore and other herbaria (van Steenis-Kruseman 1950). No other collector has amassed such a size of collection for Malaya since. Subsequent directors and curators of the herbarium at Singapore Botanic Gardens continued to build upon the foundation set up by Ridley. Of particular importance were the contributions from I.H. Burkill, M.R Henderson, E.H.J. Corner, R.E. Holttum and C.X. Furtado. All of them had contributed in exploration, collections and publications, giving us a better understanding of the flora of Peninsular Malaysia.

At the turn of the twentieth century, A.M. Burn-Murdoch set up a forest herbarium in Kuala Lumpur, with the aim of producing an account of the commercially important tree species of Malay Peninsula (Wong 1987). The specimens were collected as reference specimens and duplicates were submitted to H.N. Ridley for identification. The small herbarium was at the office of the Conservator of Forests, Strait Settlements and Federated Malay States. His successor, G.E.S. Cubitt continued with the collection although at a slower rate. In 1916, the

Wray Herbarium of the Agriculture Department was transferred to the Forest Department in Kuala Lumpur (Cubitt 1919). In 1918, Cubitt secured the services of F.W. Foxworthy, as the first Forest Research Officer of the Federated Malay States and Straits Settlements. Under Foxworthy the herbarium grew quickly. By the end of 1920, the herbarium contained over 6000 numbers (Wong 1987). With the decision to form a Forest Research Institute (FRI), an area of about 800 acres was acquired at Kepong in 1926 and the main office building was constructed in 1929 with the herbarium moving into the east wing of the building. C.F. Symington joined FRI in 1929 and began to assist the running of the herbarium. He contributed a large collection to the Kepong herbarium in particular the family Dipterocarpaceae on which he was preparing a foresters' manual of the important timber family. By the time World War II broke out in Malaya with J.G. Watson having succeeded Foxworthy, the herbarium had about 43,000 specimens. Unfortunately, during the war many of the specimens were badly damaged when looters plundered the herbarium. With the internment of the British officers, V.L. Bain, a Eurasian being exempted from detention was appointed the acting State Forest Officer of Selangor. He was able to reappoint several local staff members at Kepong. Aziz Budin went on to restore the damaged collection and attempted to replace some of the lost specimens either by duplicates or by new collections.

After the war, J. Wyatt-Smith took charged of the herbarium and collection gained momentum. With the formation of the Federation of Malaya in 1957 and subsequently the Federation of Malaysia in 1963, the transition towards Malayanisation came into being. K.M. Kochummen who joined FRI as Assistant Botanist in 1953 subsequently took charge of the herbarium in 1960. In 1964, F.S.P. Ng was recruited as Forest Botanist. By 1965, the collection at FRI numbered over 74,000 specimens (Wong 1987). In 1965, T.C. Whitmore was engaged under the Colombo Plan to lead the Tree Flora of Malaya project (Whitmore 1972). In the years following, Whitmore conducted large collecting expeditions into many parts of Peninsular Malaysia, many places not collected previously. The Tree Flora project completed its last volume with the publication of Volume 4 in 1989. By then the herbarium has accumulated about 130,000 specimens. In 1980, K.M. Wong joined Kochummen managing the FRI collection. L.G. Saw joined the institute in 1982 as Hill Forest Silviculturist, later in 1985 joined the herbarium to understudy Kochummen as he was to retire. In 1985, the Forest Research Institute Malaysia (FRIM) was formed as a statutory body from FRI and in the years following; the mandate of FRIM was to expand beyond forestry related flora research it traditionally worked on and have now included the study of the total flora of Malaysia. In this much summarised survey of collections, we have not included many collectors which should be a subject of much wider review. Later botanists to join the much expanded role of FRIM included Farah Ghani (deceased), Idris Mohd. Said (have since left), L.S.L. Chua, R.C.K. Chung, Y.Y. Sam, E. Soepadmo and more recently Ruth Kiew.

Bibliography of the Flora of Peninsular Malaysia

In the following account, we have restricted the discussion to the main floristic publications that pertain to the flora of the Malay Peninsula. Other incidental accounts of local checklists and revisions of genera can be obtained from the bibliography found in the general chapter of Flora Malesiana Volume 5 (van Steenis 1955) and Turner (1997). The Flora of British India was the first major account covering all the families of Malay Peninsula. The scope of the volumes was to include plants within the British territories of India, together with those of Kashmir and Western Tibet, and Malaya (Hooker & Thomson, 1872-1897 in 7 volumes) as part of the British colony. Plants from Borneo however, were not included in the revisions. Although the Flora of India included treatment of the Flora of Malay Peninsula, it became apparent that it was not warranted from a phytogeography perspective and the manner of treatment produced from limited data available at the time had produced an unsatisfactory revision (de Wit 1949). As a result, G. King (1889), working from the Calcutta Herbarium, initiated the series Materials for a Flora of the Malayan Peninsula. The revisions, written by various authors, were originally published as separate papers in the Journal of the Asiatic Society of Bengal. King and Gamble subsequently compiled these instalments into 4 volumes. King died after completion of Volume 4 and the work of editorship was passed on to J.S. Gamble who continued the series to instalment 26 which were compiled into Vol. 5 with the last instalment published in 1936 (Ng & Jacobs 1983). These volumes however, covered only the dicotyledonous families and even so, the Urticales *viz.* Cannabinaceae, Moraceae, Ulmaceae, Urticaceae and most of the Euphorbiaceae never appeared in print (Ng & Jacobs 1983). H.N. Ridley (1907) published separately in Singapore in three parts of the Materials for a Flora of the Malayan Peninsula completing the monocotyledons. These publications were very important ground-breaking work and they become the basis for subsequent work on the Flora of the Malayan Peninsula. Using the *Materials* as foundation for the Flora of the Malay Peninsula, Ridley upon his retirement completed the Flora of Malay Peninsula and published them in 5 volumes between 1922 and 1925 (Ridley 1922-1925) for the angiosperms and a separate final fern instalment in 1926 (Ridley 1926).

Following Ridley's publication of the Flora of Malay Peninsula, botanical work continued in more detail and from different perspectives. I.H. Burkill (1935), succeeding Ridley, subsequently produced two volumes of *A Dictionary of the Economic Products of the Malay Peninsula*. Other important publications from Singapore included E.H.J. Corner's (1940) Wayside Trees of Malaya, M.R. Henderson's (1959, 1974) Malayan Wild Flowers. By the 1950s, a revised Flora of Malaya was initiated as knowledge of the Malayan flora improved with more explorations and collections. A number of publications followed, mainly by Holttum (Zingiberaceae (1950), Marantaceae (1951), bamboos (1958), orchids (1964) and ferns (1968)). The volume on grasses was published by Gilliland (1971). With the move of interest away from floristic work in the 1970s in Malaysia and Singapore, the revised Flora of Malaya was more or less discontinued. Piggott (1988) produced a popular photographic account for ferns. The orchid flora was again subjected to another revision in 1992 by Seidenfaden & Wood. Turner (1997) collated a checklist of Peninsular Malaysian flora based on literature. More recently, Clarke (2001) published the *Nepenthes* of Sumatra and Peninsular Malaysia and Kiew (2005) revised the Begonias of Peninsular Malaysia in richly illustrated volumes.

At the Forest Research Institute at Kepong, interest was towards tree species and identification manuals for foresters for the more important timber tree families and other minor forest products. Burn-Murdoch (1911, 1912) initiated the first publications of such foresters' manual with the publication of the Trees and Timbers of the Malay Peninsula. The Malayan Forest Records series was started and Foxworthy published a number of volumes on commercial timbers and minor forest products (Foxworthy 1921, 1922, 1932). In 1934, C.F. Symington was appointed the first Forest Botanist and he envisaged producing a foresters' tree manual comprising all the Malayan timber-producing families. However, it was obvious that much research was still required and that a great deal of instability still existed in the botanical nomenclature. He then concentrated on the most important timber family, the Dipterocarpaceae, which he completed in 1940 and was published as the *Foresters' Manual of Dipterocarps* in 1943 in his absence (Symington 1943).

After the War, John Wyatt-Smith served as Forest Botanist. Wyatt-Smith also saw the importance of Symington's work and the need to document similar information on timber trees of other families. However, it became evident also that the botanical knowledge of the many non-Dipterocarps was inadequate for a similar treatment. In the interim, Wyatt-Smith (1952) produced a booklet listing out the more common timber species found in Malaya that is used by staff of the Forest Department as an identification tool for the common timber species (*Pocket Check List of Timber Trees*). K.M. Kochummen subsequently revised this "Pocket Check List" three times to include new information. The *Pocket Check List* has now become an important identification reference for students of the common Peninsular Malaysian timber species. Wyatt-Smith also produced a series of other more taxonomic publications on some of the important timber families (e.g., Burseraceae (Wyatt-Smith 1953a), Leguminosae (Wyatt-Smith 1953b), Myristicaceae (Wyatt-Smith 1953c), Sapotaceae (Wyatt-Smith 1954a), Lauraceae (Wyatt-Smith 1954b) and Sapindaceae (Wyatt-Smith 1954c), and the genus *Calophyllum* (Guttiferae) (Henderson & Wyatt-Smith 1956)).

The Tree Flora of Malaya project under T.C. Whitmore as editor published two volumes (Whitmore 1972, 1973) followed by another two volumes with F.S.P. Ng (1978, 1989) as editor. The final four volumes covered over 2,800 species of trees found in Malaya. Interests in the non-timber but commercially important groups resulted in the production of J. Dransfield's (1979) *A manual of the rattans of the Malay Peninsula* and K.M. Wong's (1995b) *The bamboos of Peninsular Malaysia*.

BOTANICAL HISTORY OF SABAH AND SARAWAK (AND BORNEO)

Sabah and Sarawak lack the collection intensity of Malaya in the early years. However, in recent years both herbaria at the Forest Research Centres of Sandakan and Kuching have added much to their collections. Wong (1995a) has amply summarised the collection history and bibliography of Bornean flora in the introductory chapters of the Tree Flora of Sabah and Sarawak Volume 1. We shall not elaborate further here. Suffice to add since that review, the Tree Flora of Sabah and Sarawak has since published five volumes (Soepadmo & Wong 1995, Soepadmo *et al.* 1996, Soepadmo & Saw 2000, Soepadmo *et al.* 2002, 2004). The Plants of Kinabalu project led by Beaman and his collaborators completed the project with the publication of five volumes of the series (Parris *et al.* 1992, Wood *et al.* 1993, Beaman & Beaman 1998, Beaman *et al.* 2001, Beaman & Anderson 2004). Modern identification manuals, amounting to floristic enumerations, of the rattans of Sabah and Sarawak (J. Dransfield 1984, 1992), and the bamboos of Sabah (S. Dransfield 1992) have been published. More charismatic groups such as orchids and *Nepenthes* continue to attract interest with a checklist of the Orchids of Borneo (Wood & Cribb 1994), Slipper Orchids of Borneo (Cribb 1997) and the Orchids of Borneo (Beaman *et al.* 2001), and *Nepenthes* of Borneo (Clarke 1997) produced. A richly illustrated *Etlingera* (Zingiberaceae) of Borneo was also recently published (Poulsen 2006).

THE FLORA OF MALAYSIA – WHAT DO WE KNOW?

Currently there is no comprehensive checklist for the flora of Malaysia. A number of checklists exist as a result of the different botanical history of the two main regions of Malaysia. For

Peninsular Malaysia, the work of Ridley (1922-1926) provided the first complete enumeration of the vascular plants of the Flora of Malay Peninsula; the angiosperms were published in the five volumes between 1922 and 1925. Subsequently, Ridley published a separate checklist of the ferns (Ridley 1926). Ridley's enumeration by now has become outdated; Turner's (1997) publication of "A Catalogue of the Vascular Plants of Malaya" serves as the most recent checklist based on existing literature survey. In this catalogue Turner enumerated 8,198 species (Table 1). Parris & Latiff (1997) published a further update on the ferns and fern allies with some additions and nomenclatural changes to the group (Table 2). In this checklist, ferns and fern allies of Sabah and Sarawak were included to provide the first complete checklist of the group for Malaysia.

Table 1. Summary of the checklist of the flora of Peninsular Malaysia comparing Ridley's (1922-1925, 1926) enumeration and Turner's (1997) catalogue

Enumeration	Groups	Families	Genera	Species
Ridley (1922-1925, 1926)	Ferns	16	86	417
	Gymnosperms	3	5	23
	Dicots	132	1,048	5,009
	Monocots	31	354	1,734
	Total	**182**	**1,493**	**7,183**
Turner (1997)	Ferns & fern allies	34	133	632
	Gymnosperms	4	8	27
	Dicots	165	1,092	5,529
	Monocots	45	418	2,010
	Total	**248**	**1,651**	**8,198**

Table 2. Ferns and fern allies checklist enumerated in 1997 (Parris & Latiff 1997)

Region	Species Total
Malay Peninsula	647
Sabah	750
Sarawak	615
Total	**1,165**

For Sabah and Sarawak, no checklist exists but two important compilations were made for Borneo (Merrill 1921, Masamune 1942, 1945). Masamune's compilations provided a more critical checklist and in that enumeration, 8,164 species of Bornean vascular plants were listed (Table 3). Other and more current accounts for flora of Borneo were mostly foresters' manuals and checklists often on selected groups in the region or states of Brunei, Kalimantan, Sabah and Sarawak (e.g. Anderson 1980, Argent *et al.* 1997, Ashton 1964, 1968, 1988, Browne 1955, Burgess 1966, Cockburn 1976, 1980, Hasan & Ashton 1964, Keith 1947, Kessler & Sidiyasa 1994, Newman *et al.* 1996, Primack 1983, Smythies 1965, Whitmore *et al.* 1990a, 1990b, 1990c, Wood & Agama 1956, Wood & Meijer 1964). The other checklists and revisions have been reviewed in the previous section. The launch of the Tree Flora of Sabah and Sarawak

Table 3. Summary of the flora of Borneo based on Masamune's checklist

Checklists	Groups	Families	Genera	Species
Masamune (1945)	Ferns & fern allies		118	963
Masamune (1942)	Gymnosperms	5	7	34
	Dicots 133	996	4,997	
	Monocots	29	307	2,170
	Total	**167**	**1,428**	**8,164**

in 1991 was very significant as it was for the first time, a modern floristic approach was used in a systematic fashion to enumerate the trees species (Soepadmo & Wong 1995). Apart from these enumerations, the other sources of information on the flora of Malaysia are from the Flora Malesiana Series I & II for seed plants and ferns and other scattered publications.

Based upon the above discussion, the flora for Peninsular Malaysia now stands over 8,300 species with recent updates from Turner (1997) (e.g., Turner 2000, Latiff & Turner 2001a, 2001b, 2001c, 2001d, 2002a, 2002b, 2003, Kamarudin & Turner 2004). This is a relatively accurate estimate and provides a relatively good understanding of the actual flora for Peninsular Malaysia. For Sabah and Sarawak, however, it is more difficult to arrive at an accurate figure. Most estimates are for Borneo (e.g. Merrill (1921) estimated about 9,000 species, Masamune (1942, 1945) enumerated about 8,200 species and more recently Wong (1995a) estimated a flora of between Merrill's 9,000 and 15,000 species). Kiew (1984) stressed the urgency for the Bornean flora where at the time of her review, no singular project has been initiated for Borneo. As mentioned earlier, the Tree Flora of Sabah and Sarawak is the most important modern taxonomic project for Borneo. Since its inception in 1991, five volumes have been published and the estimation based on the revision from volumes 1 to 5 provides an indication of the diversity of the Bornean flora. Table 4 provides a comparison of the Tree Flora of Sabah and Sarawak with the Flora of Malaya comparing similar families and their enumeration.

Table 4. Comparing revisions of similar families of the Tree Flora of Sabah and Sarawak with the Tree Flora of Malaya (figures for Tree Flora of Sabah and Sarawak were extracted from volumes 1–5 included 2 single-species families not found in the Tree Flora of Malaya; figures for Tree Flora of Malaya volumes 1-4 with updates from Turner (1997))

TFSS Volumes	Tree Flora of Sabah & Sarawak			Tree Flora of Malaya			Species common to both regions
	Families	Genera	Species	Families	Genera	Species	
1	31	99	312	31	91	227	152
2	23	75	247	21	63	186	116
3	4	29	358	4	27	246	139
4	6	21	292	6	21	202	106
5	4	25	361	4	27	225	132
Total	**68**	**249**	**1,570**	**66**	**229**	**1,086**	**645**

On the average, the Tree Flora of Sabah and Sarawak contained about 44.5% more species than the Tree Flora of Malaya. If this proportion is maintained for the rest of the tree flora, then with the Tree Flora of Malaya having 2,830 species (Ng *et al.* 1990), it is estimated that the Tree Flora of Sabah and Sarawak will contain just over 4,000 species. Based upon this estimation also, with about 8,300 species of vascular plants in Peninsular Malaysia, it is estimated that the Flora of Sabah and Sarawak will contain about 12,000 species. In the table above, we have also included in the count, 645 species in the revisions that are common to both Sabah and Sarawak, and Peninsular Malaysia, i.e., 59.4% overlap. Based upon this overlap and using the estimated ratios we have worked out earlier, the total tree flora of Malaysia should be just over 5,200 species and estimated total flora of vascular plants of Malaysia will be just over 15,300 species.

HERBARIA, COLLECTIONS AND SPECIMENS

Specimens are essential in the documentation of the flora of Malaysia. Today, the collection at the herbarium of Forest Research Institute Malaysia (KEP) stands about 300,000 specimens. The other large herbarium holdings include the Forest Research Centre at Sandakan (SAN) with 253,725 specimens and the Forest Research Centre at Kuching (SAR) with about 250,000 specimens (Table 5). Other important Malaysian collections are found at the herbaria at Universiti Malaya (KLU) and Universiti Kebangsaan Malaysia (UKMB). The herbarium at the Singapore Botanic Gardens (SING) is particularly very important for the Peninsular Malaysian flora. Many type specimens for plants described from Peninsular Malaysia are found there. It has about 650,000 specimens. Other important collections for the Malaysian flora include The Forest Herbarium (BKF), Bangkok, Thailand, National Herbarium of Netherlands, Leiden (L), Royal Botanic Gardens, Kew (K), Royal Botanic Gardens, Edinburgh (E), UK, Arnold Arboretum (A), Harvard University, USA, and Central National Herbarium (CAL), Calcutta, India. For Sabah and Sarawak, the Herbarium Beccarianum (FI-B), Florence, Italy is particularly important for Beccari's collection and the herbarium of Brunei Forest Department (BRUN).

Table 5. Important herbarium holdings for Malaysia and Singapore

Country	Institutions	Specimens
Malaysia	Forest Research Institute Malaysia	300,000
	Forest Research Centre, Sandakan, Sabah	253,725
	Forest Research Centre, Kuching, Sarawak	250,000
	Universiti Malaya	65,000
	Universiti Kebangsaan Malaysia	72,000
Singapore	Singapore Botanic Gardens	650,000

STATE OF KNOWLEDGE FOR A FLORA OF MALAYSIA

Among the key resources to speeding up the documentation of a flora of Malaysia is the availability of recent revisions that may set the foundation for the flora writing. The vascular flora of Malaysia will include 250 families in Peninsular Malaysia and 253 families in Sabah and Sarawak. In working towards the flora of Malaysia, we have continued to separate the two regions for the purpose of further analysis, simply out of convenience from the historical perspective and also a general tendency in many revisions to maintain the two regions as separate. We have compiled a review of recently published revisions against these families that included the floras of Peninsular Malaysia (Malaya) and of Sabah and Sarawak (Borneo). The recent revisions include publications from the Flora Malesiana series, Tree Flora of Malaya, the revised Flora of Malaya, Tree Flora of Sabah and Sarawak, and other journal articles or series covering revisions of the whole family in the list. In the analysis, out of the 250 families occurring in Peninsular Malaysia, 207 families (83%) have recent revisions. This is a very good coverage. For Sabah and Sarawak or Borneo, the coverage is much lower, 164 families out of 253 occurring there or about 64%. In recent years, world checklists are being generated and these are being made available in the internet, for example, the checklists available from Royal Botanic Gardens, Kew (www.kew.org/wcb/), where the monocots are now available for downloading. Such checklists can certainly provide an initial update especially for Borneo where existing list by Masamune (1942, 1945) has long become obsolete.

