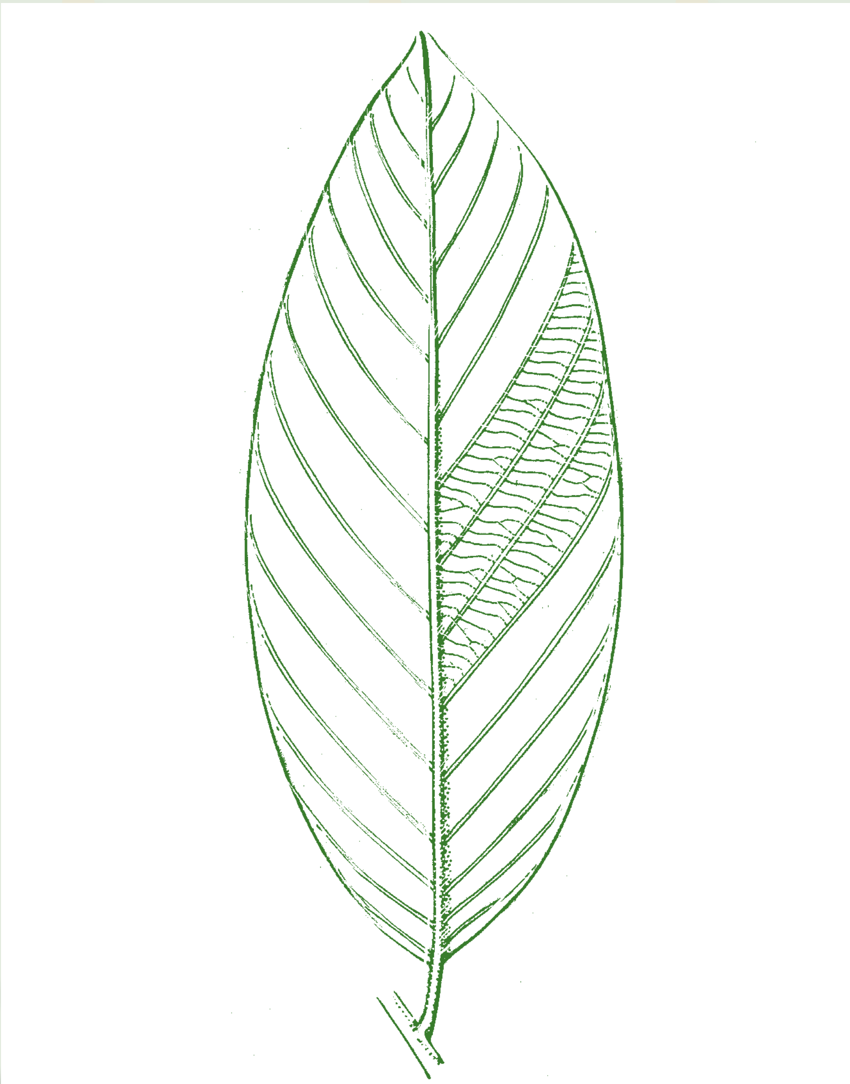
Bioversity International

MODULE 1
Species conservation strategies

Case study 1.3

Shorea lumutensis: genetic variation and conservation

David Boshier



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MODULE 1
Species conservation strategies

Case Study 1.3

Shorea lumutensis: genetic variation and conservation

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This case study presents information on *Shorea lumutensis* (Sym.), a rare dipterocarp tree, endemic to Peninsular Malaysia. Use the information to devise a conservation strategy for the genetic conservation of this threatened species. The strategy should take into account both the species' patterns of genetic variation and the forestry/socio-economic context, and may combine *in situ*, *ex situ* or other conservation measures. **Make sure your recommendations are specific and detailed** (e.g. if you recommend seed collections for *ex situ* conservation, specify from which populations, how many trees, how much seed, where you will store it, etc). Also indicate the relative priority of actions (e.g. do you want to prioritize action in one reserve above others?) as funds will not be limitless. The exercise is set in the context prior to the year 2007, both in terms of the species status and country profile. As such, more recent information and changed contexts are not included as they are not relevant to the exercise.

In your group discussions you should, in particular, think about and respond to the following:

- How has human disturbance shaped the genetics of *S. lumutensis*?
- What are the mating system, seed and pollen dispersal mechanisms?
- What are the levels of genetic variation and how are the alleles distributed across populations?

In your strategy you should detail:

- What are the threats to *S. lumutensis* (short-term/long-term) and for which populations is action a priority? Of what type should this be? ***List problems*** by type: ***genetic*** (e.g. which populations are too small? Which are different?) ***Other types of problems*** **(**e.g. social, communication, resources – see Conservation status, Country profile sections).
- ***Which*** conservation methods - *in situ*, *ex situ*, on-farms (*circa situm*)?
- How many conservation areas are required? How large does each conservation area need to be?
- How should conservation areas be designed?
- What are the limiting social factors to conservation, utilisation and planting?
- What do end-users need to know and how will you communicate that?
- ***Who*** will do ***what***, **where**, and ***how*** will you pay for it?

