VEGETATION MAPPING IN PHNOM SAMKOS AND PHNOM AURAL WILDLIFE SANCTUARIES, CARDAMOM MOUNTAINS, CAMBODIA

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A REPORT TO FFI-CAMBODIA

1. Summary

The vegetation of the Cardamom mountains is one of the treasures of Cambodia, being the northernmost outpost of Indo-Malayan forest in Indochina, but has been little explored since colonial French times. In preparation for a workshop during which conservation zones were to be decided for two important parks, Phnom Aural Wildlife Sanctuary and Phnom Samkos Wildlife Sanctuary, a preliminary vegetation classification was produced in ten days in June 2004. This was refined and ground-truthed in five week in November and December 2004. Four separate trips were made, running elevational transects up significant peaks in the two parks. Vegetation observations were recorded, and numerous plants were collected and photographed. A set of 15 ultra-rapid photographic transects were made, and the results analyzed to contribute to our understanding of floristic variation within evergreen forest. An overfight was undertaken to confirm the remote sensing interpretation. A vegetation map was then produced with four main classes: Montane Forest, Hill Evergreen Forest, Semi-deciduous Forest and Woodland. The extensive variation within these classes is discussed and mapped, where possible. Finally, the expected botanical significance of the different zones is discussed, and recommendations are given for zoning choices.

2. Table of Contents

3. Phnom Samkos and Phnom Aural Wildlife Sanctuaries

These protected areas contain a wide variety of landforms, elevations and geology, and can thus be expected to be highly biologically diverse. They also contain much of the unlogged forest remaining in the Cardamom mountains, and probably nearly all of the unlogged lowland forest, of which very little remains. The Cardamom mountains themselves are a unique outpost of Malesian rain forest in mainland Indochina, and will contain numerous new species and new records. Collecting in the Southern Cardamoms has indeed turned up many new records, and several new species are under description. The high elevation forest, in which there has been very little botanical collecting, is expected to be an area of special endemism (A. MacDonald, pers. comm.). Phnom Samkos (Fig. 1a) experiences more rainfall than Phnom Aural (Fig. 1b), according to coarse rainfall maps of Cambodia (Sloth et al. 2003[sloth2003]), and thus forest at similar elevations and on similar substrate in the two parks can be expected to have a slightly different composition.

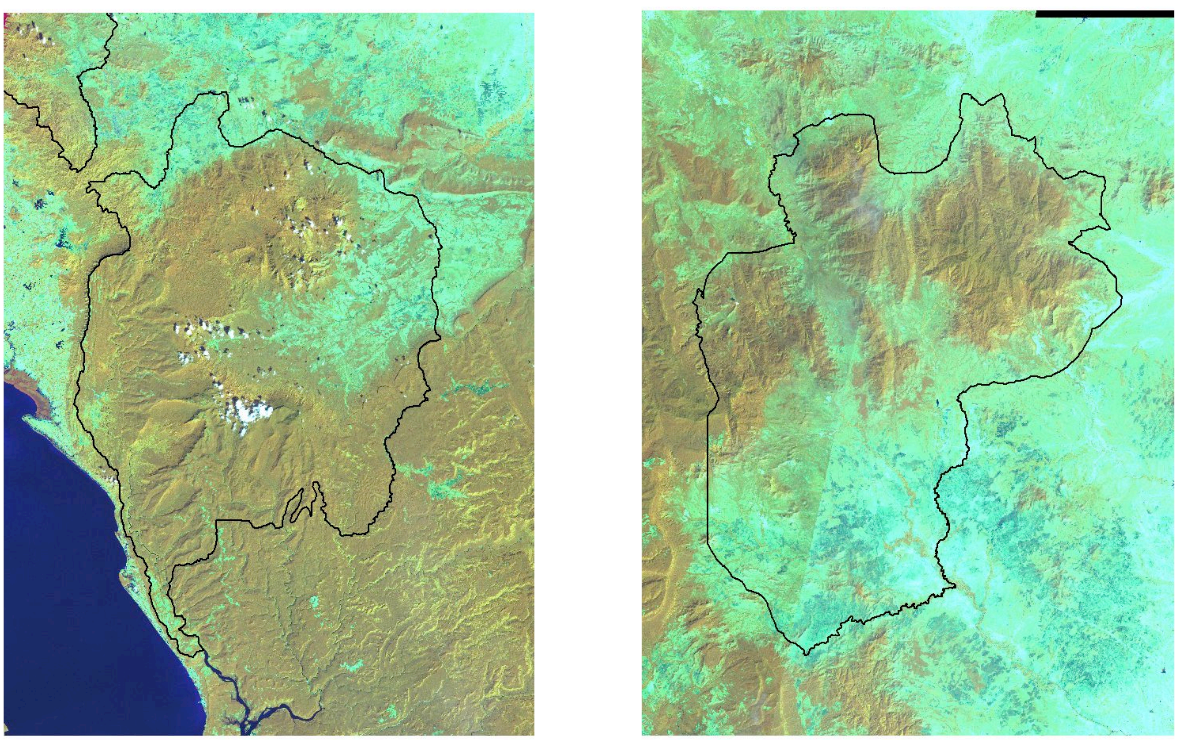

Figure 1. Landsat7 image of Phnom Samkos and Phnom Aural. Bands 4, 5, 3.

The two areas are both diverse geologically (Figs. 2 and 3), and together could hardly be more diverse except perhaps if limestone or ultramafics were to be present. Soil fertility varies even for a single parent material depending on rainfall and biotic factors, but in general fertility declines according to: basalt > [claystone] > rhyolite/dacite > [sandstone] > granite > chert. The fertility of the sandstone components is uncertain, since the sand/clay content varies continuously among sedimentary layers. The dipterocarp woodland usually appears to occur either over white sandstone (Southern Cardamoms) or laterite-forming ultisols and oxisols (Samkos Basin), all being areas that have very low agricultural potential.

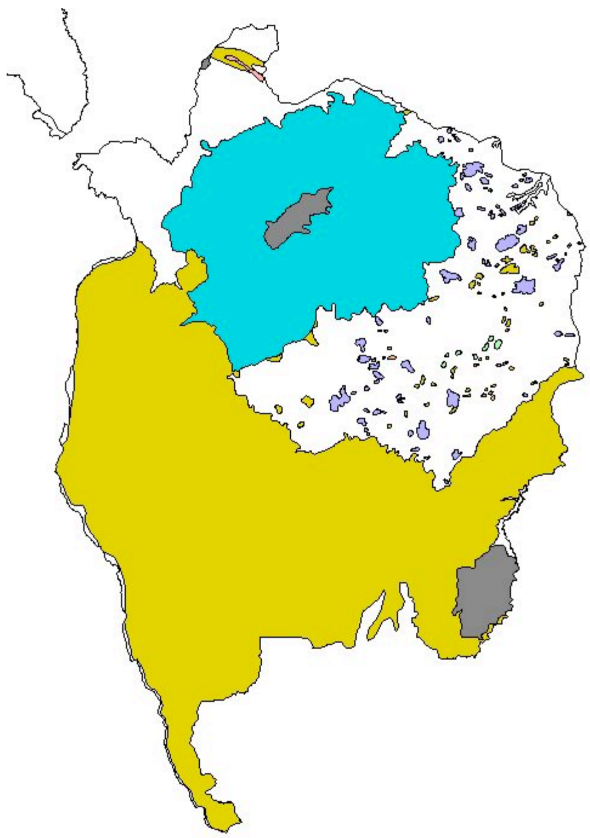

Figure 2. Simplified surface lithology map of Phnom Samkos. Source: GIS layer produced by Dept. of Geology, Ministry of Industry, Mines and Energy. Blue: rhyolite/dacite; grey: old alluvium in north, basalt on south; yellow: sandstone; white: quaternary alluvium.