TOWARDS A FLORA OF MALAYSIA

In the last decade and half, Malaysia has been very fortunate in terms of the resources available to document its floristic diversity. The Tree Flora of Malaya published its final volume in 1989 (Ng 1989). In 1990, it became apparent that the botanical work of documenting the flora of Malaysia should continue and it was an obvious decision to continue the well tested formula of the Tree Flora of Malaya to be extended to Sabah and Sarawak. The first author was then delegated to prepare proposals for funding towards a Tree Flora of Sabah and Sarawak project. The project was launched in 1991 for first five years with funding from the Malaysian Government, the Overseas Development Administration (ODA) of the United Kingdom and the International Tropical Timber Organisation (ITTO). It was originally estimated that the project will run for ten years to cover about 3,000 species (Soepadmo 1995) in eight volumes. Having completed five volumes of the tree flora, with the current estimate of about 4,000 species of trees, we envisage that the Tree Flora of Sabah and Sarawak will need at least another ten years to complete the remaining estimated 2,500 species at a revision rate of about 250 species per year using present resources.

In realising the Flora of Malaysia, a pragmatic approach is to review our existing commitment towards the Tree Flora of Sabah and Sarawak project and how else can we extend into a full national flora project. The institutions currently engaged in the Tree Flora of Sabah and Sarawak, i.e. the Forest Research Institute Malaysia, and the Forest Departments of Sabah and Sarawak would want to complete the Tree Flora project. The review of species distribution and literature provided above also provide an indication that the Flora of Malaysia can be completed in a phase approach. In this pragmatic approach, the Flora of Malaysia can be tackled as two regional projects, revisions for Peninsular Malaysia and for Sabah and Sarawak. And it is this approach that we have taken towards plans to realise the Flora of Malaysia. In April 2004, the Ministry of Natural Resources and Environment was formed. With the creation of the ministry, it became of national priority that the government was committed to document the biodiversity of the country. The work of documenting the flora of Malaysia became very quickly a national need and no more an academic wish-list for botanists in Malaysia. For the immediate use, the country requires a checklist of its flora, as Peninsular Malaysia has already a checklist; the immediate need was for Sabah and Sarawak to have an updated list. Under the Ninth Malaysian Plan, a project was prepared just to meet this need.

In 2005, plans were drawn for a Flora of Peninsular Malaysia project. It was thought that the time was ripe for the project. The Tree Flora of Sabah and Sarawak has already been running well for about 15 years and Peninsular Malaysia since the Tree Flora of Sabah and Sarawak project started has been relatively neglected. Furthermore, as explained earlier, a phase approach to realise the Flora of Malaysia was a very viable option for Malaysia. Following the proposal, the Flora of Peninsular Malaysia received funding at the end of 2005 for the next five years. For Sabah and Sarawak, we reckon when the Tree Flora of Sabah and Sarawak project is completed, attempts will be made to start the Flora of Sabah and Sarawak project.

COLLABORATIONS, CONTRIBUTORS AND RATES OF REVISION

Flora projects are always collaborative involving both local and foreign experts. The experiences from both the Tree Flora of Malaya and Tree Flora of Sabah and Sarawak projects have shown that contributions from experts are essential to their success. Experts often produce revisions at much faster pace. At the same time, local botanists must be trained to form expertise that can continue with the work within the country. Such strategy must be used for a Flora of Malaysia. Currently, Tree Flora of Sabah and Sarawak and the new Flora of Peninsular Malaysia are also using such strategy. Collaborations are at different levels, at institutional level, our traditional partners include local partners such as Forest Research Centre, Sandakan, Forest Research Centre, Kuching, Universiti Malaya, Universiti Kebangsaan Malaysia, Universiti Malaysia Sarawak, Universiti Malaysia Sabah; regional herbaria include Singapore Botanic Gardens and the Royal Forest Herbarium, Bangkok; internationally the Royal Botanic Gardens Kew, Royal Botanic Gardens Edinburgh, Natural History Museum, London, National Herbarium of Netherlands, Leiden, and Arnold Arboretum, Harvard University, USA. The collaborating institutes are important to support herbarium specimen loans, sourcing of literature, provide base for specimen consultations and taxonomic expertise. From these institutions, the current projects have over 25 collaborators promising to contribute to the revisions of the families.

To develop and build local expertise, two essential elements must be in place; opportunities to build careers in botanical sciences and availability of training regimes for those interested. The Flora of Peninsular Malaysia project when it was mooted included these elements. We are also very fortunate that in the last few years, the Forest Research Institute Malaysia has committed to increase the number of botanists to do floristic work. In the last two years, FRIM has recruited five new botanists and took in eight contract researchers for the two projects. Together with existing staff, FRIM now has 18 botanists working on both these projects. Training of these new and aspiring botanists have become a very important element of the projects together with getting the revisions done. We are confident if the current institutional and financial supports are maintained, both the Tree Flora of Sabah and Sarawak and the Flora of Peninsular Malaysia projects will be successful and will produce not just the revisions that contributes towards a Flora of Malaysia but also ensure that Malaysia will maintain a pool of botanists trained in understanding the local flora.

How many years will it take for the current flora projects to complete? It is very important that in planning towards a Flora of Malaysia, we have realistic estimation and projection of manpower and financial layout. The Tree Flora of Malaya took 24 years to complete. Kiew (1984) made some projections on the rate of revisions botanists takes in producing the different types of floras (identification and information floras) based from past flora projects. They ranged from 250 species per taxonomist per year to 20-30 per year. Based upon our experience with the Tree Flora of Sabah and Sarawak, we have estimated the rate of revision using a full-time experienced botanist as an example. We have taken the example of the late Mr. K.M. Kochummen who worked with the Tree Flora of Sabah and Sarawak project. During his tenure with the project, Kochummen revised five families covering 375 species (Table 6) from 1992 to March 1999. This gave a rate of about 54 species per year for the seven years he was with the project.

Table 6. Families revised by K.M. Kochummen (1992–March 1999) during his tenure with the Tree Flora of Sabah and Sarawak project

Families	Genera	Species
Anacardiaceae	17	92
Burseraceae	8	59
Celestraceae	10	44
Moraceae	5	173
Ochnaceae	5	7
Total	**45**	**375**

For the Flora of Peninsular Malaysia, Table 7 provides the different rates of revision against the number of full-time staff working on the flora revisions. The matrix estimates the number of years needed to complete the Flora of Peninsular Malaysia with the estimated flora of 8,300 species. Using the example of Kochummen, we estimated that for a budding botanist, it would be very difficult to maintain a revision of over 50 species per year. A more realistic figure of about 40 species may be feasible for a relatively grounded botanist. If our current manpower strength is maintained with about 10 full-time botanists working for the project, we envisage that it will take just over twenty years to complete the Flora of Peninsular Malaysia. This estimate ignores the contributions from other collaborators.

Table 7. Rate of revision based on about 8,300 species of vascular for the Flora of Peninsular Malaysia

		Number of Full-time Staff			
		5	10	15	20
Revision Rates/ Staff/ Year	20	83	42	28	21
	30	55	28	18	14
	40	42	21	14	10
	50	33	17	11	8.3
	60	28	14	9.2	6.9

For the Tree Flora of Sabah and Sarawak we have also worked out the rates using similar formulation (Table 8). The project with 5 full-time staff will take over twelve years to complete.

Table 8. Revision rates based on about 2,500 species of tree species for the Tree Flora of Sabah and Sarawak

		Number of Full-time Staff			
		5	10	15	20
Revision	20	25	12.5	8.3	6.3
Rates/	30	16.7	8.3	5.6	4.2
Staff/	40	12.5	6.3	4.2	3.1
Year	50	10	5	3.3	2.5
	60	8.3	4.2	2.8	2.1

FINANCES AND INSTITUTIONAL COMMITMENT

One of the constant challenges in any flora project is to ensure long-term commitment and sustainability in funding for the continuity of project. Projects are financed in fixed time-frame, e.g., it is fortunate that we have funding for 5 years for the Flora of Peninsular Malaysia. Following which it is often difficult to obtain extension. The Tree Flora of Sabah and Sarawak project went through a number of funding changes over the last 15 years — ODA, ITTO, Government of Malaysia until 2006 (Intensification of Research and Development Priority Areas (IRPA) funding), the IRPA funding ceased in 2006 and from then on, the project is dependent on research development fund from the Ninth Malaysian Plan for the next five years. In future, we are not certain how we can continue but it is up to the project to develop different ways to maintain the funding continuity. It is therefore important that such a project must have strong institutional commitment, failing which it would be almost impossible to secure continuity in finances and manpower commitment. Similarly, we expect the Flora of Peninsular Malaysia to go through different funding challenges as the project develops. We are fortunate that for the first five years we have quite generous funding coming from IRPA.

It is essential funding bodies would want to see good products from the project. There is a need to be creative in selling the products from the project outside the standard flora volumes which projects like this deliver. More innovative methods must be used to make the results of the projects become pertinent or relevant to both national and scientific needs.

The Tree Flora of Sabah and Sarawak now has produced five volumes, FRIM is currently making information from the project available in the internet thus disseminating the results of the project to the wider public. The Flora of Peninsular Malaysia is being implemented together with a conservation project of threatened plants of Peninsular Malaysia, thus extending the taxon information with distribution to be used in conservation.

CONCLUSION

Based upon the discussion above, the phase approach towards a Flora of Malaysia and the following points are reiterated.

- The inventory for a Flora of Malaysia can be done with resources in Malaysia and collaboration with our traditional partners;
- Based on current Tree Flora of Sabah and Sarawak and the Flora of Peninsular Malaysia projects, the Flora of Malaysia to continue with the geographical division of Peninsular Malaysia and Sabah & Sarawak;
- The project to be phased into the immediate short-term needs (checklists) and revisions of the two geographical floras; and
- Project must be seen as long-term and requires long-term institutional and financial commitments.

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FOREST RESOURCES TREND AND SUSTAINABLE FOREST MANAGEMENT IN PENINSULAR MALAYSIA

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ABSTRACT

Malaysia is well endowed with some of the world's richest forests, a richness not only in terms of numbers and uniqueness of species but also diversity of habitats and ecosystems. The total forested area in Peninsular Malaysia is about 44.7% (5.88 million hectares) of its land area. Of this total, some 35.7% (4.70 million hectares) are within Permanent Reserved Forests (PRFs). PRFs are legally gazetted Forest Reserves, managed sustainably for economic, social and environmental values. During the implementation of the New Economic Policy in 1970, the need to eradicate poverty and distribute wealth among the various communities saw the massive development of large-scale agriculture, particularly in the rural areas. This has resulted in the conversion of forest areas to plantation crops such as oil palm and rubber. Although large forest areas were cleared for this purpose, at the same time, there was a significant increase in the gazettement of PRFs. In 1970, the total forested areas was approximately 8.0 million ha and this dropped to 5.87 million ha in 2003 or a decrease of 27%. During the same period, the area gazetted as PRFs was 3.3 million ha in 1970 and it was increased to 4.7 million ha or an increase of 42% in 2003.

In an attempt to conserve the species and genetic resources in various forest and ecological types, the Forestry Department has also set aside pockets of virgin forests known as Virgin Jungle Reserve (VJR) and has taken actions to classify relevant areas of the PRFs into eleven different functional classes. Efforts are also being taken by the Department to ensure *in situ* conservation of biodiversity during forest harvesting in the PRFs. The Forestry Department is committed to forest conservation and protection of the environment, where PRF areas open for harvesting are subjected to forest management certification processes and the acreage of the PFR areas opened for harvesting are regulated and controlled. From another perspective, the Forestry Department had, to date, organised eight scientific biodiversity expeditions.

INTRODUCTION

The tropical rainforest has long been valued as a source for food, fuel, medicine and materials, for shelter and livelihood. It will continue to play an important role in the country's socio-economic development and environmental conservation.

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The economic contributions of the forest are well recognized particularly to the wood and non-wood based industry and trade. This is reflected by the fact that the country has emerged as one of the main supplier of the world's tropical hardwood products. In 2003, the forestry sector contributed RM 16.3 billion, which is 4.3 percent of the total export earnings, of which Peninsular Malaysia contributed RM 8.13 billion. The forestry sector also provided employment opportunities for over 330,000 people in Malaysia. In Peninsular Malaysia, the sector provided direct employment to 87,000 people. Forest revenue collected by various states in Peninsular Malaysia amounted to RM 335 million in 2003.

Although not easily translated into financial values, the roles of forests in watershed protection, conservation of soil and water resources, conservation of flora and fauna, conservation of genetic resources and support for agricultural and environmental conservation have long been recognized by forest managers. To meet the environmental as well as socio-economic needs, Permanent Reserved Forest (PRF) areas, wildlife reserves and water catchment areas were established.

This paper highlights the trends and current status of forest resources. It also elaborates on the forest management practices and biodiversity conservation in Peninsular Malaysia and the various initiatives and actions undertaken to achieve sustainable forest management. Forest coverage and timber production are briefly discussed here.

SUSTAINABLE FOREST MANAGEMENT

The World Conservation Strategy, which was initiated by the United Nations Environmental Program (UNEP), defines conservation as follows (IUCN 1980):

All human lives depend on the natural environment for survival and long-term well-being. Hence for any economic development to be sustainable, it must first be ecologically sustainable, and must satisfy three conditions:

- *Ecological integrity of the ecosystem must be maintained;*
- *Renewable resources must be used sustainably; and*
- *Biological diversity must be maintained.*

Article 2 of the Convention of Biological Diversity defines 'sustainable use' as the use of components of biological diversity in a way and at a rate that does not lead to the long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generation (Anonymous 2005).

The sustainable forest management concept in Malaysia is in line with the conservation and sustainable use definitions outlined by the World Conservation Strategy and Convention of Biological Diversity respectively. The definition adopted by Malaysia and the International Tropical Timber Council is "Sustainable forest management is the process of managing permanent forest land, to achieve one or more clearly specified objectives of management with regard to continuous flow of desired forest products and services, without undue reduction in its inherent values and future productivity and without undesirable effects in the physical and social environment" (Mohd Yunus *et al.* 2003).

Malaysia is committed to manage its natural forest in a sustainable manner; to ensure continuous timber production, maintain multiple functions of the forests, conserve biodiversity and control environmental impact (Mohd Yunus 1993, Anonymous 1996). The following are the objectives of the National Forest Policy 1978 (revised 1992) (Anonymous 1995):

- To conserve and manage the nation's forest, based on the principles of sustainable management
- To protect the environment and to conserve the forest biological diversity, genetic resources, and to enhance research and education

CONSTITUTIONAL PROVISIONS, POLICY AND LEGISLATIONS

Under Article 74(2) of the Malaysian Constitution, forestry comes under the jurisdiction of the respective State Governments. As such, each state is empowered to enact laws on forestry and to formulate forest policy independently. The executive authority of the Federal Government only extends to the provision of the maintenance of the experimental and demonstration stations, training and in the conduct of research.

In order to facilitate the adoption of a coordinated and common approach to forestry, the National Land Council (NLC) established the National Forestry Council (NFC) in December 20, 1971. The NLC is empowered under the Malaysian Constitution to formulate a national policy for the promotion and control of the utilization of land for mining, agriculture and forestry. The NFC serves as a forum for the Federal and the State Governments to discuss and resolve common issues relating to forestry policy, administration and management. The responsibility for implementing the decisions of the NFC lies with State Governments unless it is within the authority of the Federal Government.

In 1977, the National Forestry Policy was accepted by the National Forestry Council and later endorsed by the National Land Council on April 19, 1978. This policy was revised in November 1992 to take cognizance of the current concern expressed by the world community on the importance of biological diversity conservation and the sustainable utilization of the genetic resources, as well as the role of local communities in forest development.

STATUS OF PENINSULAR MALAYSIA'S FOREST RESOURCES

Forested Areas

During the implementation of the New Economic Policy in 1970, particularly with two prime objectives, i.e. eradication of poverty and distribution of wealth among the races, one of the strategies was the development of large-scale agricultural development, particularly in rural areas. The development of forest areas into palm oil and rubber plantations in tandem causes reduction of forested areas in Peninsular Malaysia. However, there was a significant increase in the gazettement of permanent reserved forest (PRF). In 1970, the total forested areas was approximately 8.0 million ha and this has dropped to 5.87 million ha in 2003, a decrease of 27 %. During the same period, the area gazetted as PRF was 3.3 million hectares and this was increased to 4.7 million ha or an increase of 42 % in 2003. Table 1 illustrates the trend.

In 2003, natural forest cover in Peninsular Malaysia was 5.88 million ha or 44.7 % of the total land area of Peninsular (Abdul Rashid, 2005). The bulk of these forested areas comprised the Dry Inland Forest (5.4 million ha), followed by Peat Swamp Forest (0.30 million ha), Mangrove Forest (0.10 million ha) and Planted Forest (0.08 million ha).

Permanent Reserved Forest and Protected Areas in Peninsular Malaysia

Out of the 5.88 million ha, 4.70 million ha or 35.7% of the total land area had been designated as the Permanent Reserved Forest (PRF) to be managed sustainably for the benefit of the present and future generations (Abdul Rashid, 2005).

Of the total PRF, approximately 3.18 million ha (24.2% of the total land area) are classified as production forest with the remaining 1.52 million ha (11.6 % of the total land area) being classified as protection forest (Abdul Rashid, 2005). Based on the National Forestry Policy, the role of the production forest is to ensure the supply in perpetuity, at reasonable levels, of all forms of forest produce that can be economically produced within the country. On the other hand, the role of the protection forest is to ensure favourable climatic and physical conditions of the country, the safeguarding of water resources, soil fertility, environmental quality, conservation of biological diversity and the minimization of damage by floods and erosion to rivers and agricultural lands.

Apart from the protection forests within the PRF, other protected areas, which had been gazetted as national parks, wildlife and bird sanctuaries amounted to 0.89 million ha (6.8% of the total land area) (Abdul Rashid, 2005). Of this total, 0.58 million ha are designated as National and State Parks, while 0.31 million ha are wildlife and bird sanctuaries. A total of 0.12 million ha (0.9% of the total land area) of the wildlife and bird sanctuary areas are located within the PRF.

Table 1. Forested Area and Permanent Reserved Forests (PRF) in Peninsular Malaysia (1970 to 2003)

Year	PRF (ha)	Forested Area (ha)	Year	PRF (ha)	Forested Area (ha)
1970	3,337,708	8,009,000	1987	4,288,408	6,348,000
1971	3,307,770	7,875,000	1988	4,928,646	6,288,000
1972	3,434,326	7,583,000	1989	4,866,201	6,320,000
1973	3,412,113	7,450,000	1990	4,866,470	6,270,000
1974	3,412,113	7,319,000	1991	4,748,057	6,111,000
1975	3,448,007	7,290,000	1992	4,675,021	6,042,000
1976	3,448,007	7,199,000	1993	4,698,459	6,024,008
1977	3,164,439	6,968,000	1994	4,687,463	6,003,000
1978	2,948,351	6,839,000	1995	4,684,904	5,991,000
1979	2,932,943	6,588,000	1996	4,684,094	5,820,547
1980	3,124,045	6,505,000	1997	4,731,927	5,852,869
1981	3,083,103	6,438,000	1998	4,730,216	5,838,860
1982	3,064,837	6,378,000	1999	4,853,646	5,938,068
1983	3,064,837	6,373,000	2000	4,837,500	5,979,649
1984	2,999,655	6,353,000	2001	4,840,431	5,924,407
1985	3,274,008	6,353,000	2002	4,701,858	5,892,901
1986	4,617,010	6,455,000	2003	4,696,211	5,879,723

Forest Plantations

To relieve the pressures on natural forests as well as to supplement future wood supply of the country, forest plantations, which are capable of yielding a high volume of timber per unit area within a shorter rotation, are being established. The species planted include tropical pines such as *Pinus caribaea*, *P. merkusii* and *Araucaria* species, as well as fast-growing hardwood species, such *as Acacia mangium*, *Gmelina arborea*, and *Paraserianthes falcataria.* Other species planted include *Tectona grandis*, *Shorea macrophylla* and *Durio zibethinus.* By the end of 2003, 0.08 million ha of plantation areas were established in Peninsular Malaysia.

In view of the growing importance of forest plantation and to encourage greater private sector investment, a National Committee on Forest Plantation Development with full participation from the private sector had been formed. The Committee's main role is to formulate a national strategy and action plan for the promotion and effective implementation of forest plantation programs. As forest plantation projects are being viewed as strategic projects of national interest, the Government of Malaysia provides fiscal incentives, as well as full tax exemption under the Pioneer Status for ten (10) years or 100% tax exemption under the Investment Tax Allowance for five (5) years, effective from 1993.