Introduction

In Peninsular Malaysia, the Dipterocarpaceae family comprises some 155 species. Conservation of dipterocarps was not previously seen as important, as none of the species in the family was thought to be threatened. However, research has shown that more than 57% of the species are restricted to specific zones. Thirty species are endemic to Peninsular Malaysia, with 12 considered rare. Amongst these, *Shorea lumutensis* Sym. was designated as critically endangered, due to suspected population reduction of at least 80% over the last 10 years and an overall population originally estimated to number fewer than

250 mature individuals (IUCN criteria[1]: CR A1cd, C2a). Such small populations are inherently more vulnerable to natural catastrophes, demographic and environmental stochasticity (chance events), human activities and genetic stochasticity, such as loss of genetic diversity by drift and inbreeding.

Species description, uses and conservation status

Shorea is a genus in the Dipterocarpaceae family, with some 350 species from south/south east Asia. *S. lumutensis* is a medium- to large-sized tree (most trees <50 cm diameter at breast height (dbh), occasionally >100 cm dbh) with irregular longitudinally fissured bark and short buttress. The leaves are leathery and oblong-elliptic in shape with about 14 pairs of nerves, prominent on the underside which usually has a markedly glaucous undersurface giving its Malay name *balau putih* (i.e. white Balau). Flowers are hermaphrodite (about 9 mm long, petals linear and pale yellow, 20–25 stamens), fruits sub-sessile with three outer and two inner wings.

Phenology

Flowering in the Dipterocarpaceae is notably episodic. At irregular intervals of 2-10 years, the aseasonal tropical rain forests in Malaysia show heavy mass flowering, followed by mass fruiting. During heavy flowering, almost half the mature individuals and >80% of the canopy and emergent tree species in a forest may flower over a short period of 3-4 months. A rapid increase in pollinator numbers occurs in the forest, partly through pollinator migration from forest fringes to forage on the abundant flowers. Many dipterocarp species which share a single pollinator (e.g. common flower thrips) also appear to reduce pollinator competition by flowering in sequence. Numbers of thrips increase rapidly by feeding/breeding on the millions of dipterocarp flower buds several weeks before flowering. The environmental cue for this irregular, but widespread mass flowering is linked to a small dip of about 2° C below mean night-time temperature for 4-5 nights, which occurs with El Niño events.

Observations of *S. lumutensis* in a natural forest over 3.5 years showed only one flowering event (approx. two weeks, on 5 out of 35 trees >30cm dbh in plot). Paternity assignment showed an additional seven trees within the same plot also flowered (total 12 of 35 trees flowered), but probably at a low flowering intensity which is difficult to observe with binoculars. The period from the end of flowering to mature fruit fall was approximately 10 weeks and from budding to mature fruit fall, approximately 16 weeks. The dbh of flowering trees ranged from 31-110 cm, suggesting that trees >30 cm dbh can be defined as reproductive. Seed dispersal is by gravity, aided by seed wings and there may be secondary dispersal by seed predators. Fruit predation is extensive; the majority of fallen mature seeds are consumed by small mammals (e.g. squirrels, rats). Seed of dipterocarp trees is typically recalcitrant, i.e. short viability, making normal storage often impractical.

Distribution

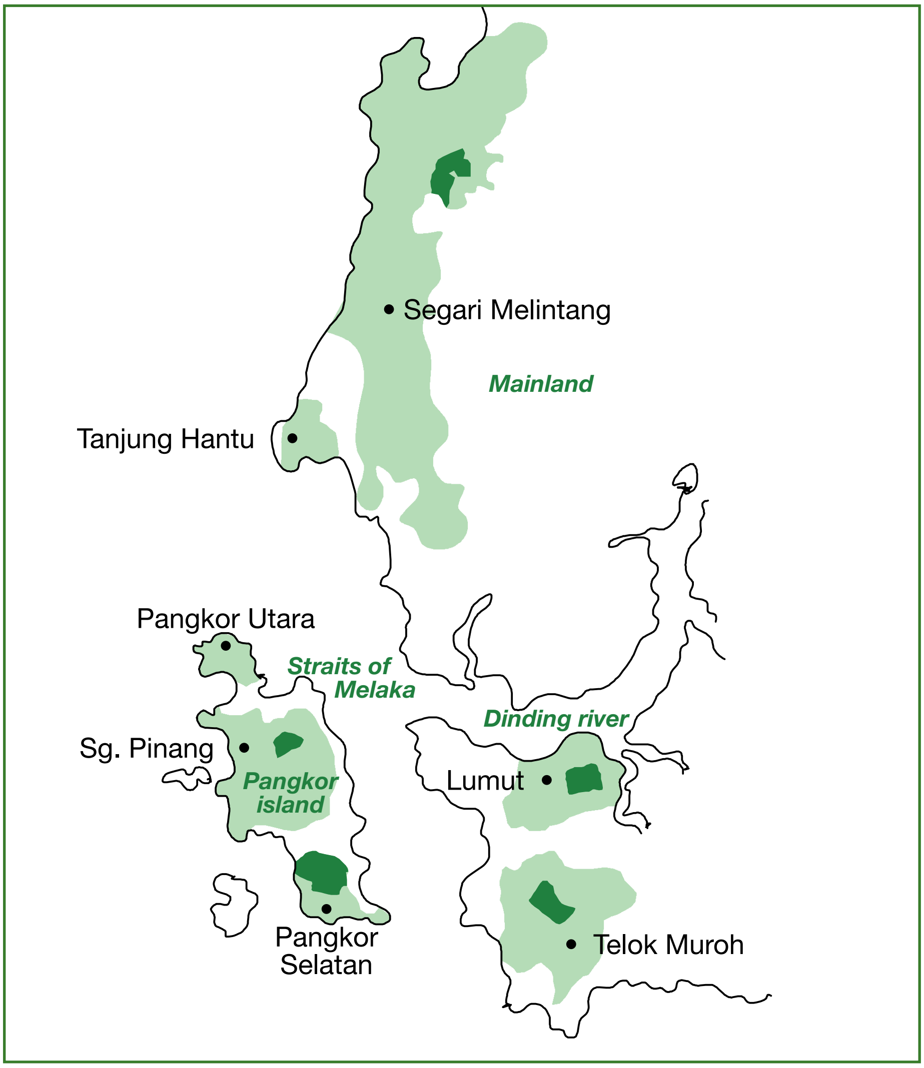
S. lumutensis is reported as being restricted to the western part of Peninsular Malaysia (Manjung District). Previous reports of occurrence in the northwest of Johor in Peninsular Malaysia were in fact *S. inappendiculata*. It is also uncertain whether the species occurs in Karimum and the east coast of Sumatra where samples may belong either to this species or to *S. inappendiculata*. *S. lumutensis* is present in five forest reserves (Sungai Pinang, Pangkor Selatan, Segari Melintang, Lumut, Teluk Muroh) and confined to an area of some 313 km^2 (Fig. 1). The two island populations (Sungai Pinang, Pangkor Selatan) are separated from the mainland by the Straits of Dinding (approx. 3 km), which became isolated from the mainland many thousands of years ago. Among the three mainland populations, there is no distinctive geographical barrier between the Lumut and