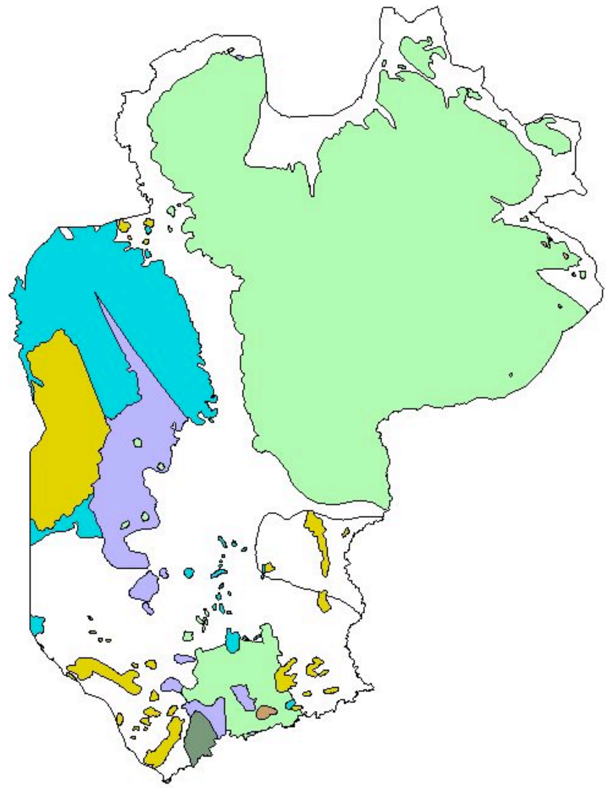

Figure 3. Simplified surface lithology map of Phnom Aural. Source: GIS layer produced by Dept. of Geology, Ministry of Industry, Mines and Energy. Blue: rhyolite/dacite; grey: basalt; yellow: sandstone; green: granite; mauve: chert; white: quaternary alluvium.

Both sites were strongholds of the Khmer Rouge, and contain mined areas, and possibly other UXO. Samkos was the site of a multi-year frontline between the Vietnamese forces and the KR, and several of the roads are heavily mined. Local sources also said several mountainous areas were mined, and in our preliminary fieldtrip in June we ran across a very extensive trench system on the watershed boundary on route 56 in the west of the park. A heavily mined area was traversed on the way to Phnom Thom.

4. Vegetation Types

Classification of vegetation is an important tool for management. However, there is no single best classification, since the classes are defined in the context of a goal for the classification. There are also serious philosophical and methodological issues with classification of diverse ecological communities, because communities often inter-grade in composition almost continuously into other communities classed differently. In developing the current system, I have i) attempted to be consistent with pre-existing classifications, ii) focused on floristic variation as well as structural variation, iii) tried to produce a system that can be used by non-botanists (see § 4.3.).

Another problem inherent in mapping vegetation from remotely sensed images is that not all meaningful classes on the ground are separable in the image, and not all variation in the image is biologically meaningful. Some recent forest classifications (e.g., Forest Administration 2002) have been based exclusively on satellite image interpretation, and tend to miss the floristic (and structural) variation invisible in these images. My aim was to reintroduce a more ecological sense of variation in forest classification, which requires ground-truthing and botanical work. I have produced therefore essentially two classification systems, the main, biological one, and the mapping unit classification scheme. The latter is described in relation to the former.

4.1. Previous classification systems

A number of systems of vegetation classification have been proposed over the years for Cambodia (Ashwell 1997, Blasco et al. 1996, INRFSFFC 1962, Legris & Blasco 1972, Rundell 1999, 2001, Forestry Administration 2002). Wikramanayake et al. (1997) proposed an eco-regions approach, and the Cambodian Tree Seed Project is currently developing an eco-region classification based on the likelihood of reduced gene flow in tree populations (Sloth et al. 2003). A few authors have focused on the Cardamom and Elephant mountain areas (Ashton 1971, Dy Phon 1970). Ashwell’s (1999) floristic and structural analysis of sample plots (using CIFOR methodology) in Koh Kong and Bokor produced a classification into nine groups which mapped fairly closely to other classification systems. Some of these systems are reviewed in the recent Forest Sector Assessment (Ashwell et al. 2004).

4.2. Summary of this classification system

Table 1. Approximate comparison of vegetation classification systems.

This system	Mapping Unit	Dy Phon (1970)	Legris & Blasco (1972)	Ashwell (1997)	Blasco (1996)	Rundell (1999)	Boyce (2002)	FA (2002)
Montane Forest	1		Formations de moyenne altitude	Hill evergreen	Evergreen		Upper Montane Evergreen	Evergreen
High Elevation Woodland and Grassland	2	La pinede a Pinus merkusii	Les forêts claire	Conifer forest	Pine forest	Lowland pine forest		
Evergreen Hill Forest (on Sandstone, Rhyolite, Granite)	3	Forêts denses humide a Dipterocarpacées, Faciès II	La forêts dense humide sempervirentes	Tropical rain forest	Evergreen	Wet evergreen forest	Hill Evergreen + Lower Montane	Evergreen
Basalt Evergreen Hill Forest	3	Forêt semi-dense a Irvingia malayana (?)	La forêts dense humide sempervirentes	Tropical rain forest	Evergreen	Wet evergreen/Semi-evergreen forest		Evergreen
Dwarf Evergreen Hill Forest (on Sandstone)	3	Forêts denses humide a Dipterocarpacées, Faciès I	La forêts dense humide sempervirentes	Tropical rain forest	Evergreen	Dwarf evergreen forest		Evergreen
Lowland Evergreen Forest (on Alluvial soils)	5	Forêt semi-dense a Irvingia malayana (?)			Evergreen	Wet evergreen forest		Evergreen
Bamboo groves	4	La végétation secondaire, b.	Les bambousaies	Bamboo forest	Thicket			
Semi-deciduous Forest	5	Forêt semi-dense a Irvingia malayana (?)	Les forêts denses decidues	Mixed deciduous forest	Semi-deciduous	Mixed deciduous/ Semi-evergreen	Lowland Dry Evergreen	Semi-Evergreen
Dipterocarp Woodland	6	Forêts claire a Dipterocarpacées	Les forêts claire	Dry dipterocarp forest	Woodland with dipterocarps	Deciduous dipterocarp woodland	Lowland dry dipterocarp	Deciduous
Grassland	6		Les savanes	Savanna				