FOREST MANAGEMENT PRACTICES

Forest management in Peninsular Malaysia has a long history; it goes back to nearly a century ago when the first Chief Forest Officer was appointed in 1901. The forest management practices are being developed and revised to meet fluctuating market, supply and demand situations, as well as advancement made in ecological, industrial, and harvesting technologies.

Functional Classes

Section 10 of National Forestry Act 1984 required PRF areas to be classified and gazetted into eleven functional classes. Except for the first functional class (3.18 million ha), which is for timber production under sustainable management, all the remaining ten functional classes (1.52 million ha) are for purposes of conservation and protection and are as follows:

	Hectares (approximate)
Production forest	3,000,000
Soil protection forest	300,000
Soil reclamation forest	6,000
Flood control forest	6,000
Water catchment forest	800,000
Forest sanctuary for wildlife	100,000
Virgin Jungle Reserved forest	20,000
Amenity forest	70,000
Education forest	50,000
Research forest	30,000
Forest for federal purposes	20,000

The classification of the above functional classes is by no means exclusive. An area of the PRF can be classified under more than one functional class provided their uses are not contradictory. For example, forest trekking, camping, picnicking and bird watching activities should not pose problems in the catchment areas provided these are done in low densities. There is a need to formulate specific management practices for each of the functional classes. One of the aims of classifying the forest into different functions is to ensure that the forest is used and managed within its capacity. Over-use and inappropriate management result in forest health degradation that could change the forest ecosystem. The drastic changes in the ecosystem will negatively impact human welfare, health and food production.

Selective Management System (SMS)

Currently, the production forests are managed under Selective Management System. The system advocates the selection of a cutting regime based on diameter limits and species composition of the standing trees. In Peninsular Malaysia, the implementation of the SMS involves conducting forest activities that could be distinctly categorized into three stages, namely pre-harvesting, during harvesting and post-harvesting activities. The pre-harvesting activities include pre-felling forest inventory, cutting limit prescription and timber tagging. During harvesting, activities include directional felling and forest road construction while post harvest activities include forest survey, post-felling forest inventory and prescription of silvicultural treatments. Some of the activities are further elaborated below.

The SMS is designed to achieve sustainability of the forest with management objectives of economic and efficient harvesting under prevailing conditions. It requires the selection of management (cutting) regimes based on inventory data, which will be equitable to logger and forest owner, as well as ensuring ecological balance and environmental quality.

Pre-Harvesting Activities

Cutting Limits Prescription

The cutting limits prescription is based on the stand and stock information obtained from the pre-felling forest inventory, together with other relevant information needed to determine the optimal cutting regimes (diameter limits) for the forest area. Under SMS, the next cut is expected to be between 30-55 years and with an estimated net economic outturn of 30–40 cubic meters per hectare. The criteria for cutting limits prescription are as follows:

- The cutting limit prescribed for the group of dipterocarp species should not be less than 50 cm dbh, except for *Neobalanocarpus heimii* (Chengal) where the cutting limit prescribed should not be less than 60 cm dbh.
- The cutting limit prescribed for the group of non-dipterocarp species should not be less than 45 cm dbh.
- The residual stocking should have at least 32 sound commercial trees per ha from the diameter class 30–45 cm or its equivalence.
- The difference in the cutting limits prescribed between the dipterocarp and that of the non-dipterocarp species should be at least 5 cm.
- The percentage of dipterocarp species in the residual stand for trees having 30 cm dbh and above should not be less than that in the original stand.

Timber Tagging
Subsequently, timber tagging is carried out where harvestable trees are marked. This activity is carried out to ensure that only marked trees are felled, as well as to control the amount of timber output from the forest. The timber tagging system has proven to be an efficient mechanism in controlling and tracking the movement and removal of logs from the forest.

During Harvesting Activities

During harvesting, prescribed forestry activities would have to be conducted in accordance with rules and regulations as stipulated in the logging license issued by the State Forestry Department. Among others, matters given due consideration during forest harvesting include:

- directional felling to ensure minimal damage to residual stand;
- construction of forest roads, skid trails and log landings according to prescribed standards to ensure minimal adverse environmental impact; and
- demarcation of adequate buffer zones along rivers and streams to mitigate soil erosion.

Post-Harvesting Activities

Forest Survey
Immediately after harvesting, a forest survey is carried out to check on felled and un-felled trees and compliance to license conditions.

Post-Felling Forest Inventory
Normally, at two to five years after harvesting, a post-felling forest inventory is conducted to assess the status of the residual stand, as well as to determine any appropriate silvicultural treatments to be carried out.

A similar inventory is conducted at year 10 to assess the status of the regenerated forest. The sequence of operations under SMS is shown in Table 2.

Annual Harvesting Coupe

The annual harvesting coupe for the natural forests is determined for a period of five years, which follows the Malaysia Plan. For the Eighth Malaysia Plan (2001–2005), the annual harvesting coupe is 42,870 ha. This is expected to provide an annual yield of 3.43 million meter cubic (Abdul Rashid, 2005). Table 3 shows the trend of annual harvesting coupe from 1994 to 2003. Table 4 shows the log consumption by the sawmill and plywood/veneer industries. Based on the current production capacity of the forest, acreage of PRF and current log consumption, it is concluded that log supply from the PRF (natural forests) will not be able to meet the industry's demand and this supply will continue to decline further in the long term. In terms of resource sustainability, current forest planning and integrated operational studies have shown that, with average growth rates of trees over 30 cm dbh of 0.8–1.0 cm per year in diameter and 2.0–2.5 cubic meters per hectare per year in commercial gross volume, the hill forests in Peninsular Malaysia are capable of producing every 25–55 years of at least 45–85 net cubic meters per hectare.

Table 2. Sequence of Operations under the SMS

Year	Activities
n-2 to n-1	Pre-felling forest inventory of 10% sampling intensity using systematic-line plots to determine appropriate cutting regimes (limits).
n-1 to n	Tree marking incorporating directional felling.
N	Felling all marked trees.
n + $^{1}/_{4}$ to n + $^{1}/_{2}$	Forest survey to determine fines on trees unfelled, royalty on short logs and tops, and damage to residuals.
n + 2 to n + 5	Post-felling forest inventory of 10% inventory using systematic-line-plots to determine residual stocking and appropriate silvicultural treatments.
n +10	Forest inventory of regenerated forest to determine status of the forest.

Table 3. Annual Harvesting Coupe

Year	Approved Annual Coupe (ha)	Annual Coupe Logged (ha)
1994	52,250	37,725
1995	52,250	33,246
1996	46,040	37,587
1997	46,040	34,410
1998	46,040	30,408
1999	46,040	41,527
2000	46,040	30,366
2001	42,870	26,711
2002	42,780	26,482
2003	42,780	27,714

Source: Forestry Statistics Peninsular Malaysia 2003

Table 4. Log Consumption By Sawmill and Plywood/Veneer Mills (Meter Cubic)

Year	**Sawmill**	**Plywood/Veneer**	**Total**
1994	9,196,184	1,993,797	11,189,981
1995	10,046,496	1,450,941	11,497,437
1996	9,173,683	1,606,582	10,780,265
1997	9,172,923	1,599,376	10,772,299
1998	5,532,675	1,023,785	6,556,460
1999	6,348,688	1,080,691	7,429,379
2000	6,092,286	9,524,26	7,044,712
2001	5,443,689	7,977,05	6,241,394
2002	5,425,635	7,952,38	6,220,873
2003	6,279,228	7,600,45	7,039,273

Source: Forestry Statistics Peninsular Malaysia 2003

The size of forest area opened for harvesting is regulated and controlled through the National Forestry Council (NFC). To enhance regulation on harvesting operations, the NFC has decided to set output cap per unit area, at 85 meter cubic per ha. With this output cap, the damages to the forest stand is expected to be lower and will ensure sufficient trees left for regeneration and future harvesting.

Technology Development

Environmentally, socially and economically sound timber harvesting is a fundamental aspect of wise forest use. In recent years, research into reduced impact logging (RIL) and low impact logging (LIL) harvesting technologies as a systematic approach to planning, implementing, monitoring and evaluating forest harvesting has been intensified. The principal aim of the new technologies is to improve forest management by minimizing the negative impacts of forest harvesting on the residual stand and the environment.

Reduced impact logging can be described as the implementation of an intensively planned and controlled set of forest harvesting guidelines, which results in low level of damage to residual trees, soil and water so that the productive capacity of the forest after logging is sustained together with its ecological functions.

The essential components of RIL operation generally comprise pre- harvest forest inventory of individual trees, pre-harvest planning of roads and skid trails‘ direction of felling‘ efficient utilization of felled trees, minimum ground disturbances and effective field supervision. Besides the government’s efforts, the private sector has also contributed to the improvement of forest harvesting technologies. For example, Kumpulan Perkayuan Kelantan (KPK) has initiated the building of crusher-run all-weather forest roads in its concession areas, while KPKKT (Kumpulan Pengurusan Kayu Kayan Terengganu Sdn Bhd) has modified an excavator for log extraction that was found to reduce the amount of logging damage substantially when compared to the conventional method. In addition, a local company has built a modified excavator known as RIMBAKA for the purpose of log extraction.

FOREST MANAGEMENT CERTIFICATION

From the Malaysian perspective, forest management certification entails an independent assessment of a forest management operation, according to specific economic, social, environmental and ecological criteria, indicators, activities and management specifications. This forest assessment typically includes an evaluation of the economic viability of the operation, the social and environmental impact of the forest management activities and the ecological health of the forest. It covers forest inventory, management planning, silviculture, harvesting, computation and control of the annual allowable cut, road construction and other related forest management activities.

Since its establishment, the Malaysia Timber Certification Council (MTCC) has been involved in a number of internal consultative processes to formulate and revise the Malaysian Criteria & Indicators (MC&I). It involved government departments and agencies, environmental non-governmental organisations (NGOs), forest licensees, manufacturers of wood and panel products, and trade unions.

A total of 29 indicators, 87 activities and 49 standards of performance under 6 criteria of the MC&I were used to assess forest management practices in 8 states in Peninsular Malaysia; Pahang, Selangor, Terengganu, Johor, Kedah, Perak, Negeri Sembilan and Kelantan. To date, a total of 4.68 million ha of PRF covering the eight State Forest Management Units (FMUs) had been given MTCC's Certificate for Forest Management.

MS ISO 9002

The MS ISO 9000, in brief, is a series of standards for quality management and quality assurance system. The adoption of MS ISO 9000 series will ensure the establishment of quality systems, products and services. The MS ISO 9000 processes can help to attain sustainable forest management because the processes will ensure activities are carried out according to the standards.

The core process identified for the Forestry Department was sustainable timber production from the PRF while the major activities identified to ensure the achievement of this core process are forest boundary demarcation, pre-felling forest inventory, timber tagging, forest harvesting, post-felling forest inventory and silvicultural treatments.

The Forestry Department Headquarters, and eight State Forestry Departments namely, Johor, Kedah, Pahang, Selangor, Kelantan, Negeri Sembilan, Perak and Terengganu have been awarded the MS ISO 9002 certificates.

FOREST BIOLOGICAL DIVERSITY CONSERVATION

The tropical rainforest of Malaysia is one of the most complex and rich ecosystems in the world. The forest has long been recognized as a repository of genetic resources for both flora and fauna. As one of the 12 mega-diverse countries in the world, the forests are home to at least 14,500 species of flowering plants and trees, 600 species of birds, 286 species of mammals, 140 species of snakes and 80 species of lizards (Zul Mukhshar, 2000, Mohd Yunus & Mangsor 2002). In an attempt to diversify and expand the conservation of genetic resources of various forest and ecological types in their original conditions, the Forestry Department has also set aside pockets of Virgin Jungle Reserves (VJRs). A total of 87 VJRs covering 23,002 hectares were established throughout Peninsular Malaysia. These VJRs represent samples of the many forest types found in the PRFs. Represented forest types include Mangrove Forest, Heath Forest, Peat Swamp Forest, Lowland Dipterocarp Forest, Hill Dipterocarp Forest, Upper Dipterocarp Forest and Montane Forest (there are no VJRs in the upper hill and montane forests). These VJRs are unique and represent an integral part of sustainable management practice in Peninsular Malaysia. Besides VJRs, there are other protection areas under different functional classes. There is 0.12 million ha of protected areas in the PRF or 2.5% of the PRF area.

Efforts are also being taken by the Forestry Department to ensure *in situ* conservation of biodiversity during forest harvesting in the production forests of the PRFs. In this context, even though the prescribed minimum cutting limit for the Dipterocarp species in Peninsular Malaysia is 50 cm dbh; for the species *Neobalanocarpus heimii* (Chengal), the minimum cutting limit has been raised to 60 cm so as to better conserve populations of this species. In addition, other measures for environmental protection and biological conservation have been taken into consideration during harvesting: retention of mother trees and fruits trees; retention tree for protection; buffer zone along rivers and streams; timber tagging and directional felling; construction of forest roads; and skid trails and log landings according to prescribed standards approved by the Forestry Department. Seed Production Areas (SPA) have also been established in natural stands for indigenous species such as *Shorea leprosula, S. parvifolia, S. acuminata* and *Eurycoma longifolia.*

The Forestry Department together with the Forest Research Institute Malaysia (FRIM) is undertaking a project to locate and survey threatened tree species. A number of species have already been identified and the Department is taking the necessary steps to conserve areas where the populations occur.

FOREST BIODIVERSITY EXPEDITIONS

The Forestry Department is committed to forest conservation and protection of the environment. A number of projects with greater emphasis on forest bio-diversity is being implemented in the Eighth Malaysia Plan and these are expected to continue into the Ninth Malaysia Plan.

To date, the Forestry Department has organised several scientific biodiversity expeditions. The first expedition was held at the Perlis State Park, Perlis (28 September to 4 October 1999). This was then followed by the Endau Rompin State Park, Pahang (16-22 June 2002), Matang Mangroves, Perak (20-25 October 2002), Ulu Muda Forest Reserve, Kedah (23-29 March 2003), Gunung Stong Forest Reserve, Kelantan (24-29 May 2003), the Royal Belum State Park, Perak (25 July–1 August 2003), Gunung Mandi Angin, Terengganu (5-10 June 2004) and Forest Park Kenong, Pahang (16-21 August 2004). In all the expeditions, the department had the fullest cooperation and active participation from scientists from Universiti Kebangsaan Malaysia (UKM), Universiti Putra Malaysia, Universiti Sains Malaysia (USM), Universiti Malaya (UM), World Wide Fund for Nature, Malaysia (WWF), Malaysian Nature Society (MNS), SIRIM, Forest Research Institute Malaysia (FRIM), Institute of Medical Research (IMR) and other related government agencies. In addition, the Forestry Department also participated in scientific expedition organized by other organization, namely LADA and MNS for the Scientific and Heritage Expedition of Langkawi Islands from 10-19 April 2003, with UKM in the Scientific Expedition of Tasik Chini, Pahang from 22-27 May 2004 and with FRIM during the Scientific Expedition of Gunung Aais, Pahang from 3-10 July 2004.

The Forestry Department had also organised a series of seminars to disseminate the results of the expeditions. To date, three seminars had been organised, namely Endau-Rompin, Pahang (5–6 May 2003), Ulu Muda, Kedah (14–16 February, 2004) and Gunung Stong, Kelantan (20–22 April, 2004). In addition a National Conference on Sustainable Management of Matang Mangroves, Perak was held from 5 – 8 October 2004.

CONCLUSION

The need for effective forest management and conservation must be given priority, not only to ensure a sustained supply of wood and non-wood forest products but also to maintain forest health for environmental stability, to provide sanctuary for wildlife and to serve as an invaluable storehouse of genetic resources useful for indigenous tree species, agricultural crops and livestock. This renewal asset will continue to be managed in accordance with national objectives and priorities so that the country will continue to enjoy the benefits generated from the forests and forest industries.

Malaysia's commitment to sustainable forest management is best reflected through her achievements in the formulation of the comprehensive National Forestry Policy and the National Forestry Act, the establishment and gazettement of PRF and a network of conservation areas, and the marked progress made in forestry research and development. It is further attested by the operationalisation and implementation of the Malaysian Criteria, Indicators and Activities for Assessing Sustainable Forest Management based on the elaboration of the ITTO Criteria and Indicators for Sustainable Management of Natural Tropical Forest, and the allocation of financial resources to carry out forest development activities, as well as projects and studies related to sustainable management.

Sustainable forest management is the principle of the forest management practices in Malaysia and the Forestry Department will continue to enhance and improve its management practices in the light of new research findings, innovative technologies, better skills and knowledge. Thus, it will demand conscientious effort, a lot of hard work and a strong commitment, determination and collaboration from the government, private sectors and non-governmental organizations (NGOs).

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PLANT BIOGEOGRAPHY OF THE MALAYSIAN REGION

Wong Khoon Meng

ABSTRACT

The major characteristics of Malaysia's rich plant diversity are explored. Basic ideas in plant geography are recapitulated, outlining the interest and significance of studying plant distributions. The biogeography of the Malaysian region focuses on two principal components: the distribution of taxa within the region, which identify the Riau Pocket and other biogeographical elements, and affinities between geographical areas, such as the Malesian and Australasian floras. Aspects of historical biogeography, pertaining to changes in distribution with reference to earth history, i.e., geological processes and changes through geologic time (including plate tectonics, continental drift and "interplate dispersal" of plants, and climatic change), and ecological biogeography, addressing patterns of distribution in relation to prevailing environmental conditions (such as the Malesian demarcation knots and local edaphically controlled floristic differences), are dealt with. The biogeographical setting of the Malaysian region is summarized in terms of the biogeographical units recognized via repeated floristic patterns (the Malay Peninsula, Perak, the Riau Pocket and NW Borneo hotspot, the Kapuas-Lupar region, the East Coast Sabah subprovince, and seasonal Asiatic intrusions); sharp ecological definitions and isolated environments (high mountains, limestone hills, ultramafic sites, kerangas-peat swamp complexes) and the apparently high speciation rates in lowland rain forests.

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APPLICATION OF GIS TO CONSERVATION ASSESSMENTS AT THE ROYAL BOTANIC GARDENS, KEW

J. Gregson, R. de Kok, J. Moat & S. Bachman

ABSTRACT

As part of its conservation work in areas such as Madagascar and Cameroon, the GIS unit at the Royal Botanic Gardens, Kew has developed the use of Geographical Information Systems (GIS) in making rapid conservation assessments. These applications assist Kew staff to make better informed species conservation status assessments, such as International Union for Conservation of Nature and Natural Resources (IUCN) ratings, based not only on herbarium and field data, but also on up to date vegetation maps, physical and climatic conditions and known threats. This article gives an overview of the work of the South-East Asia Section at Kew, and reviews the algorithms used by the GIS unit which are relevant to the Malaysian Plant Red Data Project.

INTRODUCTION

The Royal Botanic Gardens, Kew has been at the forefront of plant taxonomy research for over 150 years, and has a long history of research and collaboration in South-East Asia. As scientists have become more aware of the worldwide threat to biodiversity, the focus of Kew's work has moved in recent years towards plant conservation and sustainable use of plants. A variety of work is being undertaken in these areas: baseline biodiversity research (producing inventories and check-lists); production of support materials, such as field-guides; seed-banking and development of specialised horticultural techniques with a view to future re-introductions and forest restoration; research into sustainable use of plants; and vegetation mapping and conservation assessments using Geographic Information Systems (GIS). This work is carried out in collaboration with local institutions, with an emphasis on training and capacity-building.

Baseline biodiversity research is being undertaken with contributions to regional floras such as Flora Malesiana (Chrysobalanaceae (Prance 1989), Nepenthaceae (Cheek & Jebb 2001)) and the Tree Flora of Sabah and Sarawak (Aquifoliaceae (Andrews 2002), Chrysobalanaceae (Prance 1995), Dipterocarpaceae (Ashton 2004)). Inventories and check-lists are also being produced, for regions including Mt Kinabalu (Beaman 1992-2004), Brunei (Coode *et al.* 1996),

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Mt Jaya and Vogelkop (New Guinea), and the Maliau Basin, Danum Valley and Imbak Valley in Sabah. Kew is also working on World Checklists of various groups: Monocots, Labiates, Euphorbiaceae, Rubiaceae, Conifers, Araliaceae, Sapotaceae, Fagales and Magnoliaceae have been completed to date.

Kew is also active in bioinformatics, and several computer-based interactive keys have been produced or are being worked on, including Rattans of Borneo, Rattans of Laos and an interactive key to the families of the Flora Malesiana region (Malesian Key Group 2004). Projects can include the production of field guides, which are an invaluable identification aid and educational tool: current projects include the production of a Field Guide to the Forest Trees of Southern Thailand, and a project to assess and conserve plant diversity in commercially managed tropical rainforests in eastern Sabah, both with funding from the UK Darwin Initiative. Kew offers a wide range of training opportunities, from informal courses and support to international courses in Herbarium Techniques, Botanic Garden Management, Plant Conservation Strategies and Tropical Plant Identification.