[1] www.iucnredlist.org/info/categories_criteria1994#categories

Teluk Muroh Reserves, but the Segari Melintang Reserve is separated from these two populations by the Manjung River (approx. 2 km wide at this point).

In the absence of fossil record data, it is uncertain whether the species was more widely distributed in the past than today. The distribution may be the result of physiological limits to growth and reproduction (i.e. rarity may reflect specific adaptation to scarce habitat), rather than historical dispersal patterns. Within the forest reserves, *S. lumutensis* generally occurs as a sub-canopy to emergent tree in small patches of dry coastal hill dipterocarp forest, usually at >100 masl, on moderate fertility soils, in microclimates where soil drainage is good or where high soil moisture levels are not permanently maintained. Isolated trees are occasionally seen. Its spatially clumped distribution is strongly related to local topographic variation, the tree being prominent in ridges and upper slopes, and absent in lower slopes and valleys. Thus, the ridges and slopes probably tend to dryness more than the lower slopes and valleys. In addition, the influence of slope on soil texture and water holding capacity partly determines the levels of available mineral nutrients, and as a result, the spatial aggregation. Consequently, distances between the remaining populations are greater than the reserve boundaries would suggest (Fig. 1 for core areas, Table 4 for actual distances).

Figure 1. Location of the five Forest Reserves in Peninsular Malaysia where *Shorea lumutensis* occurs. Within each reserve dark compartments show where most *S. lumutensis* trees occur. NB: not found in Pangkor Utara and Tanjung Hantu Reserves.



Uses and potential value for tree planting

Although the timber is classified as a Balau (a heavy dipterocarp hardwood), sawmillers in the Dinding area refuse to work it. It is doubtful that there is any reason for this other than local prejudice. While tourism poses threats to the reserves on Pangkor Island, ecotourism initiatives linked directly to the reserves may also offer opportunities for conservation and related education regarding *S. lumutensis* and other endangered species.

Field study results

In natural forest, the species' diameter distribution shows a typical reverse J-shaped curve, indicating abundant regeneration, with mortality (75 trees dying in 3 years; Table 1) only in the size classes of seedlings/saplings, and slow growth rates in the small diameter classes. Medium-sized trees constitute 1.7% of 416 individuals found within a 5 ha plot, compared with 8.2% for the largest-sized trees. The results suggest that the population is in danger of decline, although this may be a reflection of the naturally slower growth rate leading to a slower transition between the smaller size classes. Experience in planting this species is limited. Two-year old seedlings from three mother trees had 5-62 cm mean height, with 1-8 mm diameter at ground height.

Table 1. Short-term population dynamics of *S. lumutensis* over 3 years (2001-2004) in a 5 ha plot in Sungai Pinang Reserve (standard deviations in parenthesis)

dbh size class cm	# trees	% mortality	Mean diameter growth rate mm yr-1	Maximum growth 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

Conservation status

Extinction of the species is likely if nothing is done to conserve it. Only five populations of *S. lumutensis* are known with perhaps no more than 500 large individuals (>30 cm dbh) as follows: Sungai Pinang approx. 100; Pangkor Selatan approx. 50 or fewer; Segari Melintang approx. 120; Lumut approx. 90; Teluk Muroh approx. 100). It is important to note that these estimates are limited to compartment surveys and there may be others outside the survey area. The surveys indicate that numbers are higher than the original figure given in the IUCN assessment (see Introduction). Although the numbers of large trees were few in each of the populations, progressively larger numbers of associated saplings and seedlings were observed scattered around the large trees in each population. Population density of *S. lumutensis* (4.4 trees ha^{-1}) is higher than *S. leprosula*, a common and widely distributed dipterocarp in Peninsular Malaysia (3.3 trees ha^{-1}). Therefore, the rarity of *S. lumutensis* can be classified as locally common, but occurring in only a few places.