4.3. A key to vegetation classes

1a. Generally closed canopy
 2a. Extensive moss on boles, elevation generally greater than 1500 m
 MONTANE (M1)
 2b. Otherwise
 3a. More than 20% of trees deciduous for more than 1 month, often disturbed
 SEMI-DECIDUOUS FOREST (M5)
 3b. Less than 20% of trees deciduous for more than 1 month
 4a. Dark brown soils, large trees, uneven canopy layer
 5a. Higher elevation, basalt-derived soils
 EVERGREEN BASALT FOREST (M3)
 5a. Low elevation (< 200 m), alluvial soils
 LOWLAND ALLUVIAL FOREST (M5)
 4b. Orange, yellow or white, sandy soils, closed, even canopy
 6a. Tall forest (canopy 30+ m), without *Tristania* trees, sandstone-, granite- or rhyolite-derived soils
 EVERGREEN FOREST (M3)
 6b. Short forest (canopy 15-30 m), with abundant *Tristania* and some *Dacrydium elatum*, no *Parkia*
 DWARF EVERGREEN FOREST (M3)
1b. Open canopy (woodland/savanna/bamboo)
 7a. Less than 20% area tree covered
 8a. Grass (or grass-like plants) dominated
 GRASSLAND (M2, M6)
 8b. Bamboo dominated
 BAMBOO GROVES (M4)
 7b. More than 20% area tree covered
 9a. Dipterocarp dominated
 DIPTEROCARP WOODLAND (M6)
 9b. *Pinus* dominated
 PINE WOODLAND (M2)

4.4. Vegetation classes in detail

The following descriptions build on my report to WildAid (Webb et al. 2003). Some of the species names indicated in the vegetation descriptions used here are those assumed to be correct based on other authors (primarily Dy Phon 1970, Gardner et al. 2000, Hozumi et al. Legris and Blasco 1972, Martin 1997, Rundell 1999).

4.4.1. Montane forest (Mapping Unit 1)

Small-crowned forest with a unique floristic composition (see Fig. 11), forming at elevations with frequent cloud-covered (> 1600 m at Aural, > 1500 m at Samkos). Images: Aural: 9812, 9822, 9826, Samkos: 2518, 1980). Structure: dense, small pole-sized trees, with abundant moss on the trunks. Height generally less than 15 m. At Samkos, with abundant spiny palms in the understorey. The dominant species in all areas was the very common Fagaceae (morphospecies: fagpet - see photos of indicator species; Img. 9755). On Aural this has coppiced and regrown into a nearly monospecific stand, after the French cleared the top of the mountain (Img. 2667, 9822). Note that this true montane forest occupies a relatively small area of the parks. Despite the floristic differences in montane forest, there are a number of species that are ecologically widespread, and reach the montane forest either as distinct ecotypes, or plastically modified individuals. Examples include *Podocarpus neriifolius* (Podoc.; Img. 9770), *Acronychia* cf. *pedunculata* (Rutac.; Img. 1622), and a *Euodia* sp. (Rutac.; morphocode: evocom).

4.4.2. High elevation grassland and pine woodland (Mapping Unit 2)

Stands dominated by *Pinus merkusii* occur at all elevations, although the largest extent of this forest type is at high elevation (e.g. W of Suriya village in Aural WS; Img. 2413). Often mixed with *Dipterocarpus obtusifolius*, and sometimes with other dipterocarp woodland species, this vegetation develops on poor, level areas at high elevation, areas which frequently burn. Pines often grow to 25 m tall. In the extensive stand W of Suriya village, I noted a paucity of small-sized trees, and few seedlings. This may reflect a burning frequency higher than optimal, and may indicate that these areas will proceed to grassland. On the overflight, there were many areas of grassland that held charred tree boles, probably of pine. This vegetation type is beautiful, and it would be a shame to lose the pines from these areas. Ferns sometimes appeared to dominate in pine-less locations. Note that we found *Pinus kesiya* at Tumpor (new record for Cambodia); this species may replace *P. merkusii* in some pine woodland.

Figure 4. Pine woodland and grassland at Phnom Thom.

4.4.3. Evergreen hill forest (Mapping Unit 3; and 5, see iv below)

This vegetation class covers most of the area in both parks. Evergreen forest contains great structural and floristic variation, but it proved impossible to consistently map this variation using satellite images throughout the two areas. The variation is therefore described here with indicators of where subtypes should occur.

i) Low to mid-elevation evergreen forest on sandstone

This forest subtype dominates most of the Cardamom mountains, and was surveyed extensively during the WildAid mission (Webb et al. 2003). It is the dominant type throughout Samkos, and occurs in the west of Aural. The tallest incidence of this forest is on the more fertile, clay-rich soils of the hill slopes from 10 m to ca. 600 m elevation, and this was the major timber-producing forest type. The forest is quite diverse; I estimate a diversity of ca. 100 tree species (> 10 cm DBH) ha^{-1}, based on experience in other Malesian forests. Almost all of this forest has been logged, throughout the Cardamoms. Dipterocarp species (*Shorea* spp.) would have dominated, although after logging it is hard to know how abundant they were. High densities of species from the Clusiaceae, Sapotaceae, Lauraceae and Myrtaceae families make these forests reminiscent of dipterocarp forest on fairly poor sandstone soils throughout Malesia. As rainfall decreases, northwards and eastwards, the dominance of dipterocarps in these forests will decrease, with increasing Fabaceae (e.g. beng, *Afzelia xylocarpa*), Meliaceae and Lythraceae.

Figure 5. Interior of sandstone evergreen forest.

Figure 6. Canopy of sandstone evergreen forest, with the distinctive crown of a *Parkia streptocarpa* (middle right).

ii) Dwarf evergreen forest on sandstone

Mixed into the tall evergreen sandstone forest is low forest occurring on shallow and/or poor soils: thin soil over bare sandstone rock, latterite pebble layers, and deep white sand soils with a thin black humus layer. Floristically similar to tall sandstone forest, in some areas the short forest gradually changes to adjacent tall forest, with a slow replacement of species, and in some areas the boundary is sharp. Dipterocarps are less abundant than in the tall forests, often being represented only by various *Hopea* species, and poor/acid soil groups become more abundant. The original density of timber in short sandstone forest was always low, and most of these areas escaped logging. *Tristania* is a good indicators of this forest type. Many of the taxa in short sandstone forest will be present in hill elevation evergreen forest, as I noted in the field trip to the col at 900 m on route 56.

Figure 7. Interior of (disturbed) dwarf evergreen sandstone forest.

iii) Basalt evergreen forest

Another major lowland forest type is restricted to soils derived from the basalt extrusions that dot the Cardamoms. These soils are dark orange to brown and clearly richer in both moisture and nutrients than the sandstone-derived soils, and support a forest very different in composition from that on sandstone. As is seen in more fertile Malesian forests generally, there is a shift to a greater abundance and diversity of both Euphorbiaceae and Meliaceae. The forest is very tall (ca. 40-50 m), and generally has a closed canopy, although there is a general association between higher fertility and higher disturbance. In addition, on what we estimate to be the summit of the Tma Bang volcano the forest stood on 'raw' basalt rocks, and therefore had a naturally more broken canopy. The canopy is dominated by giant *Ficus* trees, *Nageia wallichianus*, *Irvingia malayana*, *Heretiera javanica*, and various *Syzygium* spp., *Elaeocarpus* spp., *Garcinia* spp. and Lauraceae spp., including the valuable 'mraya pro pnom.', which was at its densest in these forests. Common vines and lianas include *Piper* sp., *Passiflora* spp. In the understorey *Leea* sp. is dense and not found in the forest on sandstone. Where the understorey is exposed to light, luxurious stands of gingers occur (*Amomom kravanh*), and it is these that probably give the Cardamom Mountains their name. I was unable to visit the O'Som basalt area on these surveys, and base the above information on prior trips in the Southern Cardamoms.