The herbarium at Kew also contains a dedicated GIS unit, which provides GIS and Remote Sensing support for Kew, and works on various projects around the world. GIS is a useful tool for speeding up conservation assessments, by automating initial IUCN ratings based on herbarium specimen data, and by using analysis of plant distribution patterns combined with other geographical data to inform conservation planning. This paper looks at some of the ways in which GIS has been used to help with conservation assessments, looking at examples of past and current projects the unit is working on.

Geographical Information Systems (GIS) is a more powerful version of a conventional printed map, with the advantage that different sets of information can be extracted from the map, as required. In addition, databases can be linked to the geographical information stored in the map, and this data can be analyzed and modeled spatially using computer software. GIS has many applications, and can be put to use in the field of plant conservation in two main ways: using herbarium specimen data, and vegetation mapping using data from remote sensing.

GIS AND HERBARIUM SPECIMEN DATA

Point Distribution Maps

The information contained in herbarium specimen labels provides a large and useful database, which includes spatial data (locality information) and temporal data (collection dates), which is ideal for analysis by GIS. Research into plant taxonomy at Kew has generated a large body of information in plant systematics as well as accumulating one of the largest and most complete herbarium collections in the world. This information, especially when combined with data from other herbaria, can be put to use developing advice for biodiversity conservation planning (e.g., Schatz 2002).

Many families with particular expertise at Kew, for example Palms and Rubiaceae, have been studied in depth and large databases have been created for these families using data from the Kew Herbarium and other herbaria around the world; the locality information recorded on these specimens has been looked up in atlases and gazetteers and translated into numerical coordinates (georeferencing) suitable for analysis by GIS. Although the data originates from different eras and is of varying accuracy, the accuracy of herbarium specimen records can be weighted, to take into account imprecise locality data from older specimens. A series of in-house tools have been developed to aid georeferencing of Kew's herbarium specimens including converting co-ordinates from different projections e.g. UTM and taking bearings from a known locality e.g. '20 miles north of Gaborone'.

The software used by the GIS unit includes all ESRI products (previously ArcView and now ArcGIS 9) and ERDAS primarily for remote sensing work. The Digital Chart of the World can be used as a standard base map for plotting species point distribution maps. Additional maps (called layers) can then be added and queries between the map layers are possible. Standard GIS techniques and algorithms have been used in a variety of ways and are continually being developed for novel applications.

A simple example (Fig. 1) shows a point distribution map combined with a map of geological substrate. A histogram can be quickly plotted showing how the distribution of different species varies with geological substrate. By combining point distribution maps with other types of map, histograms can be produced to show the range of substrates, vegetation types or altitudes which a particular species prefers – this information can be used in conservation planning,

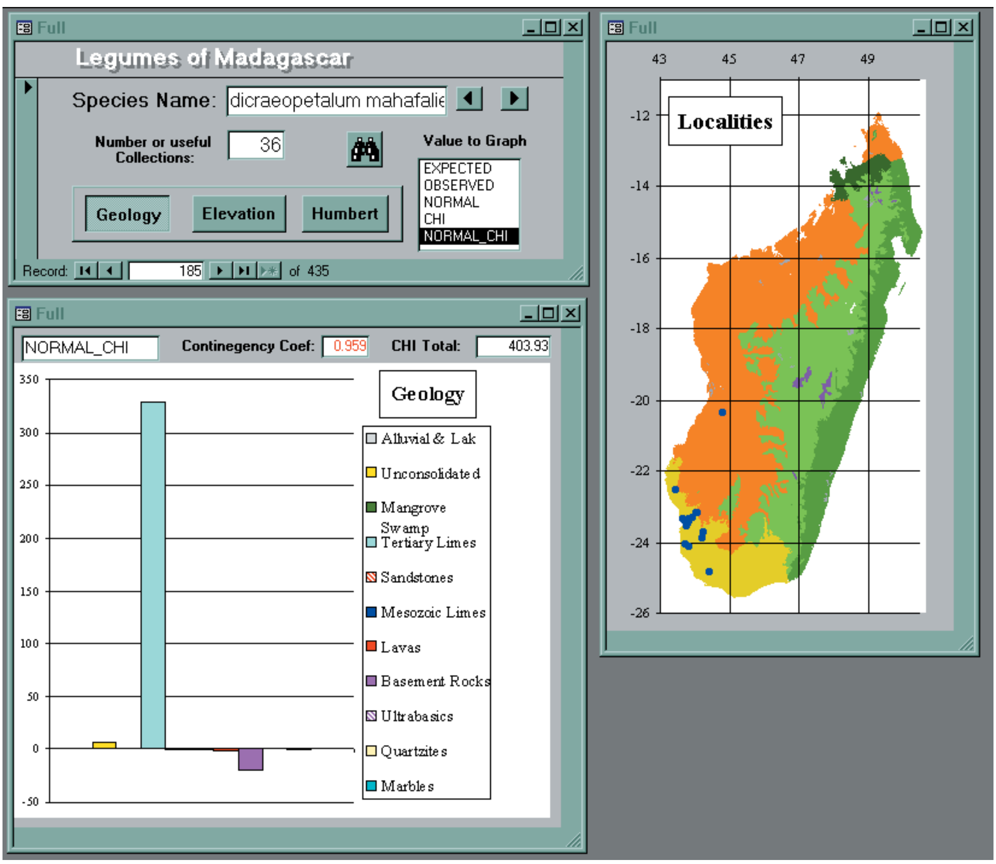


Fig. 1. Analysis of distribution in relation to geological substrate.

also to locate where a species may occur and has not been collected or even for the reintroduction of a species.

A revision of the Leguminosae of Madagascar (Du Puy *et al*. 2001) has provided the basis for applying GIS to the investigation of ecological parameters which determine the extent of species distributions. The revision produced a database of Papilionoid Legumes in Madagascar, giving the co-ordinates of each collection locality, which could be used to make a point distribution map. The species distribution map was then compared with other map layers in the system, such as altitude, substrate, climate or vegetation type and the results gave much greater precision of altitudinal ranges, substrate preferences (both difficult to determine accurately in the field, leading to inaccurate data on specimen labels) and data on other ecological parameters which dictate the distribution patterns of the species.

This data on ecological parameter preferences of species, combined with map layers, can be used to predict the full possible distribution of a species, filling in the apparent gaps caused by under-collection in certain areas: a technique called gap analysis (Scott *et al*. 1993). Point distribution maps only show where species have been collected, and not necessarily the whole range of a species: the points are often concentrated along roads and rivers or other easily accessible areas. However, by applying this technique, the full distribution of a species can be predicted from incomplete point distribution maps.

Other techniques have also been developed from this project, and are discussed below.

GIS AND IUCN RATINGS

One of the primary targets agreed under the Global Strategy for Plant Conservation (Anon. 2002) is "A preliminary assessment of the conservation status of all known plant species, at national regional and international levels" (Target (a) (ii)) – to be achieved by 2010. However, currently less than 3% of vascular plants have a global conservation status using the IUCN criteria, and between 2003 and 2004, the number of species evaluated and published was similar to the number of new species described during that period. The rate at which IUCN ratings can be assigned and published therefore needs to be dramatically increased if this target is to be met, and if IUCN ratings are to be of use in conserving plant biodiversity.

GIS can be used as a tool for applying IUCN ratings as certain parameters used in IUCN Red List criteria can be quickly calculated from databased and georeferenced species. Using herbarium datasets, scripts have been developed in Avenue (ArcView's programming language) to automate the calculation of Extent of Occurrence (EOO), Area of Occupancy (AOO), estimates of the number of subpopulations as well as the number of collections and number of unique localities. Willis *et al*. (2003) used herbarium data in Red List assessments of *Plectranthus* from eastern and southern tropical Africa, and describe the GIS techniques used.

Extent of occurrence (EOO)

The spatial distribution (range) of a species can be used in assessing its conservation status, as a species with a small distribution, or a distribution fragmented in few locations, is likely to be more threatened than a species which is continuously distributed over a large geographical area. Distribution is also the parameter which is most suitable for GIS analysis.

IUCN criteria recognise two types of range-related attributes of a species: extent of occurrence" (EOO) is the area that includes all sites of occurrence of a species (Fig. 2a), and "area of occupancy" (AOO, discussed below) is the area within a species' extent of occurrence which is currently occupied by the species (Fig. 2b).

In order to assign a category of threat to a species, five quantitative criteria are defined (criteria A-F), and at least one needs to be met for a species to qualify as threatened, but a species should be tested against all criteria where possible. Various parameters are used in each criterion and extent of occurrence is used in Criteria A (declining population) and B (geographical range size, and fragmentation, decline or fluctuations).

IUCN defines the extent of occurrence as "the area contained within the shortest continuous imaginary boundary which can be drawn to encompass all the known, inferred or projected sites of present occurrence of a taxon…EOO can often be measured by a minimum convex polygon (the smallest polygon in which no internal angle exceeds 180 degrees and which contains all the sites of occurrence)." (IUCN 2001).

Extent of occurrence can be calculated within a GIS by:

1. importing georeferenced data
2. plotting a point distribution map
3. generating a polygon enclosing the points
4. calculating the area of the shape

An algorithm should be used to ensure the shape is drawn in the same way each time (Willis *et al.* 2003). In addition it should be noted that the EOO calculation can only be made when there are at least three unique localities.

IUCN (2001) recommend that EOO is calculated using a minimum convex polygon (also called a convex hull), (see above). However, Burgman & Fox (2003) showed that estimates based on minimum convex polygons are often biased, affected by the spatial arrangement of the habitat, the sample size and the spatial and temporal distribution of the sampling. The use of Alpha hulls is recommended for estimating EOO as this method can reduce (but not eliminate) these errors.

Scripts have been developed for automating EOO calculations in ArcGIS using Alpha-hulls. Problems may arise when trying to define the value of alpha (α). IUCN (2005) suggest a value of 2 as 'a good starting point, but no further information is available.

Area of occupancy (AOO)

IUCN defines area of occupancy as "the area with its 'extent of occurrence' which is occupied by a taxon" (IUCN 2001). This definition reflects the fact that a species will not usually occur throughout the area of its extent of occurrence, which may contain unsuitable or unoccupied habitats. AOO is used in Criteria A (declining population), B (geographical range size, and fragmentation, decline or fluctuations). and D (very small population or very restricted distribution).

IUCN recommends obtaining estimates by counting the number of occupied cells in a uniform grid that covers the entire range of a taxon, then tallying the total area of all occupied cells (Fig. 2b). This is a calculation that can be easily automated within a GIS.

One problem which arises with area of occupancy calculations is that the results of this method are highly influenced by the placement of the grid. For example, if an organism is found at four localities that are less distant from each other than the distance across a grid cell, the calculated area of occupancy can vary by a factor of four (White 2004). This problem can be reduced by searching for a grid position which minimizes the area of occupancy. White (2004) describes a method for automating this procedure within ArcView and concludes that "the arbitrary nature of using fixed grid methods should be avoided". Using an automated method has the advantage that it results in a consistent grid placement, ensuring consistent results if the procedure is replicated (Willis *et al*. 2003).

However, another problem arises with calculating AOO because the "size of the area of occupancy will be a function of the scale at which is measured, and should be at a scale appropriate to relevant biological aspects of the taxon, the nature of the threats and the available data" (IUCN 2001). For example if a species has been rarely sampled, then the distance between observed locations might reflect a lack of observations rather than a lack of occupied habitat and a coarser grid may therefore be more appropriate. It is therefore not appropriate to use one set cell size for a wide range of taxa, but what is an appropriate grid size to use when automating AOO calculations?

The guidelines for using the IUCN criteria (IUCN 2005) recommend a grid size of 2 km, recognising that for intensely sampled species, a finer grid of 1 km may be more appropriate, and for sparsely sampled species, a coarser grid. Grid sizes of more than 3.2 km are not recommended as they preclude the listing of species as Critically Endangered (CR) because the AOO threshold for CR is 10 km^2. A method is described of standardising AOO estimates by scaling the AOO estimate up or down to the reference scale (a 2 km grid size).

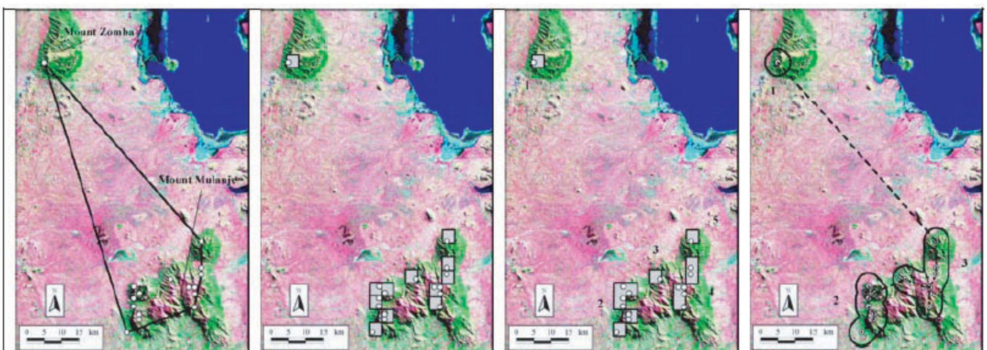
Willis *et al*. (2003) suggest that a suitable grid cell width/height is one tenth of the maximum distance between any two points on the extent of occurrence polygon. This effectively scales AOO to the EOO measurement and has given good results so far. Calculations of AOO using this 'sliding scale' grid width/height are currently adopted by the GIS unit at Kew, although the grid cell size can be manually set by the user within the application. AOO can also be calculated when there are only two unique localities; the 'sliding scale' technique can be used where grid cell width/height is one tenth of the distance between the two points.

Number of Sub-populations

IUCN defines sub-populations as "geographically or otherwise distinct groups in the population between which there is little demographic or genetic exchange" (IUCN 2001). Subpopulations are used in Criteria B (geographical range size, and fragmentation, decline or fluctuations) and C (small population size and fragmentation, decline or fluctuations). Two techniques for estimating the number of subpopulations of a species have been developed: the cell adjacency method (Schatz 2002) and Rapoport's mean propinquity method (Willis *et al*. 2003), (Fig. 2c). The cell adjacency method considers all contiguous grid cells from the AOO calculations to be a single subpopulation. Rapoport's mean propinquity technique is based on the mean line length of a minimum spanning tree (a set of lines that connect all points in the minimum possible distance). Subpopulations are separated where the limb (line) distance is greater than twice the mean limb distance (Willis *et al*. 2003).

Other parameters

The above three parameters have the advantage that they can be calculated quickly, easily and automatically from georeferenced data sets, and can be used to assign preliminary conservation ratings to species using IUCN Criteria. For taxa that are threatened, a more detailed 'desktop' conservation assessment may be required and GIS can be of use here too. Habitat level data can be used to infer declines at the species level. Remote sensing imagery including aerial photographs and satellite images were used to see how forest cover changed over time at Mount Oku and Ijim Ridge in Cameroon (Baena 2005).



A	B	C	D
Extent of Occurrence: for *Plectranthus elegans* area equals 1,321 km²	Area of Occupancy based on a cell size of 3.64 x 3.64 km (13 km²). 12 cells giving a total Area of Occupancy of 156 km²	Subpopulations using contiguous grid cells method, giving 5 sub-populations	Subpopulations :Rapoport's mean propinquity method Area 437 km² Number of subpopulations : 3

Fig. 2. Examples of EOO, AOO and subpopulations calculations using GIS. From Willis *et al*. (2003).

Habitat fragmentation for each species distribution can also be calculated: the preferred habitat of the species is first identified from the label, and species distributions compared to habitat datasets. Fragmentation of habitats can be calculated using Fragstats program and Patch Analyst in ArcView. Consideration needs to be made as to which metric of fragmentation is used; again there may not be a 'one size fits all' solution. It may also be possible to develop indices of fragmentation based on the subpopulation techniques as discussed above. Biological meaning can be added to the distances between subpopulations, i.e., by considering dispersal ability so that a more realistic measure of fragmentation can be obtained.

GIS AND VEGETATION MAPPING

As noted above, currently only c. 3% of vascular plants have a global conservation status using the IUCN criteria, and so in some areas, much more rapid methods of conservation assessment may be required.

Analysis of vegetation maps in GIS can be a powerful tool for rapid conservation prioritization. GIS analyses provide solid scientific data, which can be used for planning and management of biodiversity conservation. This technique produces relatively rapid biodiversity assessments, and so is particularly suited to conservation hotspots where information on the distribution and rarity of the vast majority of plant species is scarce, and habitats are being destroyed faster than individual species distribution data is being compiled.

Madagascar is one such conservation hotspot with high biodiversity and a high level of endemism, which is under threat from habitat degradation and destruction. At Kew, the methods described below have been used successfully in Madagascar to identify conservation priorities, and similar techniques may be applicable in other conservation hotspot areas such as South-East Asia.

Case study: vegetation mapping in Madagascar

Du Puy & Moat (1998) used the Papilionoid Legume specimen database to demonstrate that certain parameters such as seasonality and substrate (underlying rock type) have an effect on species distribution (see discussion above). Distinct preferences can be demonstrated for many species, such as exclusive occurrence in seasonally dry or perennially humid habitats, on a certain geological type such as limestones, quartzites or sand (Du Puy & Moat 1998). A more informative vegetation map can therefore be made by dividing the broad vegetation zones into narrow vegetation types based on rock type, which reflect the distribution of individual species, so that each type of vegetation contains its own distinctive range of species. This subdivision of vegetation zones based on underlying rock types is therefore a way of rapidly estimating patterns of individual species distributions. If as many vegetation types as possible are included in reserves, the resulting network of protected areas will contain as large a diversity as possible. This technique has been successfully applied to conservation and planning and management of protected areas in Madagascar (Du Puy & Moat 1996).

Initially, a map of remaining primary vegetation in Madagascar was derived from satellite imagery. Classification and mapping was done by remote sensing techniques, using Landsat and Spot data (Faramalala 1988).

In the next step, a geological map was digitised and simplified to rock types affecting vegetation (e.g. limestone, lavas etc). A composite map was then produced, of vegetation zones and rock types, showing patterns of variation within vegetation zones (Fig. 3). Each vegetation zone subdivision (vegetation type) will contain a different suite of species, so the maximum number of species can be preserved by conserving as many of the vegetation zone subdivisions as possible.