The following are the major threats to existing populations: logging activities (Segari Melintang), quarrying for stones and conversion to oil palm plantations (Lumut, Teluk Muroh), and land development for tourism (Pangkor Selatan, Sungai Pinang). The location of the core areas of the *S. lumutensis* populations in compartments bordering edges of the reserves in itself increases the threat to the species. There are no reports of diseases of this species, although a lack of research precludes any definitive statements.

Genetic variation in natural populations

Five populations, representing the entire known natural range of *S. lumutensis* (Fig. 1, Table 2) were sampled. Within each population, leaf material from 40-48 mature trees (>20cm dbh) was analysed for eight polymorphic loci microsatellite (SSR) markers (Table 4 gives allele frequencies for six of the loci). Standard measures of genetic diversity including; mean number of alleles per locus (*A*), allelic richness (Rs), expected heterozygosity (H_e) and fixation index (Fis), were calculated for each population. Given its narrow range, the species shows surprisingly high levels of genetic diversity (Table 2) comparable with those in other dipterocarps (e.g. *S. leprosula*, *S. ovalis, S. curtisii, S. macroptera*). Allelic richness ranged from 5.7 (Lumut) to 6.3 (Segari Melintang), with heterozygosity (also known as gene diversity) of 0.609 (Sungai Pinang) to 0.673 (Segari Melintang). There were positive fixation index values (Fis> 0.1; Table 2) in all populations, indicating an excess of homozygotes and inbreeding. Population sizes have probably remained sufficiently high to maintain high levels of genetic diversity within individual populations.

Table 2. Genetic diversity in *S. lumutensis* populations at eight microsatellite loci (standard deviations in parentheses)

Population	Sample size	Mean no. alleles per locus, A	Allelic richness, Rs	Mean heterozygosity, He	Fixation Index, Fis
1) Segari Melintang	48	7.9 (1.9)	6.3 (1.3)	0.673 (0.058)	0.109
2) Lumut	40	6.6 (1.4)	5.7 (1.2)	0.636 (0.074)	0.156
3) Teluk Muroh	48	7.0 (1.5)	6.0 (1.1)	0.661 (0.052)	0.194
4) Sungai Pinang	47	7.4 (1.8)	6.0 (1.4)	0.609 (0.082)	0.130
5) Pangkor Selatan	48	8.1 (1.7)	6.1 (1.1)	0.663 (0.077)	0.128
Mean	46	7.4 (0.6)	6.0 (0.2)	0.648 (0.026)	0.143

Hierarchical cluster analysis of populations using Nei's genetic distances among pairs of populations showed three clusters: Lumut/Teluk Muroh, Sungai Pinang/ Pangkor Selatan, with Segari Melintang as the outlier (Fig. 2). The clusters showed geographical relationships consistent with an 'Isolation by Distance' model, such that geographically close populations group together. However, statistical support for these clusters was very low (bootstrap support <10%), with only 5.8% of genetic diversity distributed among populations (i.e. most genetic diversity was within populations), indicating there is little evidence of population differentiation.

Table 3. Geographic distance (in km) above the diagonal for the five *S. lumutensis* populations.

Population	1) SM	2) LU	3) TM	4) SP	5) PS
1) Segari Melintang (SM)	-	15.9	19.2	15.9	18.9
2) Lumut (LU)		-	2.6	7.5	6.6
3) Teluk Muroh (TM)			-	8.0	5.1
4) Sungai Pinang (SP)				-	3.3
5) Pangkor Selatan (PS)					-

Table 4. Allele frequencies at six loci in five natural populations* of *Shorea lumutensis* (- = 0.000 frequency)

Locus	Allele	1) SM	2) LU	3) TM	4) SP	5) PS
Slu057	110	0.143	0.176	0.121	0.179	0.250
	112	0.614	0.649	0.621	0.641	0.396
	114	0.186	0.122	0.258	0.154	0.219
	116	0.029	-	-	-	0.094
	117	0.029	-	-	-	-
	118	-	-	-	-	0.010
	121	-	0.054	-	-	-
	122	-	-	-	-	0.021
	123	-	-	-	0.013	-
	124	-	-	-	-	0.010
	125	-	-	-	0.013	-
Slu110	220	0.103	-	-	0.030	0.031
	222	0.382	0.541	0.781	0.588	0.417
	224	0.485	0.459	0.219	0.368	0.552
	235	-	-	-	0.014	-
	247	0.029	-	-	-	-
Slu124	129	0.028	-	-	-	-
	131	-	-	0.024	-	-
	133	0.083	-	0.146	0.039	0.021
	135	0.097	0.038	-	0.066	0.125
	137	0.458	0.526	0.524	0.421	0.177
	138	0.014	-	-	-	0.042
	140	0.014	-	-	-	0.031
	141	0.028	0.090	-	0.066	0.010
	143	0.014	0.026	-	0.053	0.010
	145	0.014	0.026	-	0.013	-
	147	-	0.013	-	-	-
	149	-	-	-	-	0.010
	153	0.236	0.090	0.073	0.145	0.135
	154	-	-	-	0.026	0.031
	155	-	0.038	0.110	0.105	0.365
	159	-	-	-	-	0.010
	160	-	-	-	-	0.010
	162	-	-	0.012	-	-
	163	-	-	-	-	0.021
	165	-	0.141	0.085	0.066	-
	167	0.014	-	0.024	-	-
	168	-	0.013	-	-	-