Figure 8. Canopy of Tall Evergreen forest on Basalt at Tma Bang. Note the broken canopy that appears to be the natural state on this site.

iv) Lowland alluvial evergreen forest (Mapping Unit 5)

This is a forest type that is likely to have occurred in the past in the Cardamoms, but may be totally extirpated by now. Wherever they occur, alluvial forests are the richest rain forests, with the biggest trees, high species richness, high tree turnover dynamics, and usually high wildlife loads. In the north and east of the Cardamoms, where rainfall is less, I expect these forests to take on a semi-deciduous character, but in the west of Samkos, along the Thai border, there may have been some true evergreen alluvial forest. These forests would have probably have had large *Shorea* and *Hopea* trees, but with a high diversity of *Aglaia* (Melia.), characteristic of the richest soils in SE Asia. The only forest that I visited that approached this forest type was the Tumpor villages forest, on rich dark-brown alluvial soils. It still contained some large koki trees (*Hopea nervosa*), although most of these had been logged out by the Thais ten years ago (much to the disappointment of the villagers). However, this forest also contained many large spong trees (*Tetrameles nudiflora*), characteristic of the semi-evergreen forests of Central Northern Cambodia. The large-crowned nature of alluvial forests would probably have caused them to be mapped as M5.

v) Mid elevation forest on Granite and Rhyolite

This forest type covers the lower hills of Aural and Tumpor mountains. It is similar to forest at the same elevation on sandstone, but appears to have fewer dipterocarps. In fact, I noted no dipterocarps at all in closed forest above 600 m on Aural. Instead, conifers, *Schima wallichianus* (Theac.) and a common *Michelia* (Magno.) species dominated from as low as 700 m. At Tumpor, it appears that beng (*Afzelia xylocarpa*) and reach kol (Legum.) are particularly dominant, although I did see numerous *Hopea* trees (not *H. nervosa*) from 400-800 m.

vi) High elevation evergreen forest

On all geologies, there is a progression from a lowland (300-600 m) flora (dominated by dipterocarps and legumes) to an upland (1000-1500 m) one, but in all locations visited this was a gradual shift, making assignment to additional classes dubious. However, the transition corresponds generally to passing into a zone variously defined by other authors as 'conifer-oak' and/or 'oak-laural.' Fagaceae, Lauraceae, Myrtaceae, and Podocapaceae do come to dominate the forest, although the precise mix and order of turnover seems to depend on the location.

Notable is the high density and diversity of understorey Rubiaceae (*Psychotria* spp. etc.). Tree ferns of the genus *Cyathea* become more common (Img. 162), as do understorey *Areca* palms, and epiphytic orchids.

4.4.4. Deciduous forest and gallery forest (Mapping unit 5)

While the Cardamoms are generally not the domain of semi-evergreen and deciduous forests, some deciduous forest does occur, especially in the Aural area. Requiring more moisture than the dipterocarp woodland, the deciduous forest is mainly restricted to stream and river courses, and in these cases can be described as gallery forest. It does also occur on the small chert hillocks in the Samkos basin (Fig. 10). In drier areas, there is a transitional forest between dipterocarp woodland and evergreen forest that can be described as semi-evergreen, e.g., on the route up Aural and up from Poum Surya. In these situations, fire plays a large part in determining the semi-open character of the forest, licking up from the woodland below. In these fire-prone areas, there was extensive bamboo in the understorey (Img. 0318). When I visited this type of forest in late January 2003, approximately 25% of the trees were leafless.

The key genus that indicates the presence of these forests is *Lagerstroemia* (Lythr.; Img. 1056,). Other components of this forest type are various large legume species, Chrysobalanaceae: *Parinari anamensis*. Clusiaceae: *Calophyllum* spp., *Garcinia ferrea*. Combretaceae: *Terminalia nigrovenulosa*. Dilleniaceae: *Dillenia* sp. Dipterocarpaceae: *Shorea* spp., *Anisoptera* spp. Ebenaceae: *Diospyros* spp. Euphorbiaceae: *Cleisthanthus* sp. Fabaceae: *Erythrophleum cambodianum*, *Dalbergia nigrescens*, *Xylia kerii*, *Sindora cochinchinensis*. Fagaceae: *Castanopsis* sp. Hypericaceae: *Cratoxylum* sp. Lauraceae: *Cinnamomum iners*. Melastomataceae: (*Memecylon* cf. *edule*). Myrtaceae: many *Syzygium* spp. Oleaceae: *Chionanthus* sp. Rhizophoriaceae: (*Carallia* sp.). Rubiaceae: *Adina* sp. Rutaceae: *Evodia* sp., cf. *Tetractomia tetrandra*. Sapindaceae: *Nephelium* sp., 'seluh'. Simaroubaceae: *Irvingia malayana* (Eurycoma longifolia). Sterculiaceae: *Pterocarpus* sp. Ulmaceae: *Trema* sp. Verbenaceae: *Vitex* sp.

Figure 9. Semi-deciduous forest at Andong Krapur.

4.4.5. Bamboo groves (Mapping unit 4)

Where the evergreen forests are disturbed heavily groves of bamboo (*Bambusa* spp.) have formed. These groves have a dark understorey, with a forest floor littered with thick carpets of bamboo leaves. They may also have higher than average densities of seed-predating rodents. Together, these factors mean that it is very hard for tall forest species to re-invade bamboo stands, and bamboo might be considered a semi-permanent end-stage in a succession after disturbed forest. The formation is definitely 'natural' in the Cardamoms, and occurs in thick bands at the foot of the walls of cliff that characterize the areas with 'tableland' physiography. This has provided a ready seed souce for the bamboo to invade logged areas, and many of the more heavily logged areas have become bamboo groves, with associated vines, *Gleichenia* cf. *norrisii*, *Dicranopteris* sp., and *Rubus* sp. These areas will take far longer to return to forest than the non-bamboo areas. The bamboo groves themselves contain little plant diversity, and are not a conservation priority.

4.4.6. Open dipterocarp woodland with intermixed grassland

These are in general fire adapted and located on poor soils. They probably have occurred long before human influence, the fires being started by lightning. Many of the species have thick corky bark, as a protection against fire. Where fire frequency is too high, grassland vegetation takes over.