The current degrees of protection for each vegetation type were quantified, by overlaying a map of protected areas onto the vegetation types map. Amounts of protection for each type

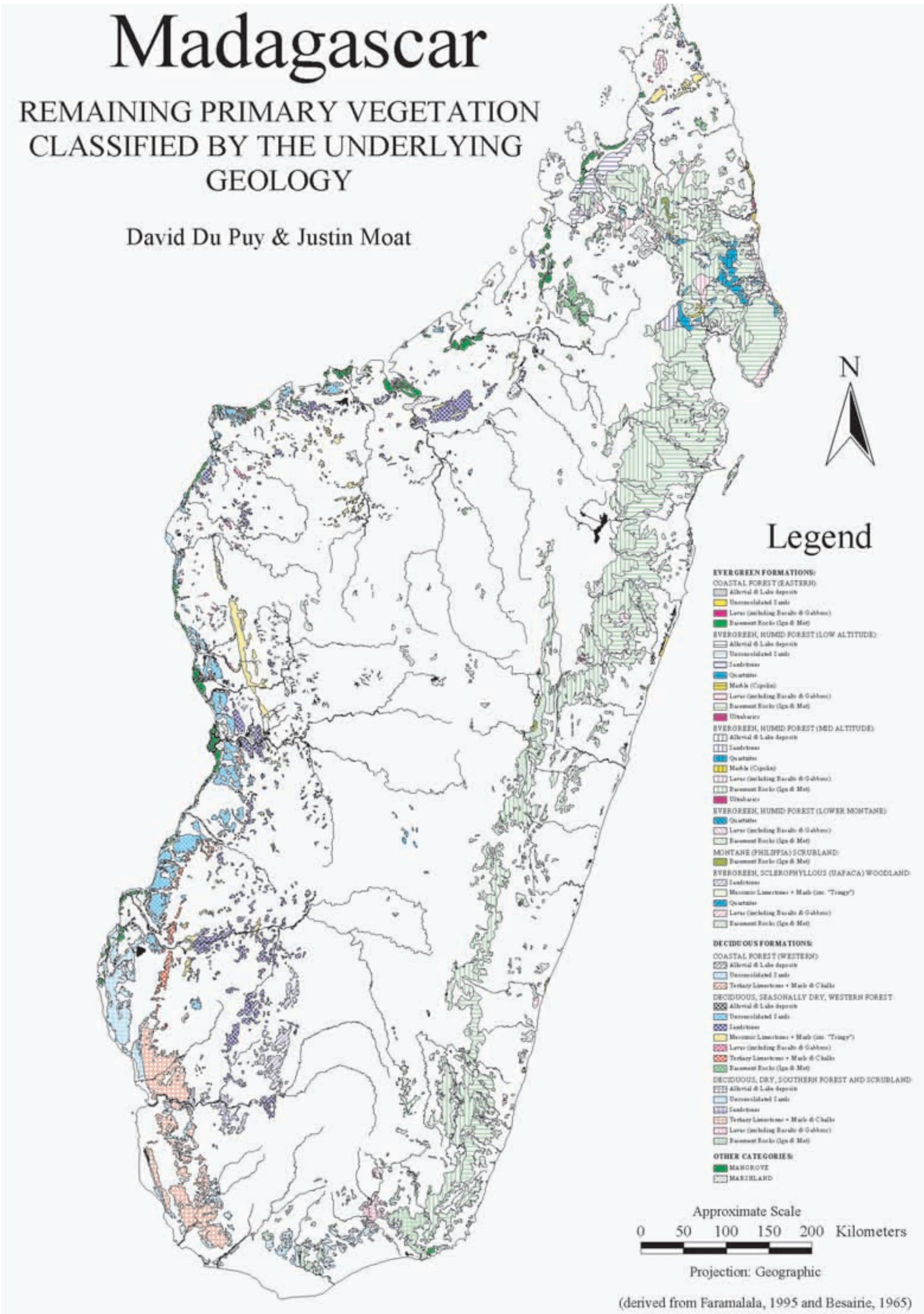


Fig. 3 (From Du Puy & Moat 1998)

were automatically calculated in ArcView, and the results displayed on histograms (Fig. 4), enabling poorly protected areas to be identified.

This technique enables plant diversity assessments of hotspot areas to be compiled relatively rapidly, which can then be used to identify conservation priorities, so that new reserves can be targeted to conserve the greatest possible diversity of species.

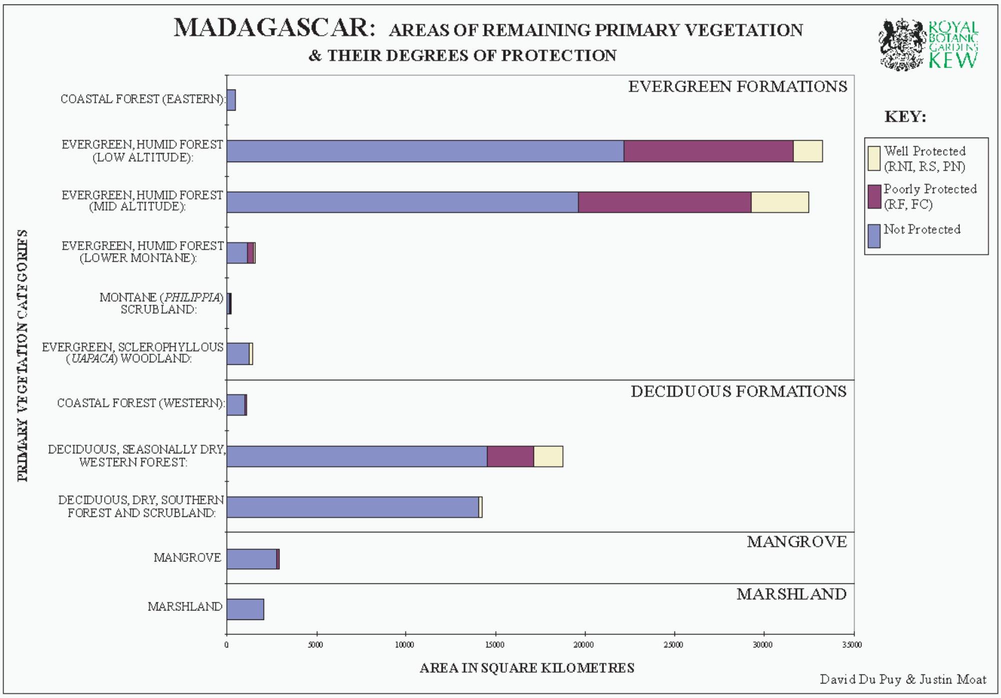


Fig. 4. (From Du Puy & Moat 1998).

FUTURE WORK

The GIS unit at RBG Kew is continuing to develop techniques to aid conservation efforts, in particular through improving automated conservation assessments based on IUCN Categories and Criteria. Ecological niche modelling has been investigated as a potential tool for estimating species range size and may be useful in delimiting isolated populations, therefore informing studies of fragmentation. Lack of data may be the biggest problem for these techniques as large numbers of data points (i.e. unique localities) are often needed to a) run the algorithms and b) validate the final models. As previously mentioned an index for fragmentation based on Rapoport's mean propinquity method and dispersal ability is also being investigated. The algorithms for the methods as outlined above are available from the GIS unit upon request.

This initial work on the Madagascar Vegetation is being updated using remote sensing techniques for the year 2000/1/2 (Anon. 2005) This uses MODIS imagery, which separates vegetation classes with a single-date surface reflectance image combined with entire year vegetation greenness data. Composite images of Landsat ETM imagery were used to eliminate cloud cover. An initial classification separated 11 land cover classes, and then a higher resolution subsequently (from 250 metres to 30 metres) obtained, using Landsat ETM (enhanced thematic mapper) on board Landsat 7.

CONCLUSION

Recent advances in information technology have led to the development of computer based methods in conservation biology, and GIS is a particularly useful tool for plant conservation. Target 2 of the Global Strategy for Plant Conservation aims for “a preliminary assessment of the conservation status of all known plant species, at national, regional and international levels” (Anon. 2002) but at current rates, this target will take a long time to reach. GIS can speed up this process by providing a means to automate the preliminary assessment of the conservation status of a particular species based upon specimen information present within existing major collections.

The application of these methods is limited by the availability of data and the uncertainties in the available data. These GIS techniques require large amounts of georeferenced specimen data, and such databases are often the product of taxonomic work. However, new technologies facilitating data transfer and electronic publication now make it possible for data held within institutions to be shared and analysed collaboratively.

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APPLYING THE IUCN RED LIST CATEGORIES IN A FOREST SETTING

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ABSTRACT

The IUCN-The World Conservation Union Red List categories provide a globally-accepted framework for classifying animal and plant taxa according to their risk of extinction. Different versions of the categories have been in use for forty years. Their present form, version 3.1 published in 2001, demands a quantitative assessment of species status, and has been carefully designed to accommodate the spectrum of case-studies from large mammals to mosses or commercially-exploited trees to poorly-known insects. Consequently, the categories are assigned by the use of any one of five major criteria that infer either past or potential species population declines, or habitat declines, restriction in geographical distribution or population numbers. For the uninitiated assessors of forest species, the categories may present a daunting need for largely unavailable data. In this paper, we would like to demonstrate that the categories can be applied through the use of available forest management data, biological inventory datasets and/or proxy information on habitats, as well as a certain amount of inference or extrapolation. Developing standards for using the criteria at a national level promotes consistency, replicability and a shared understanding of the categories. Furthermore, shared standards can be developed and applied across regions through forest genetic resource networks and species specialist networks (e.g. APFORGEN and the IUCN Species Survival Commission (SSC) Global Tree Specialist Group), and contribute to global indicators of biodiversity loss relevant to the Global Strategy on Plant Conservation and the Convention on Biological Diversity's 2010 target.

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INTRODUCTION

In 2002, the Conference of the Parties to the Convention on Biological Diversity (CBD) and world leaders at the World Summit on Sustainable Development endorsed a commitment to reduce biodiversity loss by 2010. Among the indicators of biodiversity loss that are being adopted by the CBD are the IUCN Red List categories. Red List categories and Red Data books, over the past four decades of use, have become widely recognised as an international standard and reference for species conservation status. However, only 2.5% of the estimated number of extant (and recently extinct) species has been assessed; the comprehensively covered groups being mammals, amphibians, birds, conifers and cycads (Baillie *et al.* 2004). Furthermore, at a national or local level, conservation action continues to be geared towards species that are economically, ecologically or aesthetically attractive at a local level, rather than to the species which are listed 'top of the league' in Red Lists.

It has been the expressed intention of the IUCN Red List categories not to prioritize species but to provide an objective indicator of extinction risk, which might be used as an initial step in the conservation prioritization process. In reality, throughout much of the developing world resource managers carrying out conservation on the ground do not apply or refer to the Red List categories for multiple reasons. This divorce between the processes of defining conservation priorities at a local level and global level could give reason to be sceptical of the 2010 targets being monitored appropriately, let alone achieved. However, the Workshop on Threat Assessment of Plant Species in Malaysia, organized by the Forest Research Institute Malaysia (FRIM) represents a national level initiative to bring together conservation practitioners, taxonomists and Red List assessors to provide coherence to the Red List process.

This paper is not an overview of the guidelines for the Red List categories (please see the official guidelines prepared by the IUCN SSC Red List Programme) but explores their application when assessors only have access to limited datasets. It also briefly examines the Red Listing process in comparison to a conservation prioritization process, which might be adopted by a forest resource manager, and suggests mechanisms by which Red Listing might be better aligned to conservation action on the ground.

THE EVOLUTION OF THE IUCN RED LISTING SYSTEM

Before 1994, the IUCN proposed a mechanism for Red Listing species that was based entirely on subjective judgement of experts. Species were categorized according to an increasing order of extinction risk: from 'Endangered', 'Vulnerable' to 'Rare', and 'Indeterminate' for those species which were threatened to an unknown degree. Responding to recommendations for the development of a system to promote transparency, objectivity and replicability, several new versions of the categories were drafted and tested in consultation with experts of different taxonomic fields over a five-year period. The agreed system, version 2.3, was published in 1994 (IUCN 1994) and presented a quantitative framework for the application of categories very similar to the present version (3.1). Different animal and plant groups were evaluated using version 2.3 categories and a number of issues arose, most publicly a controversy on the listing of commercially-exploited fish species. A Criteria Review Working Group was brought together to recommend revisions to the system. As a result of their discussions some small but significant changes were made and version 3.1 was published in 2001 (IUCN 2001; see box entitled “Main differences between versions 2.3 and 3.1.”). A system for the application of categories at a regional level was also devised and published in 2003 (IUCN 2003).

In version 2.3 and 3.1 the IUCN have striven to develop a scientifically thorough and robust evaluation system to represent as accurately as possible the risk of species extinction. The system is impressively flexible in being applicable to a wide range of life forms under very different types of threat, everything from corals, colonial ants, obscure mosses known only from one location, ancient redwoods, elephants and commercially-exploited fish species.

Such broad applicability has been achieved through the use of a range of criteria, of which only one need apply for the allocation of a threat category:

A. Population reduction (past, present or future)
B. Limited geographic range, fragmented, declining or fluctuating
C. Small population size and fragmented, declining or fluctuating
D. Very small population or restricted distribution
E. Quantitative analysis of extinction risk

Each criterion has three quantitative thresholds corresponding to increasing extinction risk: ‘Critically Endangered’, ‘Endangered’ or ‘Vulnerable’. Species that do not meet any thresholds are considered either to be ‘Near Threatened’, ‘Least Concern’, ‘Data Deficient’ or ‘Not evaluated’. The thresholds are arbitrary but appear to be generally applicable to a wide range of threatened taxa. For any one species, the thresholds of some criteria may be inappropriate but at least one alternative criterion should be applicable. The spirit in which the system was devised encourages the user to examine each species profile against all five criteria so that the most relevant and precautionary assessment is attained. For more details you are directed to the red list categories and guidelines (IUCN 2001; IUCN 2005; http://www.iucnredlist.org/info/programme.html).

Main differences between versions 2.3 and 3.1 of the IUCN Red List Categories

- New A subcriterion with a more challenging threshold (reductions of at least 50% as opposed to 20%) for species which are subject to population declines because of known and reversible threats. This provides leeway for species undergoing a controllable decline (e.g. commercial exploitation) to avoid classification as threatened until a more serious population decline has taken place;
- The threshold for species classified under VU A have risen from a 20% population decline to 30%;
- Allowance of population declines within a ‘moving window’ of the past or future in A4
- Maximum time cap for derived future declines of 100 years;
- Addition of subcriterion on extreme fluctuations under C2;
- VU D2 guidelines for restricted area of occupancy reduced from $100km^2$ to $20km^2$
- Loss of ‘Lower Risk - Conservation Dependent’*
- Some important changes in definitions have taken place
- National and regional level assessments possible

* this affects the evaluation of 20% of Peninsular Malaysian tree species which were assessed against version 3.0 categories – the most appropriate category for these species is now ‘Near Threatened’

The present version is not expected to be updated in the foreseeable future. A comprehensive set of guidelines (IUCN 2005) and a documentation format have also been produced. Evaluated species must now follow a submission system, involving the completion of a four-page information sheet with a 15-page annex to capture information on habitat, threat, conservation measures, use and trade. Forms are submitted to the Red List Secretariat and evaluated by the appropriate Red List Authority. Depending on the approval of the assessment the species will be published in the next edition of the IUCN Red List of Threatened Species™.

A QUANTITATIVE ASSESSMENT WHERE FEW QUANTITATIVE DATA EXIST

All numerical data, as well as less quantitative information, are uncertain to some extent and most of the difficulty of using the red list categories is related to uncertainty of various kinds (Akçakaya *et al.* 2000). Estimating population sizes and declines for individual species depends, at best, on the use of statistical distributions that are subject to environmental influences, intra and inter-population variation, or, at worse, on circumstantial information, inferences from related taxa or trends in the species' habitat.

The way in which uncertainty within the data is handled has a significant influence on the outcome of the assessment. Perversely, the more data available on a species the greater the number of options available to carry out the categorization, and as a consequence additional uncertainties creep into the assessment and the need for detail in the guidelines increases. An illustration of this paradox is the category 'data deficient', which is intended for both species that are "well-studied, with biology well known, but where appropriate data on abundance and/or distribution are lacking"; and for species known from type specimens for which there are no available data at all.

Data uncertainty is recognized to be a result of either measurement error or natural variation or semantic vagueness (Akçakaya *et al.* 2000)—the latter being the payback for designing a system that has to limit explicitness in order to conserve its general applicability. The authors of the guidelines and criteria make a considerable effort to describe how assessors deal with data paucity and uncertainty. Specific methods for dealing with different forms of uncertainty are developed using fuzzy numbers (Akçakaya *et al,* 2000). Assessors are suggested to provide range values and best estimates and describe the means through which these were attained—through confidence limits or expert opinion etc. They are also advised to be explicit about their attitude to risk and dispute, both of which influence the interpretation of data and the management of uncertainty. The qualification of individual species under a range of categories to reflect data uncertainty is acceptable—although only one category will be published in a red listing.

Fuzzy numbers are most effective when datasets are relatively rich and measurement error is the greatest constraint. Where data are poor, the assessor is faced with the quandary of using estimation, inference and even suspicion in what appears to be a well-defined quantitative framework. In these cases, where qualitative data are used to answer a quantitative question the possibilities for interpretational and semantic errors become more significant. For example, a 'subpopulation', which is used in criteria B and C, is defined by rates of genetic exchange ("typically one successful migrant individual per year or less"). Taking tree species as an example, this knowledge is confidently or partly known for perhaps 100 or so tropical trees in total, which have been the focus of detailed studies—for lesser known species defining subpopulations remains highly assumptive, based less on measurement and more on the assessors willingness to make a judgement based on general ecological knowledge of the taxonomic group and the presumed extent and distribution of subpopulations. Similarly putting an estimate on the age of 'mature individuals', as a basis for estimates of population size, or the 'average age of parents', the unit for estimating the timeframe within which population reductions are measured, are challenging for the vast majority of tropical plant species, especially as these values may not be constant throughout the range of a species.

There are some criteria that are more lenient than others at allowing the use of inference or proxy data. There are defined terms of assessment based on an increasing degree of assumption:

- *Observed* is based on firm data.
- *Estimated* is based on data with an allowance of statistical estimation or assumptions about observed variables (e.g. indices of abundance) and the measure variable (number of mature individuals). Estimations are also *projected* into the future.
- *Inferred* is a calculation based on indirect evidence but at least within the same units of measurement (e.g. population declines based on rate of habitat loss). Inferences may also be made when imposing trends from certain subpopulations to infer the status of lesser known subpopulations and the global population as a whole.
- *Suspected* is a type of inference that is based on indirect evidence concerned with another unit of measurement (e.g. population declines based on changes in habitat quality).

A first step to approaching the Red Listing process might be to realize the potential of the available dataset and work with the criteria that are suited to the levels of assumption that are required. For criteria **C1** and for **D** (categories of 'Endangered' and 'Critically Endangered') population size must be **estimated,** whereas criterion **A** allows the use of proxy data to **infer** population reductions.

RULES OF THUMB AND USING PROXY DATA

Rules of thumb can help to tighten the definitions for defined groups of species or geographical areas so that assessments can be made using a common understanding. Rules of thumb are "rules of general guidance that are based on experience or practice rather than theory". They represent a pragmatic approach to dealing with limited information or circumstances. In the case of the Red List categories they potentially help to improve replicability, consistency and

Ways of dealing with lack of data:

- estimations, projections, inferences, and suspected trends, including:
  - the use of proxy data
  - extrapolation from known subpopulations to less well-known subpopulations
  - ecological inference from close relatives to less well-known species
- using criteria which are more accepting of qualitative data e.g. A & B
- describing range values and giving best estimates
- establishing rules of thumb

transparency and introduce some certainty about how the evaluation took place. The guidelines are full of rules of thumb that are applicable at a general level. However, more specific rules of thumb may be defined for groups of related taxa or unrelated taxa either with shared life forms, biological or ecological traits, habitat preferences or geographical ranges.

There are numerous points in the Red List process where decisions on interpretation make a considerable difference to the assessment and where rules of thumb may be particularly useful; the interpretation of the main definitions in particular:

1. **Generation length/Mature individuals** – estimating the average age of parents and when age at effective reproductive maturity is particularly influential for species exhibiting wide ranging values (e.g. for trees between <5 years to >100 years). The interpretation of these definitions influence estimated population size and the estimated timeframe by which population declines are judged (Criteria A, B, C & D).
2. **Location/Subpopulation/Severely fragmented –** defining subpopulations that exist in almost complete isolation from incoming genetic influence or locations that may be potentially influenced by a single event is a relatively subjective judgement, especially for lesser known species. These definitions influence population status estimates (Criteria B, C & D).
3. **Extent of occurrence (EOO)/Area of occupancy (AOO) –** measuring EOO and AOO is entirely subject to the scale of measurement and influence distribution estimates (Criteria A & B). The guidelines recognise that the scale used should be appropriate to the biological aspects of the taxon, the nature of threats and available data. Clearly rules of thumb are called for here.
4. **Population reduction/Continuing decline/Extreme fluctuations –** depend on judgements as to whether a decline is part of a natural fluctuation or a more serious extinction process (Criteria A, B & C). Assessors also must consider whether the trend will continue.

Developing a common understanding of the spirit of the definitions and how they should be interpreted or defining rules of thumb within a group of assessors or a network may significantly speed up and simplify the evaluation process. Using proxy data provides a special case. Where specific habitat types harbour a number of endemic species, it may be possible to share estimates of habitat loss among relevant species. Inferences of decreasing habitat extent or quality are acceptable for criteria **A** and **B**. Quantifying the reduction of specific habitat types at a national level through a consensual approach may facilitate the assessment of diverse species. However, careful attention should be paid to assessing the habitat-specificity of the species in question and the impact of forest loss and fragmentation on those species, as well as whether other criteria may apply. Proxy data should not be used to carry out bulk assessments of large numbers of species without giving thought in each individual case to whether the species might be more or less prone to extinction and deserve more detailed assessment.

The other alternative is to give species a category of ‘data deficient’. The problem with this category is that it is a hold-all for assessments suffering diverse data limitations and has no application in conservation prioritization. More compelling support for pursuing a path of assigning threat categories wherever possible is provided by the hundreds of resource managers, who are making decisions on conservation priorities every day.