Table 4. Continued

Locus	Allele	1) SM	2) LU	3) TM	4) SP	5) PS
Slu175	220	0.758	0.875	0.400	0.890	0.895
	221	-	0.013	0.314	-	-
	223	-	0.013	0.114	-	0.023
	226	0.242	0.100	0.143	0.110	0.047
	228	-	-	0.029	-	0.012
	240	-	-	-	-	0.023
Sle111a	147	0.020	-	-	-	-
	148		-	-	0.013	-
	149	0.100	0.237	0.154	0.179	0.281
	150	0.020	-	-	-	0.010
	151	0.120	-	-	-	-
	155	0.060	0.053	0.019	0.013	0.010
	156	0.100	0.092	0.058	0.090	0.156
	157	0.560	0.461	0.635	0.513	0.469
	158	-	0.132	0.058	0.167	0.073
	159	0.020	-	-	-	-
	160	-	-	-	0.026	-
	161	-	-	0.038	-	-
	163	-	0.026	0.038	-	-
Sle267	108	0.016	-	-	--	-
	116	0.203	0.117	0.069	0.147	0.064
	118	-	-	-	0.015	0.106
	120	0.016	0.100	0.167	0.074	0.043
	122	0.078	-	-	-	-
	124	-	-	-	0.015	-
	126	0.234	0.167	0.306	0.397	0.255
	128	-	0.050	0.083	-	0.074
	130	-	0.017	0.069	0.118	0.298
	132	0.063	0.250	0.069	0.221	0.053
	134	0.281	0.250	0.097	-	0.011
	136	0.063	-		-	0.043
	138		-	0.056	-	-
	146	0.016	0.017	0.028	-	-
	148	-	0.033	0.042	0.015	-
	149	-	-	0.014	-	-
	150	-	-	-	-	0.053
	152	0.031	-	-	-	-

*SM, Segari Melintang; LU, Lumut; TM, Teluk Muroh: SP, Sungai Pinang; PS, Pangkor Selatan.

S. lumutensis shows a mixed mating system (Table 5, mean outcrossing rate 63.4%), with great variation among the four trees sampled (22-92%), and no evidence of apomixis. Less fit seed produced by selfing may well be eliminated during initial germination/establishment when mortality is high (Table 1). Pollen flow is moderately extensive, mean distances varying from 122-220 m (Table 5).

Figure 2. Dendrogram of genetic similarities between the five populations of *Shorea lumutensis* (bootstrap % values on branches based on 1000 replications).

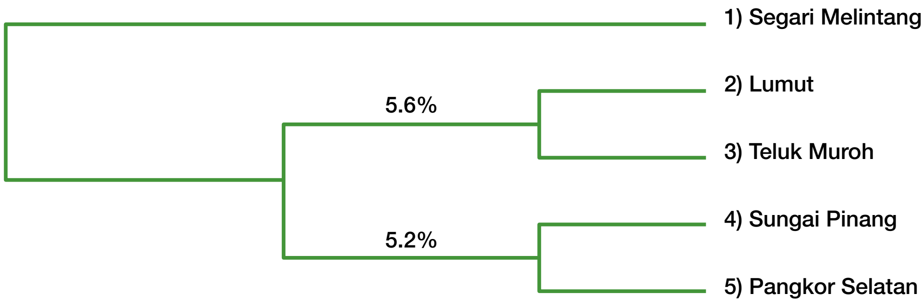
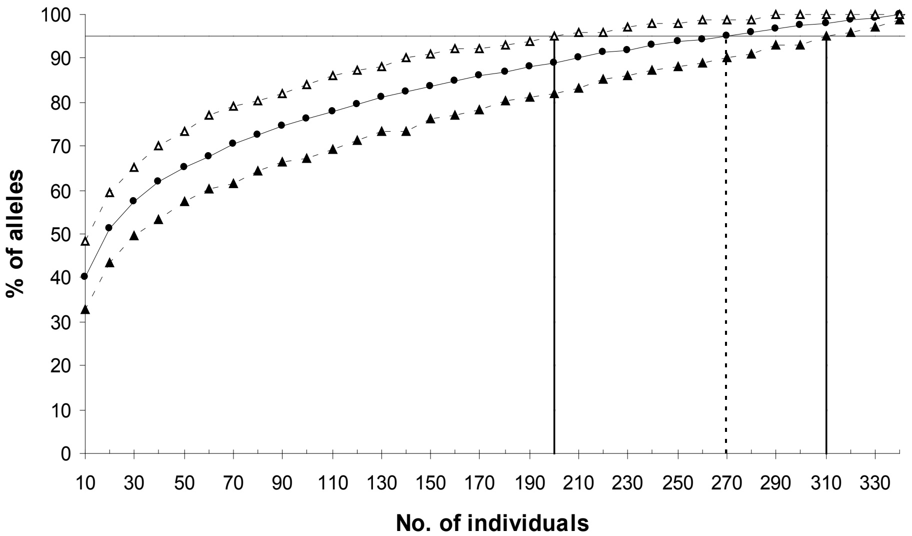


Table 5. Summary of mating system, paternity assignment and breeding unit parameters for four open pollinated families of *Shorea lumutensis* in Sungai Pinang (values in parentheses are standard deviations).