Throughout much of Indochina, dipterocarp woodland is dominated by mixtures of *Shorea siamensis* and *Dipterocarpus obtusifolius*, each species often occurring in nearly pure stands on a small scale (50-100 m), visible from the air in March as patches of green and grey respectively. In the dipterocarp woodland of the Samkos basin, stands of the latter dominate, with a mixture of other dipterocarp species, including *Shorea talura*, *Shorea obtusa* (which can also form pure stands), *Dipterocarpus tuberculatus*, with *Dipterocarpus intricatus* on better soils. Other tree species in these forests include: *Pentacme siamensis*, *Pinus merkusii*, *Diospyros erhetioides*, *Melanorrhea* (*Gluta*) *laccifera*, *Parinari anamensis*, *Apousa sphaerosperma*, *Terminalia alata*, and *Careya sphaerica* (see images in range 323-345). Understory members include *Ochna integrifolia*, *Cratoxylum*, *Lagerstroemia*, *Memecylon edule*, *Rhodomyrtus*, *Dillenia*, *Corypha lecomtei* (a palm), *Arundinaria falcata* (a bamboo). The woodland canopy is generally not closed, and grass species cover the ground (e.g., *Themeda triangularis* and *Imperata cylindrica*) and sedges (*Fimbristylis*, *Cyperus* and *Cladium*). Surprising for such a dry forest is the heavy load of epiphytes on many trees including *Dischidia* sp., *Cassytha filiformis*, *Asplenium nidus*, and *Platycerium coronarium*. The ant-plants, *Myrmecodia* and H*ydnophytum* are collected for medicinal purposes.

Figure 10. Canopy of Dipterocarp Woodland, surrounding a patch of more species diverse semi-deciduous Forest.

In heavily burned areas, *Imperata cylindrica* grows in nearly pure swathes, as in the rest of SE Asia. In less severely affected areas, *Themeda* spp. and *Cymbopogon* spp. are common. The mixtures of other herbs depends on the substrate. On pure white quartz sand, sundews (*Drosera burmanii*) and pitcher plants (*Nepenthes* spp.) grow, with some taller, fire-tolerant shrubs: *Melastoma* sp., *Rhodomyrtus* sp. In wetter areas with richer soil, permanent marshes form.

5. Floristic Variation assessed with rapid photo-plots

Despite the difficulty in mapping variation within evergreen forest, understanding the distribution and causes of this variation is important both for scientific and management reasons. I have recently been using a method for ultra rapid assessment of floristic variation based on photo-plots (Webb, ms. in prep., see also Webb et al. 2003). I applied this technique on this trip at 15 locations. The (current, revised) method involves collecting 100 unique morphotypes of woody plants (knee- to shoulder-height) at a site, within ca. 30 minutes, using short-term memory to guide the determination of what is unique. Small voucher cuttings are made and placed in a bag. Later in the day, the underside of each cutting is photographed (see image samples in 'indicator_species' directory).

Taxa in the photos are then matched across plots and a standard species x sample matrix constructed. Where time permits, a full matching of all taxa is desirable. However, for this project, I used a subsample of 223 taxa that are particularly recognizable in photos. It is acknowledged that using photos of taxa for matching is inferior to using physical samples, and some images may be mis-classified, but for overall floristic work this error has little effect.

The species x sample matrix was analyzed using standard community ecology methods, implemented in the R statistics language.

Table 2 Location of sample plots.

Location	code	E/W	N/S
Aural 1700 m	AH	410119	1329882
Aural 600 m	AL	405132	1327028
Aural 1100 m	AM	407511	1329142
Surya 1400 m	BH	376123	1309258
Surya 500 m	BL	376732	1302436
Surya 1000 m	BM	376334	1306034
And. Krop. Decid	KD	300050	1364566
And. Krop. DW	KW	300050	1364466
Samkos 1600 m	SH	287558	1344267
Samkos 600 m	SL	295596	1340933
Samkos 1000 m	SM	292556	1341562
Tumpor 900 m	TH	284600	1374600
Tumpor 700 m	TI	282058	1376185
Tumpor 600 m	TL	286009	1373650
Tumpor Village	TV	293314	1369609

We found that in a cluster analysis (Bray-Curtis distances, Ward's joining method) the sites separated into three main classes: Dry, lowland sites, Montane sites and Mid-elevations sites

(Fig. 11). These correspond well to the vegetation classes the sites were assigned to: Semi-evergreen, montane and evergreen forests. An analysis of similarity also showed that the relative variation in species composition differed among groups; i.e., the “Low” plots were the least homogeneous, and the “Mid” plots were more homogeneous than the “Low” plots even though there were more plots classes as “Mid” (Fig. 12). Together, these results support the classification system used.

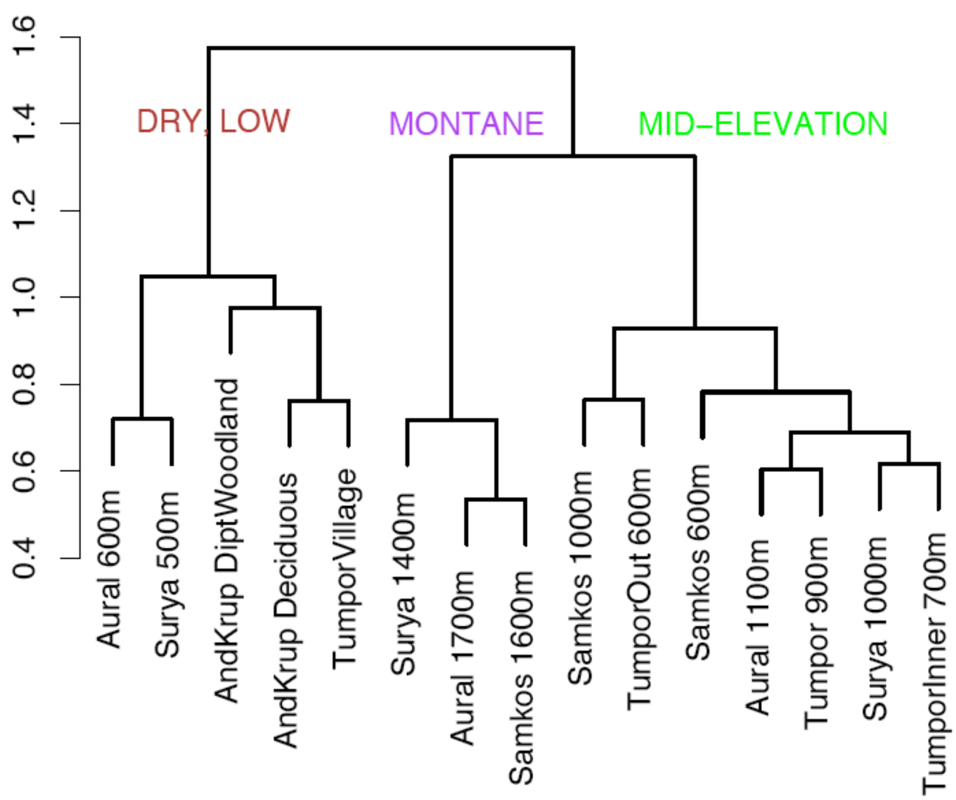

Figure 11 Cluster analysis of species in photo plots. The presence of 223 distinctive species was determined for all plots. Clustering using Bray-Curtis plot-plot distances, and Ward’s cluster method (in R).