THE CASE OF TREE SPECIES

Between 1995 and 1998 a Dutch Government-funded project undertaken by the World Conservation Monitoring Centre and the IUCN SSC assessed 10,000 tree species according to the 2.3 version of the IUCN categories, of which 5999 were threatened and documented in the World List of Threatened Trees (Oldfield *et al.* 1998). As part of the project William Hawthorne reviewed the 2.3 version of the IUCN categories and suggested several rules of thumb for the application of the criteria and associated definitions; many of which were taken up and presented as guidelines to the several hundred assessors involved. One of the main recommendations that arose from his review was that assessing tropical tree species according to their distribution (i.e. criterion B) is the most appropriate and practical way of optimizing use of available data; by contrast "approaches via notions of population size or change are likely to be unreliable or untenable" (Hawthorne 1995).

Examples of rules of thumb used in the assessment of trees include:

– defining mature individuals as those which have reached potential according to their ecological niche – canopy species which have reached the canopy etc.;
– estimating generation length to be 10–20 years for medium-large pioneer trees, 50 years for most tropical species and 100 years for slow-growing species;
– measuring EOO for tropical species using degree squares (i.e. slightly more than 100 km square) and a finer resolution for higher threat categories

More than half the assessments of threatened tree species fulfilled the B criterion and were assigned the 'Vulnerable' category (Table 1). Many of these assessments were 'inferred' from declines in habitat. These are tree species usually from restricted areas of forest type habitats, which have declined by at least 20% in the past 100 years (i.e., approximately 2–3 tree generations). The lack of data may have precluded more severe threat categories from being assigned; available data to estimate population size were very rare and those species that were assessed using the C criterion were usually highly specified or confined to islands or mountains. Very few classifications were listed under more than one criterion.

Table 1. The assessment of tree species using the 2.3 version of the IUCN categories

	A criterion Declining population of at least 20%	**B criterion** Population confined to 20,000km^2 and declining	**C criterion** Less than 10,000 individuals and declining	**D criterion** Population confined to 100 km^2 or 5 locations	**Total**
% tree species assessed	22%	**56%**	6%	16%	
Number of tree species assessed	1320	**3359**	360	960	5999
	Ex	**CR**	**EN**	**VU**	**DD**
% tree species assessed	2%	16%	22%	**60%**	5%
Number of tree species assessed	95	976	1,319	**3,609**	375

Source: Oldfield & Lusty (1998)

CONSERVATION PRIORITIZATION PROCESSES

An unsurprising but nonetheless striking insight provided by William Hawthorne's study is that conservation prioritization processes for forest resource management use much the same datasets as might be used in the assignment of a Red List category. Graudal *et al.* (2004) propose that resource conservation assessments should consider past and present geographical distribution, prevailing utilization patterns in terms of direct use or indirect land-use, occurrence in protected areas – i.e. data types that would feed directly into an A or B criterion Red List assessment. However, as a rule, Red List categories are not used or applied in the resource management setting, except in various developed countries where resource management and nature conservation are more effectively linked.

Evidently there are often substantial differences between typical national conservation prioritization processes and Red Listing, not least the scale at which either is carried out: Red Listing categories were designed for use at the species or global level; conservation prioritization is applied at a local level and is frequently customised to the local conditions and situations, although they often respect global distribution patterns. Furthermore, the main criterion for including species in some forest conservation programmes is their present and possible future value (Graudal *et al.* 2004, although not for example Hawthorne and Abu Juam 1995). Resource managers place emphasis on a wider range of factors, including costs of intervention, potential success, legal issues and particularly on species' value in phylogenetic, economic, ecological or cultural terms. Assessments may be based on qualitative data, soliciting different stakeholders to provide a subjective score for each variable. Weightings and judgement values may also be used. For example, a multistakeholder group, comprising scientists, researchers, farmers, local peasants, and business people, scored forest tree species for their 'utility', 'ecological value' and 'threat' in Sao Paulo State, Brazil (Koshy *et al*. 2002).

The Ghana Forestry Department uses the "Star system" (Hawthorne & Abu Juam 1995, Hawthorne 1996, 2001), which aims to define plant species priority for conservation on the basis primarily of species' global distribution. Aspects of a species' biology, economic and ecological value have a minor influence on the categorization. Black, Gold, Blue, Scarlet, Red, Pink and Green stars are assigned in order of declining conservation priority. Species that are extremely rare on a global scale automatically attain a high significance (Black Star) without regard for other species or data attributes. Other species might have been sampled in more degree squares, but are estimated to be sparser or more ecologically sensitive and so may also earn high significance despite their wider range. Common and widespread but heavily exploited species earn a reddish (Scarlet, Red or Pink) Star according to degree of exploitation in proportion to inventories of standing crop. One of the main applications of Stars is in a weighted average score of rarity for the plant community (a Genetic Heat Index), and for this purpose, the weight is approximately in inverse proportion to the numbers of degree squares occupied for a subsample of species in each of the Stars. Stars have also been useful in Ghana to frame management regulations – e.g. allowable cut in logging operations is reduced for Scarlet Star species, and Black Star species are to be protected wherever they occur; and to justify patterns of uneven apportionment of global funds to local conservation initiatives (Hawthorne *et al.* 1998). Similar Star categorisations have been applied in Mexico and Honduras, Cameroon and Malaysia (see Chua *et al*. 1998; Gordon *et al.* 2004)

As a rule conservation prioritization processes—and there many types, often very divergent from each other—do not necessarily register changes in threat but are more clearly aimed to provide managers or policy makers an indication of which species are worth conserving at any one time. The change in priorities over the years may not necessarily be linked to changes in extinction risk, especially where assessments are based on subjective judgements of *ad hoc* groups of stakeholders. The conservation prioritization process, therefore, may not provide a reliable monitoring tool. Assessments in the Red List system should hypothetically be comparable over time, although it is too early to judge whether this proves to be correct, especially for the more subjective assessments.

Numerous other differences between the two systems exist, including the following:

- IUCN Red List system offers the option of classifying species according to just one dimension or parameter of the current status or trends of their population. In this way it encourages a precautionary approach. A conservation prioritization approach would usually be more holistic, taking account of all available data.
- Conservation prioritization occurs at a local scale and may not be applicable at a global level. The Red List system was designed for global level assessments and works best at this level.
- Conservation prioritizations are undertaken by resource managers and stakeholders. IUCN Red List assessments are most often carried out by taxonomists and as a result are frequently considered to be ‘top down’ and academic, but that is not to say they would not benefit from more local inputs.
- Resource managers are obliged to make further within species assessments about which populations or gene pools are a priority for conservation.

However, the similarities between the two scales of approach are fundamental. The baseline data are often the same. The Red List categories depend on a much broader use of ecological, biological and utilization aspects of species than is immediately obvious when first discovering the criteria. The two systems can share the following data types:

- geographical distribution
- number of individuals
- regeneration rates and population trends
- threats and sustainable use considerations
- ecological specificity
- levels of protection or conservation measures

The effectiveness of both systems is underpinned by reliable taxonomy and nomenclature, and, obviously, both are constrained by the lack of information. Conservation prioritization is constrained by the availability of data on species occurrence, frequency, ecology and status (Amaral *et al.* 2004). Basic surveys are needed to locate populations, estimate population numbers, study population dynamics and monitor threats. Both assessments, therefore, share the challenge of dealing with data uncertainty and different attitudes to risk and both would potentially be advanced by the pooling of expert opinion and developing a consensual or synergistic approach.

MECHANISMS FOR SHARING INFORMATION AND METHODOLOGIES

The Red List workshop held in Kuala Lumpur, Malaysia, brought together nearly 200 people from around 50 different institutes, including national and state forest departments, the national forestry research institute, environmental and conservation organizations, botanic gardens and universities. The workshop represented a first step towards the development of a national Red Data book of plants and focused on familiarizing participants with the Red List categories. Some dissatisfaction had previously been expressed by Malaysian scientists and resource managers with the way certain published Red Data assessments had been derived mainly through remote desk work with insufficient reference to details on the ground (Chen, 2004). Red List assessments, furthermore, are perceived by some to play an important role in determining both government and international trade policy concerning commercial species and, therefore, are treated with political interest (despite the expressed intentions of the IUCN for the Red List categories not to be used for prioritization without the consideration of multiple additional factors). Given this context the workshop played a pivotal role in developing a common understanding of the Red List system among a diverse group of stakeholders and allowed taxonomists and researchers to benefit from the insights of resource managers and for the latter to contribute directly to the assigning of Red List categories.

One of the main challenges in both resource management and Red List assessments is to ensure that the species of concern out of the thousands of described species are the focus of attention. The highly rare species are well-known by the taxonomist but possibly not by the resource manager. From the latter's perspective rare species may be overlooked if their use and value are not considered to be significant, or they may simply be unrecognised. However, mutual territory of appreciation to both taxonomists and resource managers exists in the form of species that are locally widespread (and hence appear in forest inventories) but suffering (or have suffered) significant declines either through habitat decline or direct exploitation. These species potentially may be considered threatened through the use of criterion **A** or **B**. These are the same criteria that allow the use of inference and are more open to interpretation. The Malaysian workshop allowed resource managers and researchers to air their different views on and discuss the impact of past, continuing or future habitat declines on species extinction rates. In the future, such a group could come to an agreement on the estimated decline in specific habitat types and how species might be consistently assessed using criteria **A** and **B**. Fortunately, the Malaysian Red Listing process has only just begun and according to the project manager will involve a number of follow-up workshops to achieve this kind of consensus (Saw L.G. pers. comm.).

There are further existing mechanisms for facilitating more informed assessments, including networks, databases and electronic conference groups. Numerous forest genetic resources (FGR) or forestry networks are already functioning and these are viable and valuable channels for facilitating, enhancing awareness and also assisting in informed assessments across the region as well as nationally. Examples of networks associated with IPGRI include the South Pacific Regional Initiative on Forest Genetic Resources (SPRIG), which has coordinated work in five south pacific island nations, the Central Asian and Transcaucasian Network on Plant Genetic Resources (CATCN-PGR) in the central Asian sub-region, the Sub-Saharan African Programme of Forest Genetic Resources (SAFORGEN) coordinating work in sub-Saharan countries and the Asia Pacific Forest Genetic Resources Programme (APFORGEN). Such networks could provide the channels for introducing and discussing the Red List categories and carrying out joint assessments.

The IUCN/SSC Global Tree Specialist Group (GTSG) was established in 2003 with two specific aims. The first is to act in an advisory capacity to the action-based Global Trees Campaign which is run by UNEP/World Conservation Monitoring Centre and Fauna and Flora International and aims to conserve the world's most threatened plant species. The second is to promote and implement Red Listing for trees. The GTSG takes a pragmatic approach to red listing, attempting to use all available information to evaluate species in priority regions and taxonomic groups. The intention is to provide evaluations which can be used as part of conservation planning for tree species where possible using evaluation workshops as a means to determine conservation priorities. In its first year of operation (2004) the GTSG contributed to the evaluation of over 1200 tree species using various approaches including desk studies, correspondence with experts, workshops and liaison with other IUCN/SSC plant specialist groups. The GTSG also evaluated several major commercial timber species and in doing so sought input from a wide range of stakeholders in an attempt to develop a robust evaluation model.

CONCLUSIONS

Despite its quantitative framework, the IUCN Red List categorisation inevitably demands varying degrees of subjective judgement. It is a well-matured system, in the sense that the rules have evolved through more than a decade of use and feedback, but is somewhat complicated and time-consuming to absorb and use. The risk that such a system presents is that while a few relatively well-known groups may be intensively assessed by well-versed assessors the vast majority of threatened species remain either unevaluated or their assessment is unrecognised. A small percentage (3%) of described plant species has been assessed using versions 3.0 or 3.1 Red List categories. Whereas, an exercise to approximate for missing data carried out by Pitman & Jørgensen (2002), using proxies of endemic species and threatened species for different combinations of countries, hotspots, tropical and temperate zones, suggest that somewhere between 22% and 47% of described plant species are likely to be threatened. It is widely recognised that global-level biodiversity monitoring needs to address a far broader range of species and means should be sought to increase the involvement of a wider group of stakeholders, the use of local calibration, ground-truthing and locally collected data (Balmford *et al.* 2005).

The feasibility, therefore, of assessing plants using the IUCN Red List system may be brought into question. However, the knowledge that resource managers and policy makers are obliged to make daily decisions about genetic resources and that species-level information and indicators are increasingly sought in international and national policy-making should encourage us to maximise on the strong points of the Red List system and on all information and expertise available to accelerate the application of the Red List categories. We are advocating that this process might be better facilitated through the use of rules of thumb and coordinated through joint initiatives between taxonomists, conservationists and resource managers typified by the Workshop on threat assessment of plant species in Malaysia. In addition, some of the raw data used to categorise the species (e.g. degree square distribution data; estimates of population size) could also be used to frame local systems (focused initially through the Red List priorities themselves), and can be checked and updated periodically as a means of monitoring conservation status and Red List categorization. While there is a place for more informed Red List assessments, involving experts and resource managers on the ground, the application of the Red List categories in conservation prioritization processes is less clear and not seriously explored here. This is an area that should be more formally reviewed and studied.

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CONSERVATION STRATEGIES OF *SHOREA LUMUTENSIS* (DIPTEROCARPACEAE) IN PENINSULAR MALAYSIA

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ABSTRACT

To conserve a rare plant, conservation programs must be guided by the biological attributes of the species. *Shorea lumutensis* is a rare and endemic dipterocarp in Peninsular Malaysia. A comprehensive research study was initiated to assess the population ecology and population genetics of *S. lumutensis* to elucidate specific ecological and genetic requirements and subsequently to recommend conservation strategies. This paper is apparently the first attempt at applying both the ecological and genetic approaches into conservation management of a rare dipterocarp. This paper also attempts to link the gaps between conservation research and conservation management in a realistic approach. It is our hope that this study will serve as a model for the other studies related to conservation of rare dipterocarps.

INTRODUCTION

In Peninsular Malaysia, the family Dipterocarpaceae comprises 155 species (Ashton 1982). In the past, conservation of the dipterocarps was not an important issue as the family was seen as common and none of the species were presumably threatened. However, a recent study by Saw & Sam (2000) indicates that over 57% of the species have distribution patterns restricted to specific zones. There are also 30 species that are endemic to Peninsular Malaysia, and out of these, 12 species are considered rare. Many rare plants are endangered in part because their populations are small. Small and isolated populations are inherently more vulnerable to natural catastrophes, demographic and environmental stochasticity (Shaffer 1981, Lande 1998, Holsinger 2000). They are also threatened by genetic stochasticity such as loss of genetic diversity by drift and inbreeding (Keller & Waller 2002). In addition, plants with narrow habitat specificity and limited dispersal potential are at particular risk for global extinction, as landscapes become mosaics due to anthropogenic activities.

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Shorea lumutensis is one of the rare and endemic dipterocarps in Peninsular Malaysia. It was assigned as critically endangered according to IUCN (1994) version 2.3 criteria (CR A1cd, C2a) due to suspected population reduction of at least 80% over the last 10 years and the population estimated to number less than 250 mature individuals. Taxonomic characteristics of *S. lumutensis* have been described by Symington (1943) and Ashton (1982). It is a medium-sized to large tree with irregular longitudinally fissured bark and short buttress (Fig. 1). The leaves are leathery and oblong-elliptic in shape and have about 14 pairs of nerves, prominent beneath and usually markedly glaucous on the undersurface. The species produces hermaphrodite flowers (about 9 mm long, petals linear and pale yellow in color with 20-25 stamens) and subsessile fruits with three outer and two inner wings. Locally known as balau putih (*putih* in Malay means white, referring to the leaf undersurface), it is reported to be restricted to the western part of Peninsular Malaysia.

Very little is known about the biology of *S. lumutensis*. Consequently, we do not know how to address specific conservation problems and how to set conservation strategies and priorities. This research was aimed to assess the population ecology and population genetics of

Fig. 1. Morphological characteristics of *S. lumutensis*.

S. lumutensis to elucidate specific ecological and genetic requirements for the species' existence. The specific objectives were: (1) to generate information on the population status, habitat association, spatial distribution, demographic structure, population dynamics, flowering and fruiting biology, and germination and seedling behaviour of *S. lumutensis*; (2) to generate information on the levels of genetic diversity, spatial genetic structure, population genetic structure, inbreeding, mating system, gene flow, minimum population size and breeding unit size for conservation; and (3) to integrate the outputs to recommend management prescriptions and conservation priorities for the species and its habitats.

MATERIALS AND METHODS

Population Survey

Since *S. lumutensis* is reported to be restricted to the western part of Peninsular Malaysia, a forest survey was conducted in seven forest reserves, i.e., Segari Melintang, Tanjung Hantu, Lumut, Teluk Muroh, Pangkor Utara, Sungai Pinang, and Pangkor Selatan in the Manjung District. For these reserves, the major threats to the existence of the species were identified.

Study Plot

For the purpose of ecological studies, an 8-ha study plot (200 × 400 m) across an elevation gradient of 65-125 m, in Compartment 5, Sungai Pinang Forest Reserve, was demarcated for the study. The plot was subdivided into 400 subplots, each of 10 × 20 m. Within the study plot, all *S. lumutensis* individuals >1 cm dbh were mapped and their diameters recorded.

Topography and Spatial Distribution

Influence of topography on its spatial distribution was examined by their relative abundance in four different elevation classes, i.e., valley ranging 65–80 m above sea level (asl), lower and upper slopes ranging 81–95 m asl, 96–110 m asl respectively, and ridge ranging 111–125 m asl. The subplots were assigned to their respective elevation classes, taking the elevation at the center of the subplots as the mean.

Spatial Distribution Analysis

Diameter sizes were defined into four classes: large trees (BIG) >25.0 cm, pole trees (POL) 4.0-25.0 cm, saplings (SAP) 2.0–2.5 cm, and seedlings (SEE) 1.0–1.1 cm. Five continuous distance classes, each of 20 m, were considered, from 0–20 m to 80–100 m. The spatial distribution of each stem diameter class was tested using the Ripley's (1976) *K*-function. Confidence limits were estimated using the bootstrap method; the location of individuals was randomized in 19 Monte Carlo trials to determine a 95% confidence interval within each 20-m distance class.

Demographic Structure and Short-term Population Dynamics

The demographic structure of the species was examined by assigning individuals to one of five size classes (dbh): 1–5 cm, 6–10 cm, 11–20 cm, 21–30 cm, and >31 cm, and fitted to inverse *J*-shaped curve ($y = ae^{-bx}$), the shape distribution of natural tree populations with abundant regeneration (Condit *et al.* 1998). Short-term population dynamics was derived from the initial census in September 2001 and a repeat census in August 2004 for growth rates (based on increase in dbh) and mortality.

Flowering and Fruiting Biology

Phenological observations were carried out using binocular from January 2002 to October 2005. Periodic surveillance was undertaken following Appanah & Chan (1982) to establish the flowering stages (budding, initial bloom, peak bloom, tail bloom, and termination of bloom), flowering intensity (intense, moderate, and poor) and fruiting stages (seed development, seed maturing and seed fall).

Germination and Seedling Studies

Seed collections were conducted in December 2002 for trees B026 and B385, and in January 2003 for trees B004 and B005 within the 8-ha study plot in Sungai Pinang. The seed weight variation and its effect on germination and speed of germination were tested using binary and ordinal logistic regression analyses, respectively. The relationship between seed weight and seedling vigor (seedling height after three months of growth) was tested for $y = bx + c$, in which y represents the seedling height, x the seed weight, and a and b are the intercept and the slope of the curve, respectively.

Development of Microsatellite Loci

The total genomic DNA was extracted from leaf tissues using the procedure described by Murray & Thompson (1980), with modification, and further purified using CsCl-ethidium bromide gradient (Sambrook & Russell 2001). The microsatellite library enriched for dinucleotide (CT) repeats was constructed following Lee *et al.* (2004). For those loci showing multiple alleles, low stutter and robustness of interpretation, forward primers labelled with 6-FAM, HEX, or NED fluorescent dyes were synthesized and further used to confirm the polymorphic loci using 24 large trees of *S. lumutensis* from Sungai Pinang.

Sample Collection and DNA Extraction

During the mapping process at the 8-ha study plot in Sungai Pinang, leaf or inner bark samples were collected for individuals >1 cm dbh for genetic studies. In addition, a total of 40–48 representative samples were also collected from Pangkor Selatan, Lumut, Segari Melinting and Teluk Muroh, using the transect-line sampling method, as explained by Lee *et al.* (2000). The 54 individuals of *S. lumutensis* >20 cm dbh in Sungai Pinang were also used together with the four half-sib families (B004, B005, B026, and B385) collected within the 8-ha study plot for mating system and gene flow studies. Genomic DNA was extracted using the procedure described by Murray & Thompson (1980), with modification.