Tree no.	No. of seeds	Mating system and paternity assignment			Breeding unit parameter	
		% of seed due to outcrossing	% of seed received pollen from outside plot	Mean outcrossed 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)

Figure 3. Simulation of changes in % of alleles maintained with changes in number of individuals of *Shorea lumutensis* removed. Values based on 1000 resamples with standard errors (dotted lines).



Trees with higher outcrossing rates and receiving pollen from many distant paternal trees produced larger seeds with a greater probability of germination and seedling establishment. From pollen flow distances and density of *S. lumutensis* trees, the mean breeding unit size and area were estimated at 52 trees and 11.8 ha, respectively. Simulation shows that the minimum population size to maintain current levels of genetic diversity (95% of alleles) is 270 trees (200–310 trees; Fig. 3).

Malaysia – background information

- Area: 330 000 km^2. Altitudes: from sea level to 4095 masl.
- Population: 26 600 000. 33% live in rural areas, 15.5% of population live below the poverty line.
- GDP: US$5859 per capita. Incomes mostly below the global average. The situation is worse in rural areas, where >80% of the population have incomes which do not meet their basic needs (1993 data).
- Area defined as forest: 208 900 km^2, i.e. 63.6% of total land area.
- During the 15 years from 1990 to 2005, forest cover decreased by 14 900 km^2 (0.4% per year).
- Principal causes of deforestation: migratory agriculture, extensive cattle grazing/ranching and pasture, over-exploitation of trees for fuelwood, and forest fires, all of which affect 20 000 ha annually.

Forest legislation

In Malaysia's federal system of government, land/forest, is a state responsibility with each state empowered to enact laws and formulate policy independently. Hence, designation and change of the Permanent Forest Estate/conservation areas are affected by each state's legislation. Federal government authority extends only to provision of advice/technical assistance to states and the conduct of research. This division of powers poses a challenge to ensure coordinated implementation of national policies covering forests. A National Forestry Council (members include Chief Ministers of all states, ministers for forestry, agriculture, environment, and trade) was endorsed in 1978 as a forum for federal/state governments to discuss forestry issues and plays a major role in encouraging adoption of federal acts at state level. The National Forestry Policy (1978) and National Forestry Act (1984) provide a basis for systematic management, development and conservation of forest resources. Revisions in 1992-1993 show a vital change in forest management philosophy, from only sustainable timber yields to sustainable management of forests' multiple functions, striving to balance ecological, social and environmental functions with economic importance. Other federal legislation complements the National Forestry Act (e.g. Waters Act of 1920 - guidelines for maintenance of riparian strips Land Conservation Act of 1960, National Land Code of 1965, Protection of Wildlife Act of 1972 - legal framework for protection of endangered species, National Parks Act of 1980). Some state governments also have their own forest policies. The National Biodiversity Policy of 1998 aims to enhance conservation of Malaysia's plant and animal life. With multi-sector involvement (Ministry of Primary Industries, Ministry of Agriculture, Department of Wildlife, National Parks & Fisheries), it includes strategies for conserving biodiversity and for the sustainable use of biological resources to ensure long-term economic benefits, food security and environmental stability.

Institutional framework

The Forest Research Institute Malaysia (FRIM), Forestry Departments of Peninsular Malaysia, Sabah and Sarawak, the Malaysia Timber Industry Board and Malaysia Timber Council are directly involved in administration, management, research and development in the forestry sector. All fall under the Ministry of Primary Industries. Other centres conduct research and development (e.g. Forest Research Centre at Sandakan (Sabah), Timber Research and Technical Centre/Forestry Research Division of the Sarawak Forestry Department, Sarawak

Timber Industry Development Corporation, Faculty of Forestry at Universiti Putra Malaysia). NGOs (e.g. Environment Protection Society of Malaysia, Malaysian Nature Society, WWF, Sahabat Alam Malaysia) are active in issues related to conservation of biological diversity and its sustainable use (e.g. policy, legislation, awareness programmes).

Utilization of forest resources

Malaysia's forests have multiple functions contributing significantly to its socio-economic development. They are generally associated with timber harvesting, non-wood resources (rattans, bamboo, fruits, vegetables, spices, medicinal plants, ornamentals), wildlife habitat, as well as services, e.g. water, recreation. In 2001, forest revenue in Peninsular Malaysia totalled US$69.7 million, roundlog production being 4.15 million m^3. In the same year, export of major timber products (i.e. logs, sawn timber, plywood, veneer) totalled US$2.3 billion, with the forestry public sector employing 196 612 people and the private forest sector, 185 891. Expansion of the forest resource base is being made a priority and so employment is expected to increase substantially through intensive forest management, development/establishment of fast-growing tree plantations, as well as modernisation of forest industries, all aiming for production of higher value-added products. The forestry sector is expected to continue to generate substantial revenues for Federal and State Governments. Forests will also play important roles in climatic/environmental stability, conservation of valuable biodiversity and management of water resources.

Forest management and harvesting

For management purposes, forest land in Malaysia falls broadly into three categories: 1) Totally Protected Areas under Federal Government control (Department of Wildlife & National Parks); 2) The Permanent Forest Estate (PFE i.e. Forest Reserves, under the control of the Forestry Department; 3) State land - this is forest land owned by states and essentially viewed as land reserves for development. Under the National Forestry Policy, the PFE should be strategically located throughout the country while under the amended National Forestry Act of 1984 (amended 1993), the PFE is classified into functional classes, i.e. forests for: sustained timber production, soil protection, soil reclamation, flood control, water catchment, wildlife sanctuaries, virgin jungle reserves, amenity, education, research and for federal purposes.