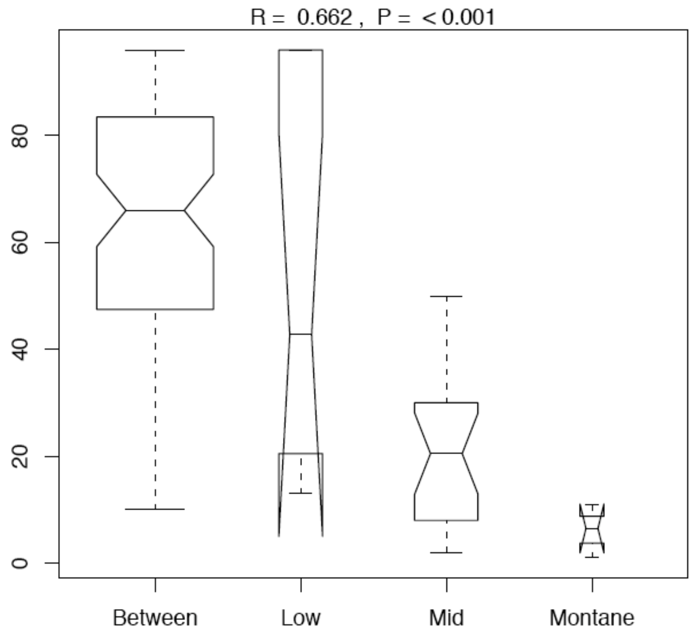

Figure 12 Analysis of Similarity for three main vegetation types defined by the clustergram branching pattern. (Algorithm: anosim in the vegan package of R).

6. Mapping Procedure

Overall, several iterations of the classification and mapping process were done during the project. This describes the final method we arrived at.

6.1. Image preparation

I obtained three Landsat7 images (taken January and February 2003) from the Tropical Rain Forest Information Center (TRFIC), for $50 each. This order was processed after I arrived in Cambodia, and we had to download the images using the services of Cogetel (contacts: Chany and Sakphea). They were imported into ERDAS Imagine, using the HDF Import function. The images were already geo-referenced to UTM/WGS84, but were re-projected onto UTM/Everest (Indian/Cambodian1950) to match the other map layers. The images were then cropped and mosaiced to form a single image covering the entire Cardamoms. The image is nearly cloud free, although Path 126 was taken earlier than 127, and there is a slight color difference between them. Color histogram matching may fix this, but was beyond the skills and technology at hand.

6.2. Defining vegetation classes

Differentiating among types of closed canopy evergreen forest is especially challenging. In the WildAid study (Webb et al. 2003), I was able to divide the evergreen forest into tall and short classes, which were caused in the field by soil factors, the former occurring on clay-rich soils, the latter on sandy or rocky soils. In the present study, similar divisions could be made, but unfortunately the Landsat image over Aural had a slightly different hue to the others, which caused the evergreen sub-classes to have different likelihoods on either side of the division line. Also, the severe topography in much of the area has caused shadows which are sometimes spuriously classed as short evergreen, when the land is actually tall evergreen. Hence for the present system, all evergreen forest has been classed together, and subdivisions have been added based on other GIS layers. Similarly, within the "Grassland/dipterocarp woodland" class, areas of open grassland could be differentiated from the woodland, but the density of woodland varies continuously from very sparse to almost closed canopy. Additionally, the problem of the hue of the Aural image caused the interpretation of grassland to differ across the boundary. Hence, I have combined these classes. The Landsat-derived classes used in the classification are thus:

1. Bare soil/rock plus agriculture
2. Grassland & dipterocarp woodland
3. Lowland deciduous forest and river gallery forest, and lowland evergreen forest
4. Evergreen forest
5. Bamboo and liana-dominated forest

[Cloud]
[Cloud Shadow]
[Open water]

Additional information from other GIS layers gave the following divisions within the evergreen class used in the mapping:

- Evergreen rain forest on sandstone (from Geology layer)
- Evergreen rain forest on basalt (from Geology layer)
- Evergreen rain forest on rhyolite/dacite (from Geology layer)
- Evergreen rain forest on granite (from Geology layer)
- Montane forest (>1,500 m in Samkos, >1,600 m in Aural; Elevation model)

It is probable that in the montane areas the influence of substrate converges for sandstone, granite and rhyolite, with all areas become nutrient poor and acidic. This conclusion is supported by the photo-plot analysis. Finally, lowland grassland and woodland was separated from upland grassland and woodland using a cutoff of 500m.

6.3. Image classification

Using the AOI polygon tool and the Signature editor, I picked 5-8 training areas for each class, based on examination of areas I have visited, and by reading the image. The training areas were scattered around the two WSs, with some always on the Path 126 side of Aral. The signature for these multiple areas per class was combined (including all 6 usable bands) to produce an 11 class signature file. The image was then classified ("Supervised"), using default options and an AOI of first Aural, then Samkos.

6.4. Map production

The classification images in .img format were opened in ArcView, and converted to grids. The colors were set, combining tall and short evergreen into one color and grassland and dipterocarp woodland into one color. The geology polygon layer was then also converted to a grid, and using the "map query" tool, grid layers were formed that contained the evergreen forest on basalt, granite and rhyolite/dacite. Finally, the contour map layer was modified to contain just the 1,000 m, and 1,500 m contours, the files were converted to polygons using GIS Tools 1.9, and displayed over all other layers on the map. Finally, the park boundary was added. Roads and streams can also be added if desired. See figures 13 and 14.

6.5. Mapping units

The final mapping classes, and map legend units are:

1. Montane forest
2. High elevation (> 500 m) woodland and grassland
3. Evergreen hill forest
   - 3a. on sandstone
   - 3b. on granite
   - 3c. on rhyolite
   - 3d. on basalt
4. Highly disturbed areas with abundant bamboo
5. Large-crowned forest, generally in lowlands, usually with significant deciduous character. Includes semi-deciduous forest, lowland evergreen on alluvium, and a few areas of high elevation large-crowned forest.
6. Lowland woodland and grasslands. Woodlands dominated by dipterocarps.
7. Agriculture and bare soil.