Microsatellite Analysis

The samples were genotyped for four native microsatellite loci (*Slu057, Slu110, Slu124* and *Slu175*) and four microsatellite loci developed for *S. leprosula* (*Sle111a, Sle118, Sle267* and *Sle303a*; Lee *et al.* 2004). PCR amplifications and fragment analysis were performed according to Lee *et al*. (2004) using a GeneAmp PCR System 9700 (Applied Biosystems) and an Abi Prism 377 DNA Sequencer (Applied Biosystems), respectively.

Data Analysis

Allelic frequencies were determined for each locus in each population (individuals with dbh >25 cm were used to represent the Sungai Pinang population). Based on these data, the following levels of genetic diversity were estimated: average number of alleles per locus (A_a), allelic richness (R_s; Petit *et al.* 1998), gene diversity (H_e; Nei 1987) and fixation index (F_{is}; Nei 1987). Spatial genetic structure in the Sungai Pinang was evaluated using Moran's *I* coefficient (Moran 1950). An indication of the trends in spatial scale of genetic substructuring was obtained using correlograms (Sokal & Oden 1978). A permutation procedure using Monte Carlo simulation was applied to test significant deviation from random distribution of each calculated measure (Manly 1997). Population genetic structure was quantified using *R*-statistics (R_{st}; Slatkin 1995, Goodman 1997). Relatedness among populations was quantified using D_A genetic distances (Nei *et al.* 1983) for pairwise comparison of divergence between populations and cluster analysis on genetic distances via the neighbor-joining (NJ) method (Saitou & Nei 1987). Relative strength of the nodes was determined using bootstrapping analysis (1000 replicates). For the direct estimation of gene flow, parentage was determined by simple exclusion method and likelihood-based approach in the program Cervus 2.0 (Marshall *et al*. 1998). The breeding unit parameters were estimated according to Nason *et al*. (1998). The minimum population size to maintain current level of genetic diversity was estimated according to Lee *et al*. (2002).

RESULTS

Ecology

The species was present in five forest reserves, i.e., Sungai Pinang, Pangkor Selatan, Segari Melintang, Lumut and Teluk Muroh, which were confined to an area of approximately 313 km². As the two island populations (Sungai Pinang and Pangkor Selatan) are separated from the mainland by the Straits of Dinding, they must have been isolated from mainland populations many thousand years ago. Among the three mainland populations, no distinctive geographical barrier divided the Lumut and Teluk Muroh but the Segari Melintang population was separated by the Manjung River.

Within these reserves, *S. lumutensis* occurs as small patches in a general matrix of coastal hill dipterocarp forest, usually at >100 m asl. Isolated individuals are occasionally seen but rare. The species is most often a subcanopy to emergent tree. Symington (1943) reported that the species seldom exceeded 50 cm dbh but in Sungai Pinang and Lumut, four trees >100 cm dbh were encountered. The preferred habitat for these five populations appears to be dry coastal hill forest on moderate-fertility soils, in microclimates where drainage is good or where high soil moisture levels cannot be permanently maintained. The number of large trees was estimated to be less than 500 for these five populations. Although the number of large trees was low in each of the populations, progressively larger numbers of associated saplings and seedlings were observed scattered surrounding the large trees in each of these populations. We also identified the following potentially major threats for population endangerment: logging activities (Segari Melintang), excavation for stones (quarry) and conversion to oil palm plantations (Lumut and Teluk Muroh), and land development for tourism (Pangkor Selatan and Sungai Pinang).

A total of 416 individuals >1 cm dbh were recorded within the 8-ha plot in Sungai Pinang. The population density of *S. lumutensis* >30 cm dbh within the plot was 4.4 trees ha^{-1}. The prominent associated species within the habitat are two palm species, i.e., *Eugeissona tristis* and *Calamus castaneus*. The study of the relationship between microtopography and spatial distribution showed that the species distribution was strongly related to topography; prominent on ridges and upper slopes, and totally absent in the lower slopes and valleys. This was further supported by spatial distribution analyses, in which significant spatial aggregation was detected at four size classes (Fig. 2) and the level of aggregation was highest in SEE and SAP, followed by POL, and then BIG.

Diameter distribution was skewed, with many more small than large individuals being present. The distribution was significantly fitted to inverse *J*-shaped curves ($y = ae^{-bx}$; $a = 154.6$; $b = 0.6$; $r^2 = 0.98$, $P < 0.01$), indicating abundant regeneration. The medium-sized trees (11–20 cm) constituted 1.7% of the total 416 individuals found within the plot, compared with 8.2% in the largest-sized trees (>31 cm) and 82.2% in the smallest-sized trees (1–5 cm). Short-term population dynamics derived from the initial census in September 2001 and a repeat census in August 2004 showed that a total of 75 trees died over the 3-year study period. Mortality was detected only at the two lowest-sized classes (1–5 cm and 6–10 cm), 22% and 8% respectively (Table 1). Growth was slow in most of the trees enumerated, at mean rates around 0.3 mm yr^{-1} (lowest-sized class) to 2.4 mm yr^{-1} (highest-sized class) and the mean growth rate increased with increasing size class.

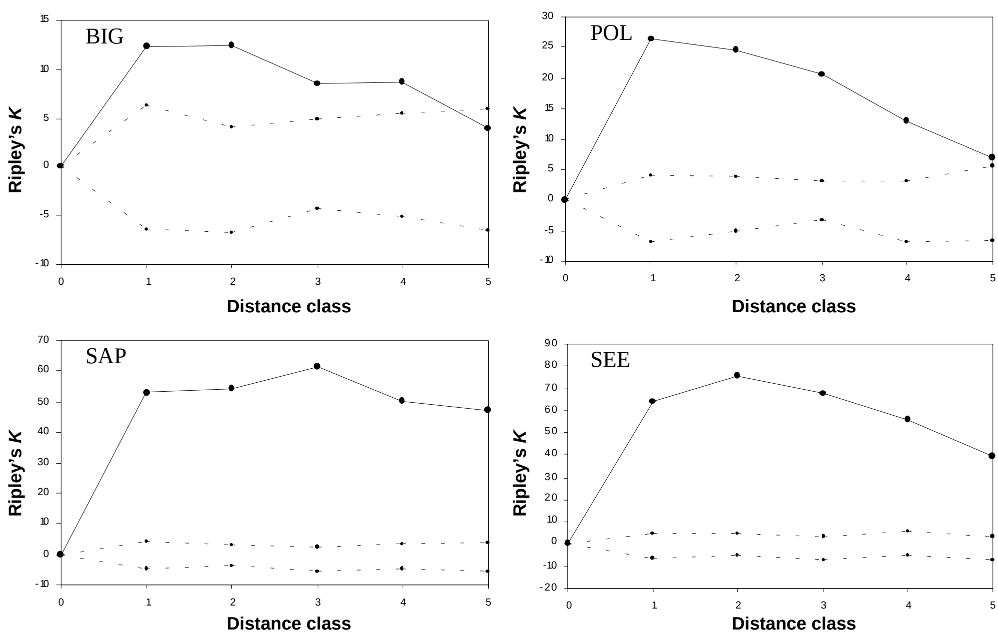

Fig. 2. Spatial distribution analysis using Ripley's *K*-function on four diameter classes of *S. lumutensis* within an 8-ha (400 × 200 m) plot: large trees (BIG >25 cm), pole trees (POL 4–25 cm), saplings (SAP 2.0–2.5 cm) and seedlings (SEE 1.0–1.1 cm). Distance classes were defined at five intervals, each of 20 m, from 0–20 m (class 1) to 80–100 (class 5). Dotted lines represent 95% confidence limits.

Table 1. Percentages of mortality, mean and maximum growth rates of *S. lumutensis* at five diameter size classes in the Sungai Pinang plot between 2001 and 2004. Value in parentheses is the standard deviation.

Size class/cm	No. of trees	% mortality	Mean growth rate/mm yr^{-1}	Max. rate/ mm yr^{-1}
1–5	342	22	0.3 (0.5)	1.3
6–10	14	8	0.7 (0.7)	2.3
11–20	7	0	1.4 (1.1)	3.7
21–30	19	0	1.6 (1.2)	3.7
>31	34	0	2.4 (1.9)	6.3

Phenological observations within the 8-ha study plot from January 2002 to October 2005 showed a flowering event in August 2002 on five trees, i.e., B004, B005, B026, B325 and B385. The budding stage was observed on B026, B325 and B385 on 15 August 2002 and two weeks later on B004 and B005. The duration of bloom was short, approximately two weeks. The period from tail flowering to mature fruit fall was approximately 10 weeks and the period from budding stage to mature fruit fall was approximately 16 weeks. Variation of seed morphology was obvious among trees; the tree B385 produced the biggest mature seeds with shorter wings. Fruit predation was extensive; the majority of the fallen mature seeds were consumed by small mammals (e.g., squirrels and rats).

The distribution of seed size based on 200 individually weighed seeds from four mother trees was approximately normal (Fig. 3A). The average seed weight was 18.8 mg (SD = 5.5). Germination study showed that the proportion of seed germinated was 35.5%. All the fertile seeds germinated within 22 days and more than 50% germinated within nine days (Fig. 3B). An ordinal logistic regression analysis showed that seed weight did not affect the speed of germination (z = 0.73, P = 0.465). However, a binary logistic regression analysis on the probability of seedling emergence vs. seed weight revealed that a significant relationship exists between these variables (z = 6.23, P < 0.001). Accordingly, seed weight did influence seedling emergence but did not influence the speed of germination.

There was a weak relationship (seedling height = 0.26 [seed weight] + 3.17; n = 71, r^2 = 0.19, P = 0.11) between seedling height (after three months of growth) and seed weight (Fig. 3C); only 19.1% of the variability among the observed values of seedling height was explained by the linear relationship between seedling height and seed weight and the remaining 81.9% of the variation was not explained by this relationship. The germination rate and seedling performance according to mother tree are shown in Table 2. The germination rate ranged from 6% (B004) to 60% (B385). At the age of two years, the mean seedling height ranged from 23 cm (B005) to 38 cm (B026) and the mean diameter at ground height (dgh) ranged from 3.7 mm (B005) to 5.3 mm (B026). B026 produced small seeds (mean seed weight = 17.8 ± 2.8 mg) with low germination rate (22%) but had seedlings with the most vigor (mean height and dgh after two years of growth were 38 ± 12 cm and 5.3 ± 1.2 mm, respectively).

Genetics

From the microsatellite library enriched for dinucleotide (CT) repeats, a total of 336 clones were sequenced. A high proportion of the clones were identified to contain microsatellite repeat

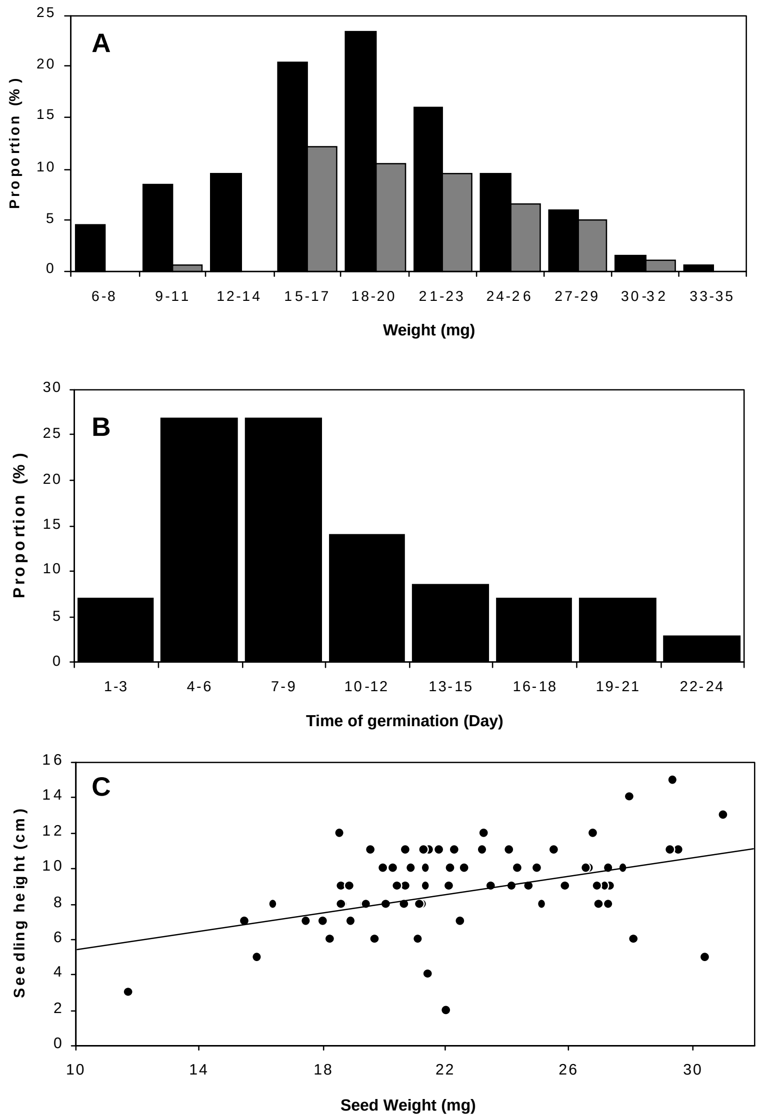

Fig. 3. (A) Distribution of seed sizes (black) and proportions of germinated seed (grey) based on 200 individually weighed seeds from four mother trees in one population. (B) Proportions of seeds germinated at three-day intervals within 24 days. (C) Relationship between seed weight and seedling height (after three months of growth): seedling height = 0.26 (seed weight) + 3.17 (r^2 = 0.19, P = 0.11).

(97.9%). However, these microsatellite clones showed high redundancies and only 55.3% were unique (single copy). For these unique microsatellite clones, 87.3% were CT/GA repeats, 8.3% were GT/CA repeats, and 4.4% were other repeats (e.g., GT/CA, AAG, and GGA). Screening of 48 primer pairs of unique microsatellite clones, however, managed only to obtain five polymorphic loci after screening on 24 large trees from Sungai Pinang (Table 3). The number of alleles ranged from two (*Slu175*) to nine (*Slu124*), and the probability of paternity exclusion

Table 2. Mean seed weights, germination rates and seedling performance after two years of potting of four mother trees of *S. lumutensis*. Value in parentheses is the standard deviation.

Tree No.	No. of seeds	Germination test			Seedling performance after two years	
		No. of seeds	Mean seed weight/mg	% seed germinated	Mean height /cm	Mean dgh/mm
004	85	50	12.0 (3.1)	6	-	-
B005	190	50	20.5 (2.9)	54	23 (9)	3.7 (1.3)
B026	100	50	17.8 (2.8)	22	38 (12)	5.3 (1.2)
B385	120	50	24.6 (3.7)	60	28 (10)	4.1 (0.8)

Table 3. Locus names, primer sequences, repeat motifs, annealing temperatures (*T*), numbers of alleles observed (*A*) and allele size ranges of microsatellites sequenced from the CT-enriched genomic library of *S. lumutensis*. Expected heterozygosity (H_e), polymorphic information content (*PIC*) and probability of paternity exclusion (P_e). * indicate a significant departure from Hardy-Weinberg equilibrium ($P < 0.05$).

Locus	Primer sequence (5' - 3')	Repeat	*T*	*A*	Size	H_e	*PIC*	P_e
Slu 044a	F: ACA AAA AGT GGA TGG TGA G R: TTG TAG TGT TGT CCA GTG TG	$(GA)_{15}$	50	3	138-152	0.535*	0.409	0.218
Slu 057	F: TTT GTG GTC CCC GCC TTC TG R: ATC AGA CAA TCT TTT TGG AC	$(CT)_{12}$	50	3	109-113	0.525	0.459	0.273
Slu 110	F: CAT CCT TAC CTT TGT CAC CC R: TCA GGC TCC ATT CTT CTT TT	$(GA)_{21}$	50	5	216-222	0.649	0.567	0.368
Slu 124	F: GCA AAA TAA TAC TCA ATG GG R: TGT CAC ATG GGT AAT AAA CT	$(CA)_{12}$	50	9	130-161	0.759	0.713	0.544
Slu 175	F: CAT CAT TAC AAT CAT CCA TC R: CAC TTG CTT CGT CGT CTA CC	$(GA)_{15}$	50	2	217-223	0.294	0.246	0.123

ranged from 0.123 (*Slu175*) to 0.544 (*Slu124*). A significant departure from Hardy-Weinberg equilibrium was detected on Slu044a. Linkage disequilibrium was found between *Slu044a* and *Slu175*.

The study revealed high levels of genetic diversity in *S. lumutensis* (Table 4). The allelic richness ranged from 5.7 (Lumut) to 6.3 (Segari Melintang) whereas the gene diversity ranged from 0.609 (Sungai Pinang) to 0.673 (Segari Melintang). The study also showed high positive values of fixation index ($F_{is} > 0.1$) in all populations, an indication of an excess of homozygotes. The spatial distribution of alleles study showed significant spatial genetic structure in SEE, SAP and BIG but not in POL (Fig. 4). The coefficient of population differentiation quantified using *R*-statistics showed that most of the total genetic diversity was partitioned within population. The proportion of genetic diversity distributed among populations was estimated as 0.058, thus only 5.8% of the genetic variability was distributed among populations. The cluster analysis among populations, however, formed three genetic clusters; Lumut/Teluk Muroh, Sungai Pinang/Pangkor Selatan, with Segari Melintang being the outlier (Fig. 5).

Table 4. Genetic diversity statistics (A_a, R_s and H_e) and fixation indices (F_{is}) of *S. lumutensis* based on eight microsatellite loci. Value in parentheses is the standard deviation.

Population	Sample size	A_a	R_s	H_e	F_{is}
Sungai Pinang	47	7.4 (1.8)	6.0 (1.4)	0.609 (0.082)	0.130
Pangkor Selatan	48	8.1 (1.7)	6.1 (1.1)	0.663 (0.077)	0.128
Segari Melintang	48	7.9 (1.9)	6.3 (1.3)	0.673 (0.058)	0.109
Lumut	40	6.6 (1.4)	5.7 (1.2)	0.636 (0.074)	0.156
Teluk Muroh	48	7.0 (1.5)	6.0 (1.1)	0.661 (0.052)	0.194
Mean	46	7.4 (0.6)	6.0 (0.2)	0.648 (0.026)	0.143

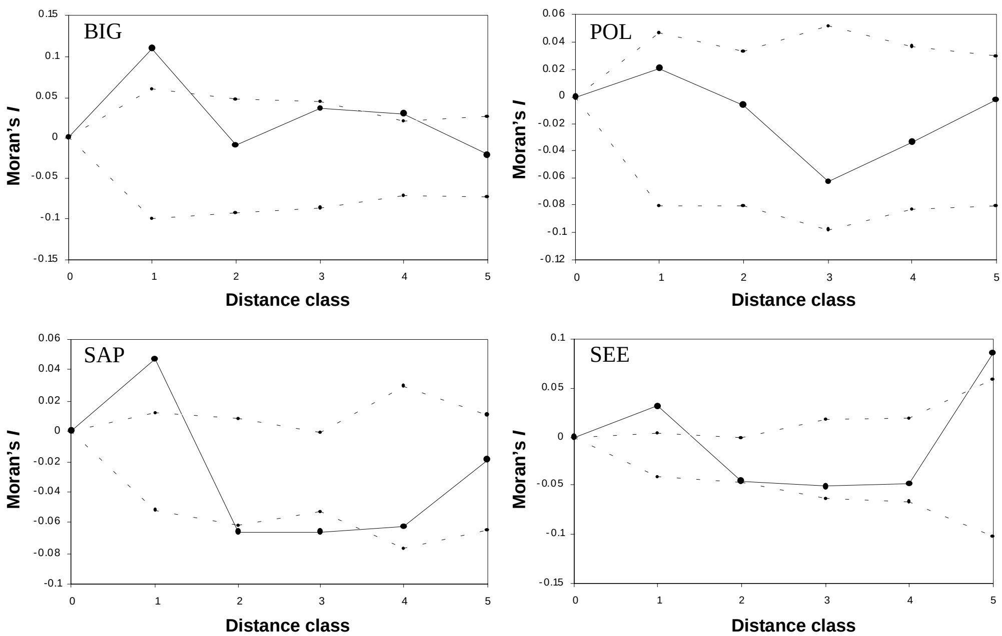

Fig. 4. Correlograms of average Moran's *I* coefficients on four diameter classes of *S. lumutensis* within an 8-ha (400 × 200 m) plot: large trees (BIG >25 cm), pole trees (POL 4–25 cm), saplings (SAP 2.0–2.5 cm) and seedlings (SEE 1.0–1.1 cm). Distance classes were defined at five intervals, each of 20 m, from 0–20 m (class 1) to 80–100 m (class 5). Dotted lines represent 95% envelopes of average *I* distribution after 1000 permutations of individual multi-genotypes within each diameter class.