In Peninsular Malaysia, timber production in the PFE is managed under two systems Malayan Uniform System (MUS) with a 55-year cutting cycle and the Selective Management System (SMS) with a 30-year cutting cycle. In the MUS, the mature crop is removed in a single felling of all trees >45 cm dbh for all species. Any large trees left behind due to defects or low market value, are removed by poison girdling. The next crop develops from seedlings, and is thus of uniform age with a larger proportion of commercial species. While not environmentally degrading, MUS is not oriented towards genetic conservation. As it relies primarily on seedlings/saplings to form the next crop, silvicultural treatments favour these groups. Such treatments tend to lead to more intense poison girdling than necessary and in some cases open the canopy too drastically. Hence, emphasis has shifted from seedlings/saplings to advanced growth with more discriminating use of poison girdling and more conservative silvicultural treatments, thus conserving forest genetic resources. This system has been applied successfully to lowland dipterocarp forests, but is unsuited to hill dipterocarp forests because of more difficult terrain, uneven stocking, lack of natural regeneration, erosion risk on steep slopes, and the incidence of other secondary growth favoured by drastic canopy opening. The SMS was introduced for hill dipterocarp forests in Peninsular Malaysia, with selective removal of the mature crop in a single operation based on inventory data. This allows more flexible harvesting regimes with emphasis on advanced growth of trees of 15-45 cm dbh as the next crop. It discourages poison girdling of non-commercial species, thus conserving the forests' genetic resources. Felling is selective; a difference in dbh cutting limits of at least 5 cm between dipterocarp and non-dipterocarp species aims to conserve a higher percentage of dipterocarps in the next crop.

Guidelines with special emphasis on environmental measures have been adopted to supplement forest management and harvesting plans. The Continuous Forest Resources Monitoring System of Peninsular Malaysia has been operational since 1993, with an integrated system of remote sensing, GIS and field data. Practices have also been introduced to reduce logging damage in forest stands. In recent years, research on reduced impact logging (RIL) and low-impact logging harvesting technologies has intensified, with Sabah formulating standards and guidelines for RIL operations.

Malaysian criteria and indicators for sustainable forest management (SFM) and timber certification

As an International Tropical Timber Organisation (ITTO) member, Malaysia adopted its guidelines and criteria for assessing sustainable forest management (SFM) with a national committee established in 1994 to ensure full implementation of ITTO criteria and indicators for SFM. The national committee formulated Malaysian criteria and indicators for SFM at national and forest management unit (FMU) levels, with numerous refinements to take into account latest forestry developments. A technical monitoring committee monitors implementation of all activities undertaken by each state Forestry Department in Peninsular Malaysia. To strengthen measures towards SFM, the Federal Government established the Malaysian Timber Certification Council (MTCC), an independent national certifying and accrediting body. As of 2003, the MTCC had certified three FMUs (Pahang, Selangor, Terengganu) and chain-of-custody certificates to 29 companies in Malaysia. Recently the MTCC joined the Pan-European Forest Certification Council, aiming for a Pan-ASEAN forest certification scheme.

Management and conservation of forest genetic resources

The exact number of plant species in Malaysian forests is not known, though a recent assessment estimates about 15 000. The Tree Flora of Malaya describes nearly 2830 species of woody plants in Peninsular Malaysia, of which 746 are endemic and 511 endangered (including *S. lumutensis*) as they are rare, endemic or their habitats threatened. Over 1300 plant species have been documented for potential pharmaceutical properties and some are used traditionally in herbal medicine.

In situ *conservation*

Malaysia has adopted several measures to conserve forest biological diversity, including creation of a network of totally protected areas (national parks, state parks, wildlife/bird sanctuaries, Permanent Forest Estates - PFEs). Currently, Malaysia has 2.15 million ha of protected areas gazetted or proposed, of which 0.32 million ha are within the PFEs. With the 3.81 million ha of protected forests, the total area designated for protection totals 5.96 million ha, that is to say 29.5% of the country's total forested land.

Peninsular Malaysia has 40 Totally Protected Areas (TPAs) totalling 751 413 ha. Taman Negara National Park is the largest of all the TPAs in Peninsular Malaysia (434 351 ha), covering three states, Pahang, Kelantan and Terengganu. It represents the flora of central Peninsular Malaysia, together with Krau, Sungkai and Sungai Dusun Wildlife Reserves. Endau-Rompin (Johor) National Park and Endau-Rompin (Pahang) Wildlife Reserves represent the southern flora while Perlis and the proposed Belum State Parks form a continuous link with the monsoon forests of Thailand and Myanmar. One hundred and twenty Virgin Jungle Reserves (VJRs) covering 111 800 ha, have been established to serve as 1) permanent nature reserves and natural arboreta; 2) control plots for comparison with harvested and silviculturally treated forests; 3) undisturbed natural forests for ecological and botanical studies. VJRs represent samples of the many types of virgin forest (e.g. mangrove forest, heath forest, peat swamp forest, lowland dipterocarp forest, hill dipterocarp forest, upper hill dipterocarp forest). Malaysia also established two Genetic Resources Areas, in Ulu Sedili Forest Reserve in Johor (4806 ha) and Semengoh Forest Reserve (Sarawak). These initially target 8 and 14 commercial species respectively, for genetic conservation and research is underway to identify additional species. *In situ* conservation stands exist for *Agathis borneensis*, *Aquilaria malaccensis*, *Calamus manan*, *Dryobalanops aromatica*, *Neobalanocarpus heimii*, *Nepenthes hamulatum*, *Rafflesia* sp., *Shorea curtisii*, *S. glauca*, *S. hemsleyana*, *S. macrophylla*, *S. splendida*, and *S. stenoptera*.