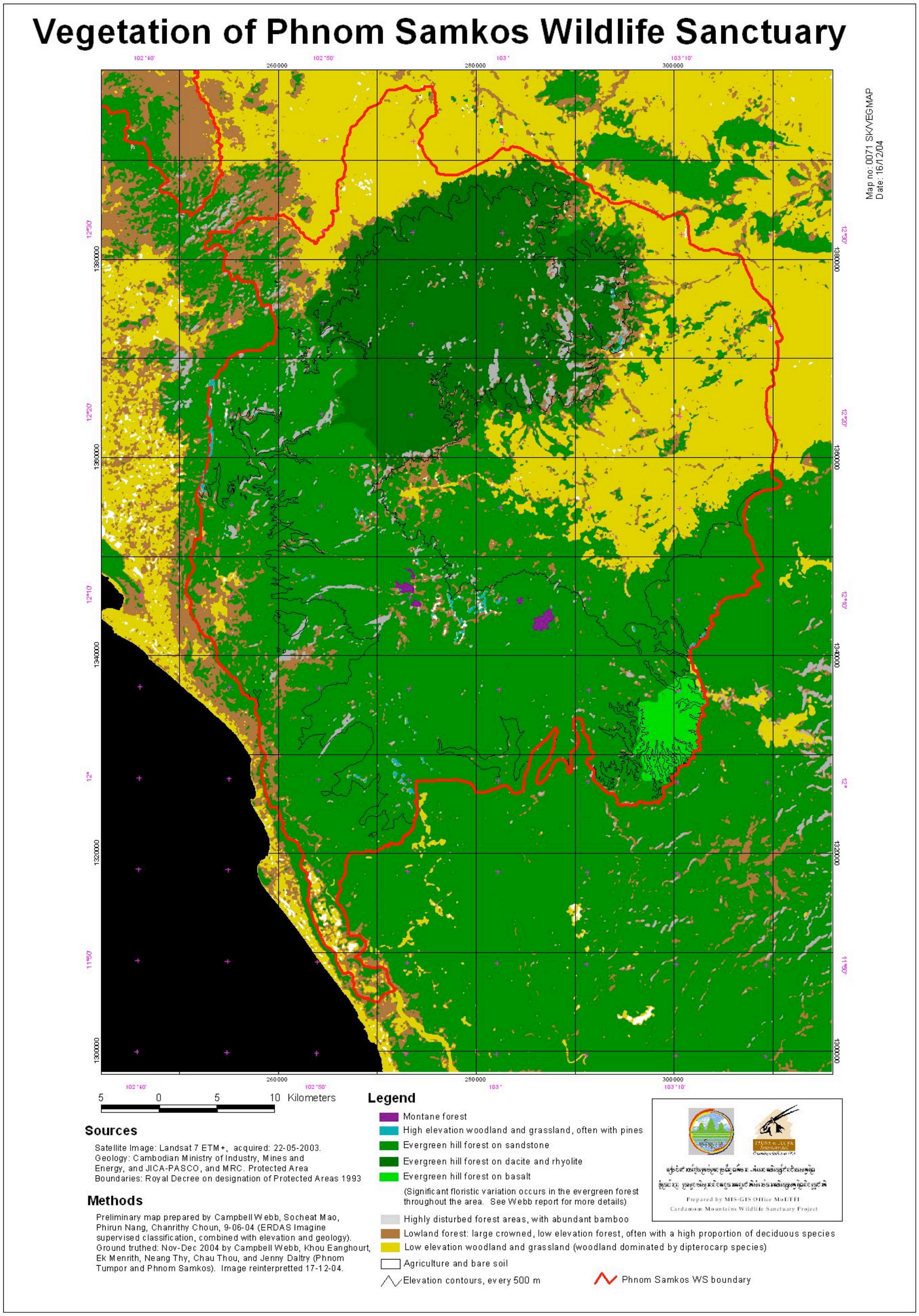

Figure 13. Final vegetation map of Samkos.

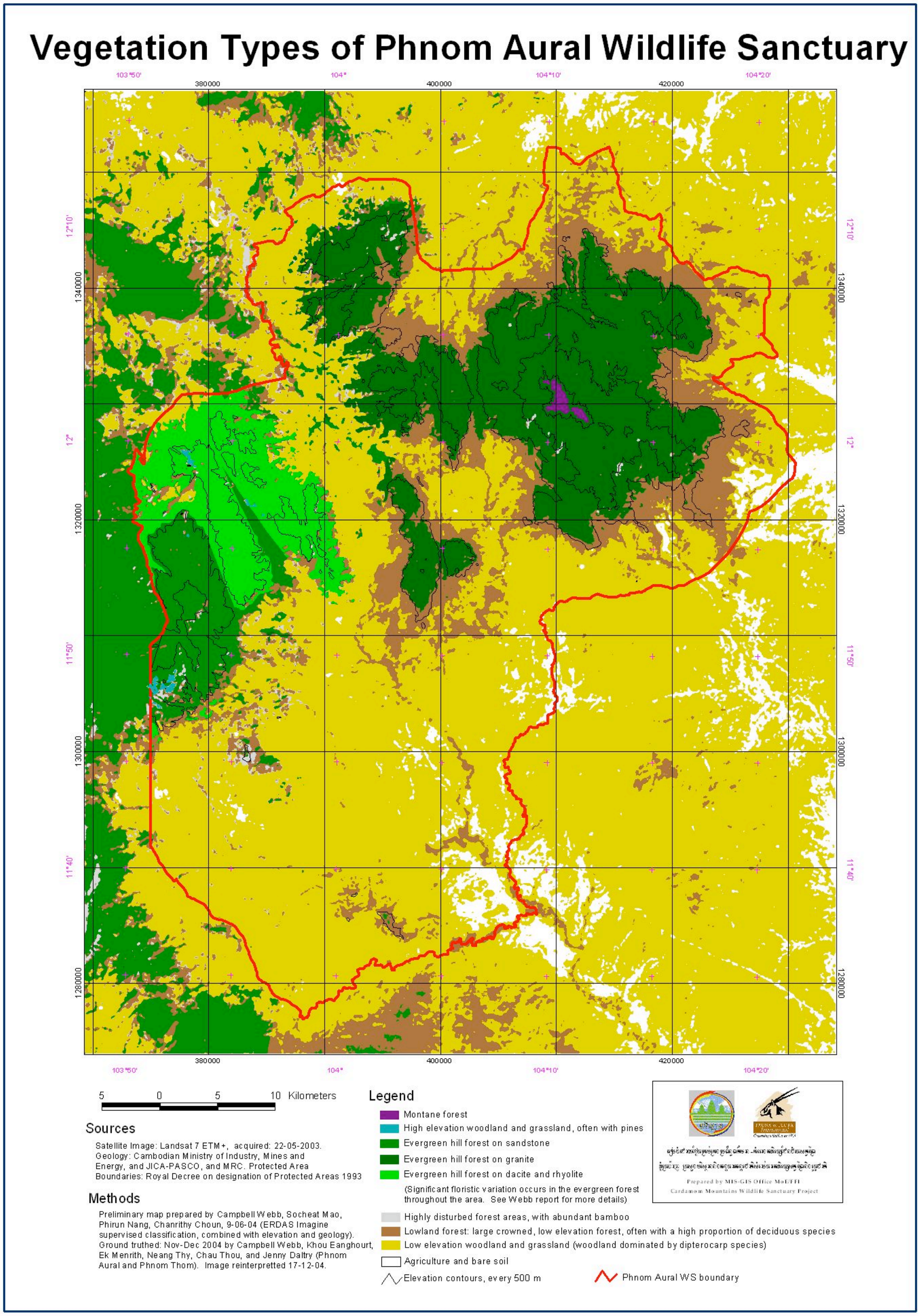

Figure 14. Final vegetation map of Aural.

7. Indicator Species

Much more botanical work will be needed here, but a preliminary group of indicator taxa can be extracted from the photoplot analysis. Taxa that were significantly associated with one of three main classes (ChiSq anal.) are given in Table 3. Images of these taxa are provided on the distribution disk (directory: "indicator_species"). Further lists of indicators will be available from the author as species determinations are processed.

Table 3 Significant associations of photo taxa with three main classes of vegetation. Association column: '0/1' - indicates significantly associated with or significantly avoiding, 'Low, Mid, Mnt' is Lowland, Mid-elevation and Montane, respectively. See figure 11 for classes.