The phenological observations using binocular showed five flowering trees (B004, B005, B026, B325 and B385) during the flowering event in August 2002. However, paternity assignment showed that an addition of seven trees (B003, B011, B012, B023, B030, B349 and B397) within the 8-ha plot also contributed pollen for the reproduction of the four mother trees. In other words, these trees might have flowered but at low density which could not be picked up through binoculars. The dbh of the flowering trees ranged from 31–110 cm and this allowed us to make the assumption that trees above 30 cm dbh can be considered as reproductively mature.

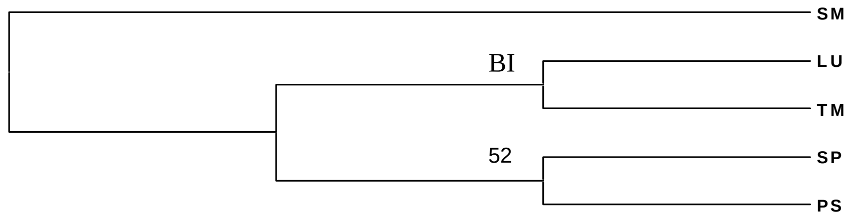

Fig. 5. Neighbor-joining (NJ) cluster analysis based on D_A distances (Nei *et al*. 1983) among the Sungai Pinang (SP), Lumut (LU), Pangkor Selatan (PS), Segari Melintang (SM) and Teluk Muroh (TM) populations. The bootstrap values (based on 1000 replications) were generated by PowerMarker software (Liu & Muse 2005).

The summary results of mating system, paternity assignment and breeding unit parameters are given in Table 5. *Shorea lumutensis* can be inferred to follow the mixed-mating model (mean outcrossing rate = 63.4%), with B004 showing the lowest value of outcrossing rate (22.2%) and B005 the highest (92.0%). The pollen flow is moderately extensive, in the range of 122.0 m (B004) to 220.3 m (B385) with the mean of 175.2 m, and this allowed us to postulate that low energy insects might be the main pollinators for *S. lumutensis*. In comparison with the germination study, mother trees with higher outcrossing rate and receiving pollen from many distant paternal trees produced bigger seeds, and bigger seeds have a greater probability to germinate and establish seedlings. The mean breeding unit size and area were estimated as 52 individuals and 11.8 ha, respectively. The minimum population size to maintain current levels of genetic diversity (number of alleles) is shown in Fig. 6. The basic relationship between A_t with sample size was logarithmic. To maintain 95% of alleles, 270 individuals are required (in the range of 200-310 individuals).

Table 5. The summary results of mating system, paternity assignment and breeding unit parameters of four half-sib families of *S. lumutensis* in Sungai Pinang. Value in parentheses is the standard deviation.

Tree No.	No. of seeds	Mating system and paternity assignment			Breeding unit parameter	
		% of seed due to outcrossing	% of seed received pollen outside plot	Mean pollen flow distance/m	Size/individual	Area/ha
B004	38	22.2	11.1	122.0 (0.0)	70	16.0
B005	50	92.0	24.0	220.0 (120.2)	47	10.7
B026	44	61.4	13.6	138.4 (28.3)	45	10.3
B385	50	78.0	16.0	220.3 (78.5)	44	10.1
Mean	45.5	63.4 (15.1)	16.2 (2.8)	175.2 (26.2)	52 (6)	11.8 (1.4)

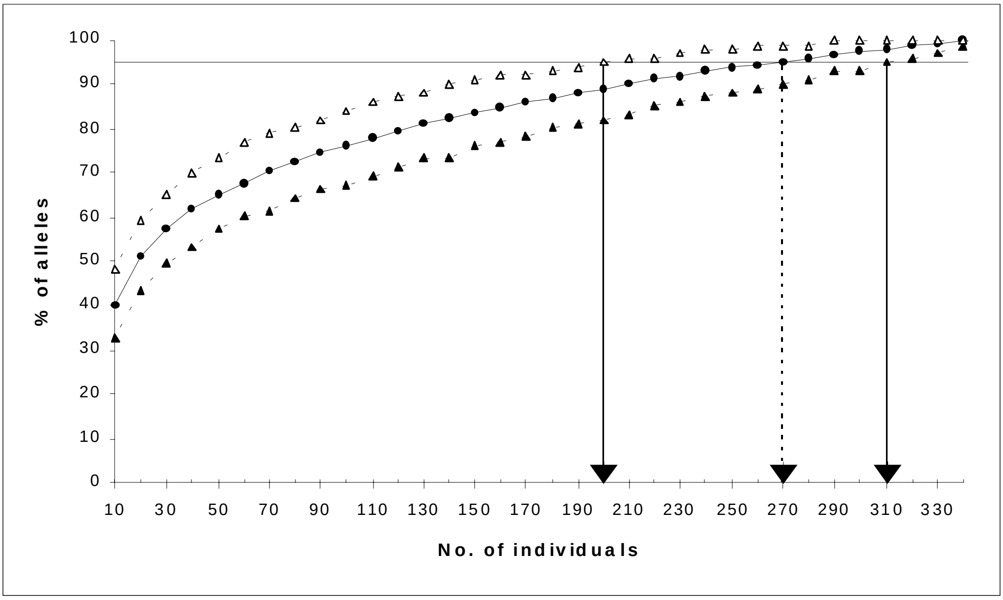

Fig. 6. Changes in % of alleles maintained with changes in the number of individuals of *S. lumutensis* removed. All values were based on a mean of 1000 resamplings with standard errors (SE). Dotted lines represent standard errors.

DISCUSSION AND RECOMMENDATIONS

This study showed that *S. lumutensis* comprises only five populations and perhaps no more than 500 large individuals; extinction of the species is likely if nothing is done to conserve it. There are two basic conservation strategies for plants, *in situ* and *ex situ* conservation. *In situ* conservation involves the designation, management and monitoring of species at the location where they are currently found, whereas *ex situ* conservation involves the sampling, transfer and storage of species away from the original locations where they were found. Conserving *S. lumutensis* in its natural habitat is clearly the first step. However, *ex situ* conservation is also necessary to provide insurance against catastrophic events and to facilitate the possibility of future reintroduction into appropriate habitats.

Selection of *In situ* Conservation Area

Shorea lumutensis has >90% of its total genetic diversity residing within the population and displays mix-mating system. As the species is endemic to Peninsular Malaysia and comprises only five populations and perhaps no more than 500 large individuals, the five populations need to be conserved. The cluster analysis showed that Segari Melintang harbors some unique genetic characteristics which should receive additional attention for conservation purposes.

The minimum population size needed to maintain 95% of its genetic diversity was estimated as 270 individuals (in the range of 200-310) and the mean breeding unit size was estimated as 52 individuals. When planning a conservation area, however, a minimal population size should be regarded only as a last resort and an extreme compromise. For added safety, much larger population or area should constitute units of *in situ* conservation (Hawkes *et al.* 1997). However, as the resources available for conservation programs are limited, it is unrealistic simply to recommend *in situ* conservation area "as large as possible". In practice, the size of a conservation area, rather than the number of trees, is often dictated by the relative concentration of people and the suitability of the land for human exploitation (agriculture, urbanization, logging, etc). Therefore, for *S. lumutensis*, conserving an area no less than 100 ha with at least of 300 individuals >10 cm dbh (including 60 reproductive trees >30 cm dbh) in each population will be sufficient to maintain maximum levels of genetic diversity to withstand loss of genetic variability due to drift and should be enough to contain the minimum number of reproductive individuals to prevent inbreeding.

The areas should be demarcated within the Compartments where *S. lumutensis* is found, such as Compartment 5 of Sungai Pinang (N 04º14'32"; E 100º33'33"), Compartments 1 and 2 of Pangkor Selatan (N 04º12'19"; E 100º34'23"), Compartment 5 of Teluk Muroh (N 04º11'13"; E 100º37'47"), Compartment 3 of Lumut (N 04º13'38"; E 100º38'26"), and Compartments 41 and 42 of Segari Melintang (N 04º22'36"; E 100º37'13") (Fig. 7). Extensive surveys should be carried immediately to enumerate, measure and tag the individuals within these compartments. The survey should be extended to other compartments if the criterion of conserving 300 individuals cannot be fulfilled. The criterion of at least 100 ha should always be satisfied even when the number of individuals exceeds 300. There is a possibility that the number of individuals is less than 300 in Pangkor Selatan; than the population might require re-introduction to increase its size and gene pool.

For each population of *S. lumutensis*, the conservation area to be established should have a central core area, surrounded by a buffer zone and perpheral to this, a transition zone (Fig. 7). Laidlaw (1994) and Lee *et al*. (2002) have shown that there is a higher occurrence of deleterious effects on reserves that are situated at the edge of a forest reserve. The presence of a buffer zone will protect the core from edge effects and other factors that might threaten the population viability of *S. lumutensis* present in the core. The transition zone, however, may be made available for sustainable harvesting activities.

To ensure these conservation areas are fully protected, legal provisions must be in place at the State level. The establishment of *in situ* conservation areas will not only conserve *S. lumutensis*, but also help to conserve the forest ecosystem and other important, but non-targeted species, such as tongkat ali (*Eurycoma longifolia*, Simaroubaceae) in Sungai Pinang.

Monitoring and Management *In situ* conservation Area

Monitoring is a quantitative assessment of the status of a population and its component individuals over time (Tuxill & Nabhan 2001). Monitoring is important both before and after legal protection of *in situ* conservation areas. Before protection, monitoring gives a basis for prediction and allows a critical situation to be identified. During protection, monitoring indicates the effectiveness of protected areas in preserving and enhancing the species they contain.

Once the conservation areas are demarcated, the areas shall be monitored at frequent intervals to note disturbances or encroachments. Habitat protection from anthropogenic catastrophes represents the first and the most important measure for the existence of the species in a natural habitat. Phenological observations can be initiated during this process to check the reproductive status and to enable seed collections.

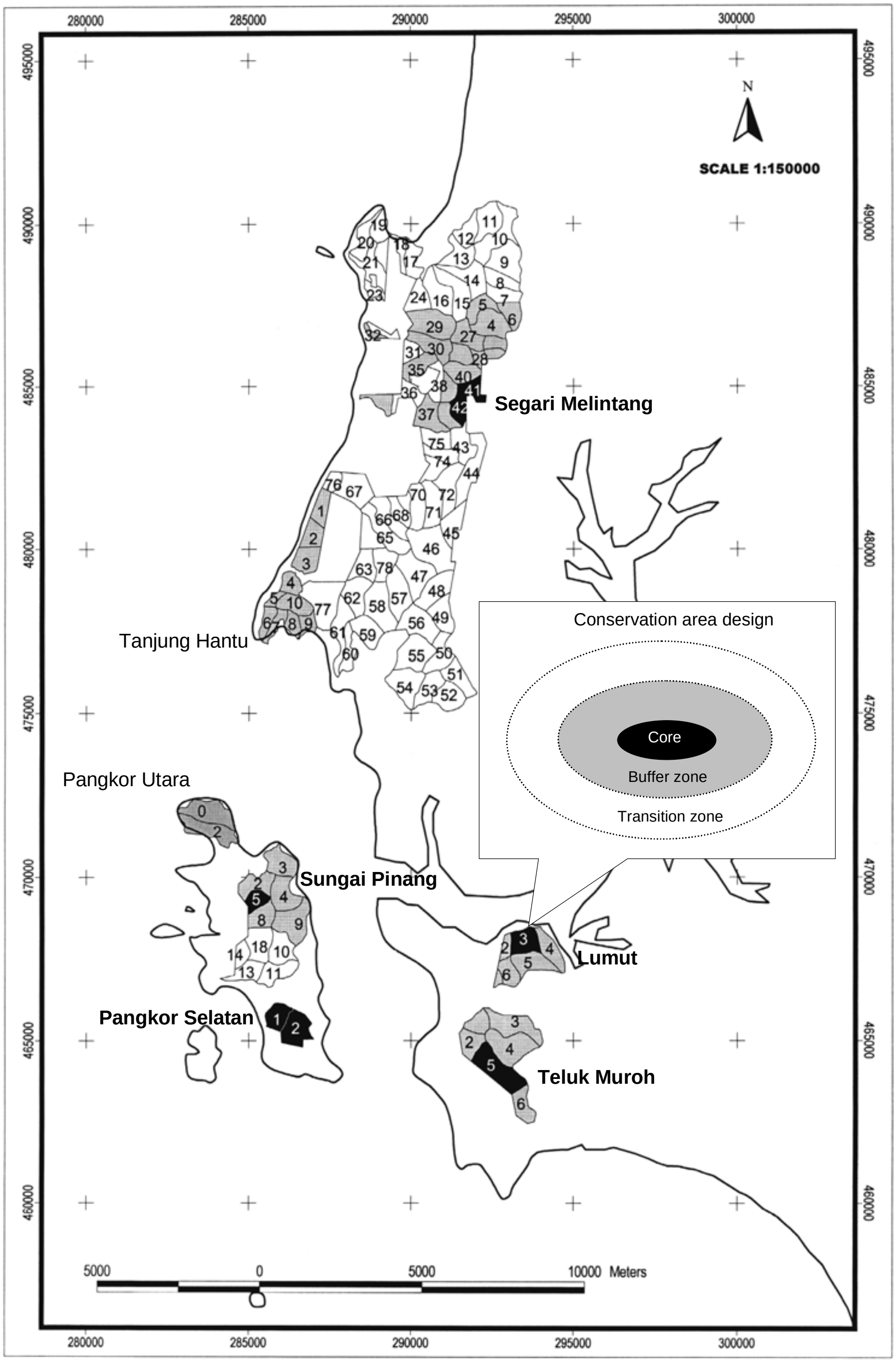

Fig. 7. Proposed *in situ* conservation areas (compartments highlighted in black) and model for reserve design (inset) of *S. lumutensis*. Compartments where the survey was conducted are highlighted in grey. The species is not present in Pangkor Utara and Tanjung Hantu.

Even if the habitat remains untouched, all populations face some risk of decline through exposure to the vagaries of natural temporal and spatial variations, such as environmental and demographic variations. Hence, monitoring of population size should also be conducted at appropriate intervals to detect any drastic reduction so that timely management prescriptions can be provided to ensure their health.

At five-year intervals, the populations should be enumerated to determine its size distribution, mortality, recruitment, population growth and other demographic variables. The information generated helps to understand the mechanisms that influence population behavior and can be used to predict population trends. In addition, genetic assessment should also be conducted to determine population bottlenecks and inbreeding depression. The 8-ha study plot is already available for Sungai Pinang and this should be included in the core area. A similar study plot shall be established in Pangkor Selatan, Segari Melintang, Lumut and Teluk Muroh. Although monitoring is an expensive process in terms of time and resources, it is the only way to ensure that *S. lumutensis* is conserved effectively.

A management plan for the conservation areas must be developed to regulate human intervention in a manner that ensures the population viability of the target species is maintained or enhanced (Maxted *et al*. 1997a). Given the large amount of genetic diversity detected presently, *S. lumutensis* should have enough genetic resources necessary for short-term ecological adaptation and for long-term evolutionary change. However, all the populations exhibited high positive values of fixation index, an indication of homozygote excess, which might indicate depression due to inbreeding. In Sungai Pinang, the inbreeding depression can be either due to high selfing rate or biparental mating. Inbreeding causes the loss of heterozygosity with no change in allele frequencies, because continuous selfing and mating between relatives will purge the deleterious recessive alleles and expose them as homozygotes to the environment (Oostermeijer *et al*. 2003). It is generally agreed that inbreeding is associated with increased seed abortion, low germination rates, high seedling mortality, and poor growth and flowering of the offspring (Dudash & Carr 1998). Thus, if a population consists of less than 60 reproductive individuals, the priority should be to enlarge the population size to minimize inbreeding depression due to small population size. If a population consists of a few hundred reproductive individuals, thinning is required to reduce the degree of spatial genetic structure and thus minimize the inbreeding depression due to biparental mating.

The direct estimation of gene flow showed that its pollen flow is not extensive, which might indicate that its pollen do not cross large forest openings. Because the five populations were isolated from each other due to geographical barrier or fragmentation, if the populations are allowed to exist in small population sizes for a long period of time, it is expected that the loss of genetic variation by drift cannot be compensated for by immigration of seeds or pollens from other populations. This leads to genetic erosion and increased genetic differentiation among populations. Consequently, low levels of genetic diversity might reduce evolutionary potential and increase the probability of population extinction. The most effective way to counter genetic risks is to allow for migration, i.e., the exchange of pollen and seeds with neighbors. The idea of habitat corridors initially developed for animal conservation (Simberloff & Cox 1987) might be an option, and provided resources are available, this approach may be applied to bridge the Sungai Pinang population with that in the Pangkor Selatan, and Teluk Muroh population with the Lumut population.

In situ conservation areas should be intensively managed to support the natural regeneration of target species and prevent them from competition with other species that may become dominant following the rules of natural succession. The demographic study conducted in Sungai Pinang showed that the population consisted of a low number of medium-sized trees and had high mortality of seedlings. Thus, silviculture treatments should be designed to encourage seedling regeneration and enhance sapling growth by selectively eliminating the two prominent associated palm species (*E. tristis and C. castaneus*), so as to minimize the space competition and maximize the sunlight exposure. Nevertheless, as the two island populations were entirely isolated from mainland populations and the three mainland populations were isolated from each other either due to geographical barrier or fragmentation, restricted gene flow and contemporary demographic independence are anticipated. Therefore, the five populations should be considered as distinct management units, which will require specific management prescriptions. Like monitoring, management prescription activities are often expensive in time and resources. Hence, active management should be carried out with decreasing intensity and eventually stops when monitoring indicates that survival and reproduction, especially the quality of the offspring, have achieved acceptable levels.

Ex situ Conservation

Ex situ conservation can be divided into several specific techniques, such as seed storage, *in vitro* storage, DNA storage, field gene bank and botanical garden. As the species produces recalcitrant seeds which are extremely short-lived in nature, *ex situ* conservation based on seed storage and periodic regeneration appears to be more in principle than in practice. Although in vitro conservation is seldom useful or economically viable for the conservation of forest trees, it may be more relevant to *S. lumutensis* with seed storage problems. The use of DNA storage method is rapidly increasing in importance. It is now routinely possible to amplify specific oligonucleotides or genes from the entire mixture of genomic DNA. The advantage of this technique is that it is efficient, simple and takes up little space but the obvious problem is that it does not allow the regeneration of entire plants (Maxted *et al*. 1997b). A better assurance against possible extinction in its natural habitat is the establishment of the species in *ex situ* conservation areas, such as botanical gardens and arboreta. Realistically, however, botanical gardens and arboreta collections are always limited to a small number of individuals.

Although the establishment of new populations to areas outside their historic range might not be successful due to genetic and ecological adaptation problems, increased use of *S. lumutensis* in terms of planting in forest areas, watersheds and degraded lands or as field gene bank should be encouraged. The idea is that the cultivation of a valuable but rare tree species can result in multiplication and distribution of its germplasm. Moreover, when a rare species becomes common as a result of planting, and its products have economic value, the harvesting pressures on its natural populations will decrease.

As the species is outcrossed and the majority of its genetic diversity was partitioned within the population, a minimum of 10 unrelated mother trees per population should be used to establish a field gene bank. In addition, as the species exhibited significant spatial genetic structure up to the scale of about 20 m, the selected mother trees for seed collections should be more than 20 m apart. Chances for success are greatest if seeds are drawn from a composite cross among the available populations so that natural selection will weed out unsuccessful genotypes from among the segregating progeny of such hybrid populations (Barrett & Kohn 1991). Larger seeds have a greater chance of germination compared to smaller seeds. Using 30 progenies per mother tree and combining the progenies from five populations would provide a stand of 1500 individuals. In addition to the genetic considerations, stand sizes should be kept at a manageable level and that the burden of future management and regeneration is within the capacity of the institution in charge. A minimum of 10 ha is recommended. Initial planting may want to consider planting 2000 individuals (40 progenies per mother tree) because this number will decrease as a result of mortality and other factors.

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Status of Biological Diversity in Malaysia and
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