Ex situ *conservation*

Ex situ conservation can be important for long-term storage of germplasm for future breeding programmes or reintroducing species to the wild. In Malaysia, most research has been on improving agricultural crop species, with little work on conserving the genetic resources of forest plant species. The largest groups of forest plant species under *ex situ* conservation are orchids (1639 species), fruit trees (434 species), timber trees (364 species) and medicinal plants (115 species). *Ex situ* conservation of most species is of <10 accessions (except for *Anisoptera costata*, *Casuarina equisetifolia*, *Dryobalanops aromatica*, *D. oblongifolia*, *Durio* sp., *Dyera costulata*, *Eusideroxylon zwageri*, *Garcinia* sp., *Hopea odorata*, *Intsia palembanica*, *Metroxylon rumphii*, *Neobalanocarpus heimii*, *Nepenthes* sp., *Nephelium* sp., *Rafflesia* sp., *Shorea macrophylla*, *S. pauciflora*, *S. splendida* and *S. stenoptera*). Malaysia has 26 *ex situ* conservation areas, mainly in arboreta of research institutions, universities and government agencies. The Forest Research Institute Malaysia (FRIM), Malaysia Palm Oil Board, Malaysia Rubber Board and Malaysian Agricultural Research and Development Institute have arboreta for various groups of wild species (e.g. arboreta at FRIM have >500 forest plant species, including 150 dipterocarp species). The Penang Botanical Garden is the oldest *ex situ* conservation area in Malaysia but little research has been done there recently, the major functions being education, recreation and tourism. FRIM is developing a national botanical garden (Kepong Botanical Garden) with federal government and private institution support. Planning for two other botanical gardens at Putrajaya and Sungai Buluh is also underway. Seed gene banks are not appropriate for many Malaysian forest species as most produce recalcitrant seeds that cannot be stored for long. On-going research on the use of cryogenic and *in vitro* techniques for long-term *ex situ* conservation has led to successful cryopreservation of *Bambusa arundinacea, Dendrocalamus membranaceus*, *D. brandisii, Dipterocarpus alatus, D. intricatus, Pterocarpus indicus* and *Thyrsostachys siamensis*. Tissue culture has been studied in *Hopea odorata, Shorea leprosula, S. macrophylla, S. ovalis* and *S. parvifolia*.

Identification of national priorities

One hundred and five species are listed as priorities for Malaysia (*S. lumutensis* is not listed) and are mainly popular timber species for plantations (e.g. *Azadirachta excelsa*, *Khaya ivorensis, Tectona grandis*, *Dyera costulata*), popular medicinal plants (e.g. *Eurycoma longifolia*, *Labisia pumila*) and valuable timber species (e.g. *Neobalanocarpus heimii*, *Eusideroxylon zwageri*). Some popular timber species are exotics, introduced to Malaysia for forest plantations (e.g. *K. ivorensis*, *Melaleuca cajuputi, T. grandis*). Also included are indigenous timber species which are not currently popular for plantations (e.g. *Shorea glauca*, *S. curtisii*, *S. platyclados*), medicinal plants with clear potential (e.g. *Andrographis paniculata*, *Calophyllum lanigerum* var. *austrocoriaceum*, *Goniothalamus velutinus*), agroforestry species (e.g. *Calamus* sp.), ornamentals (e.g. *Cycas* sp., *Nepenthes* sp.), fruit trees (e.g. *Nephelium* sp., *Durio* sp.) and mangrove (e.g. *Avicennia alba*, *Sonneratia alba*).

Forest plantations

To increase future wood supply and relieve pressure on natural forests, by 2000 Malaysia had established 240 000 ha of plantations in Peninsular Malaysia (species include *Araucaria* sp. *Acacia mangium*, *Durio zibethinus, Gmelina arborea*, *Paraserianthes falcataria, Pinus caribaea*, *P. merkusii, Tectona grandis*, *Shorea macrophylla*). Plantations will be increased, particularly in Sarawak and Sabah, while those already established by the Forest Department in Peninsular Malaysia will be privatised. To encourage private sector investment in forest plantations, there is full tax exemption for ten years.

Non-timber forest products (NTFPs)

Besides timber production, policies are now geared to the development of NTFPs, forest services and agroforestry, to maximize investor returns and diversify the forestry sector. Agroforestry has been promoted to address increasingly scarce availability of land and raw materials, allowing a wider range of agricultural crops to be planted with forest tree species, thus optimising land use and returns. In addition, development of biotechnology products, extraction of natural chemicals from forest biological resources, utilisation of forest biomass for clean fuel and development of genetically engineered products from flora have been promoted. Diversification of forestry products will generate increased revenues, some of which can be invested back into the sector, making sustainable forest management a more viable option.

Information sources

This case study is based on the work of Dr S.L. Lee (Forest Research Institute of Malaysia) and collaborators.

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