Morphotype name	Association	p-value
araupi	1-Mnt	0.009
bacsma	1-Mid	0.044
cinfar	1-Mid	0.043
cinjav	1-Mid	0.013
clemat	1-Mnt	0.009
dacimb	1-Mid	0.043
evocom	1-Mnt	0.013
fagpet	1-Mnt	0.009
fagsil	0-Low	0.017
gareug	1-Mnt	0.009
gargam	1-Mid	0.013
illici	1-Mnt	0.009
knecom	1-Mid	0.013
laucry	1-Mid	0.044
lauwhi	1-Mnt	0.019
memlrg	1-Mid	0.043
neppin	1-Mid	0.013
poygps	1-Mid	0.043
psycur	0-Low	0.017
smibrd	1-Mnt	0.009
smidgr	1-Mnt	0.013
vacser	1-Mnt	0.009

8. Recommendations for Park Zonation

Park design and zoning choice must optimize the preservation of viable populations of as many species as possible. Internal to this optimization is a tension between diversity and population size. For tree species this is a compromise by definition: the more species you pack into an area, the smaller the population size of some of the species, because the total number of individuals is fixed. For other, non-space-holding species the tension is more abstract, involving the inclusion of more or fewer habitats, with more or fewer taxa, and lower or higher mean population sizes. Also weighing in this calculus is the global uniqueness of species: preserving fewer endemics may outweigh preserving more widespread species.

In general in our areas, the high elevation forest is likely to contain more endemics than the lowlands, while the overall alpha diversity of the lowlands will be higher than the uplands. However, even the lowlands are likely to contain many endemics, given the isolation of the Cardamoms from the Malesian forest they are affiliated to. The choice is not, however, uplands or lowlands, since the uplands are the least threatened, and easiest to conserve. The choice is more between different areas of the lowlands to include in high-conservation zones. Given that we don't yet know the complete extent of floristic (and faunistic) variation among forests on different substrates, we must assume conservatively that significantly different plant communities do exist. My specific recommendations, in approximate decreasing order of biological importance, follow (see Fig. 15):

1. **All montane forest** (> 1,500 m). High endemism. Easy to conserve.
2. Any remaining **unlogged lowland evergreen forest**. Small pockets of this may remain in accessible valleys on the Thai side of Samkos. If located, they should have very high priority, because of their high value to loggers, and their high biodiversity. Arial photographs can be examined to find them - full coverage exists at MIS. Of special note is the village forest near Tumpor (Img. 1670) - the villagers are currently converting a few hectares of this to ricefield, out of need.

3. **Basalt forests** in Samkos. We know from surveys further south that this forest is different in composition, of great stature, and possibly the most diverse in species. Current prognosis is good, given good behavior of the O Som villagers.
4. **High elevation plateaus (swamp/alluvium)** on Phnom Tumpur (Samkos). Irrespective of their substrate, these are highly likely to be species rich and are unique phenomena on the landscape. A small lake was spotted from the plane, ca. 3 km NW of our campsite. Unfortunately, the overflight also revealed that this area has been very heavily logged.
5. The whole of the **Aural massif**. This patch of forest forms a natural unit, and will be easier to defend than more scattered hills. Being drier and on granite, significantly different flora can be expected from other areas.
6. Permit **recovery of lowland forest** in the W of the Samkos basin. This would have been the richest forest in both parks, and was heavily logged by the Thais in the 1990s. It will recover though, and should be given strong protection.
7. **Dipterocarp woodland** in the Samkos basin. While a common forest type throughout Cambodia, this area is less disturbed than most others in the country, and may have a semi-natural fire regime. As a closed basin, it offers protection from disease spreads for its fauna, and might be tried as the site of reintroduction of large grazers. It also represents the most 'pleasant' environment, and could attract tourists to lodges. Its protection will be difficult.

Fire is the least predictable threat. While the Cardamoms do not seem to have experienced massive burns in the recent past, there is always the possibility that they will happen, especially with rapid climate change. All zoning plans should include a detailed fire threat analysis.

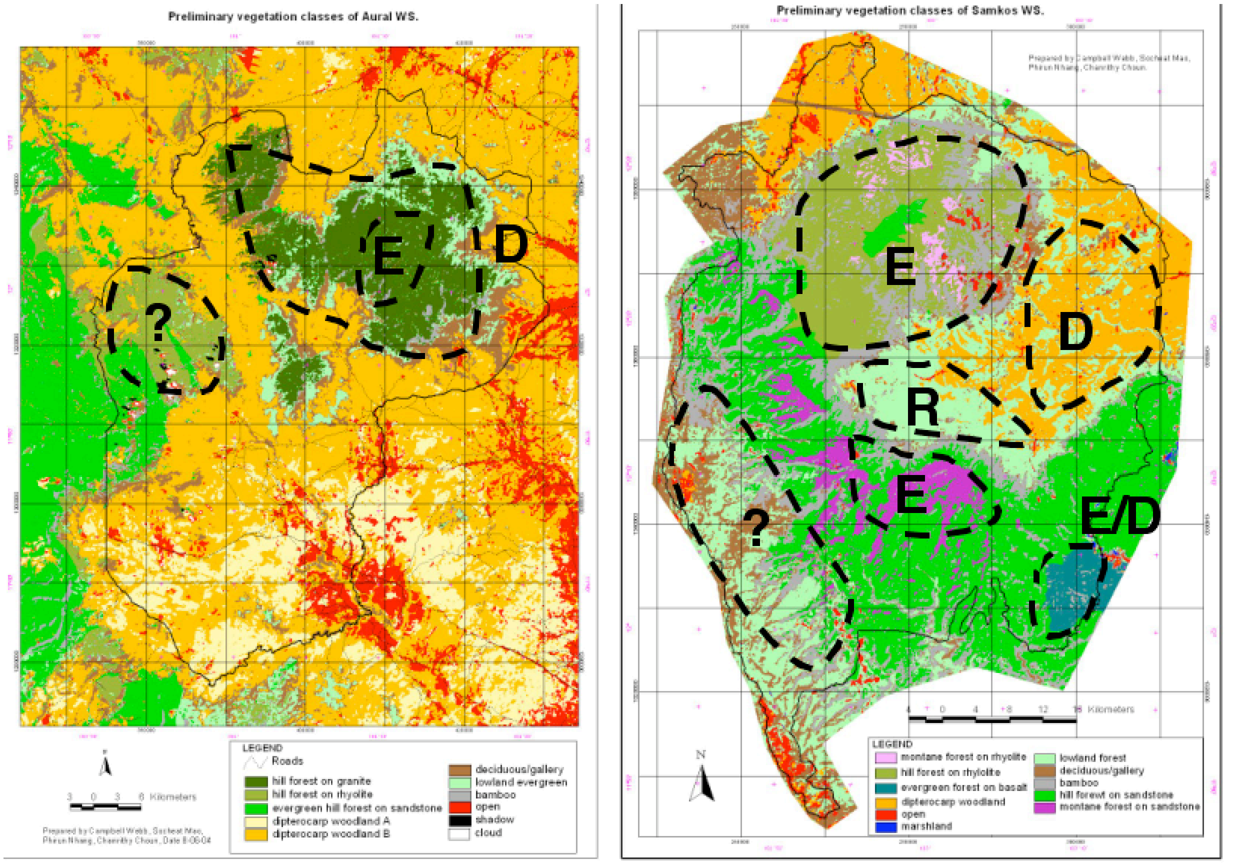

Figure 15. Zoning considerations referred to in text. Aural (left), Samkos (right). E: 'easy' to conserve; D: will be 'difficult' to conserve; R: promote recovery; ?: unknown conservation value (assumed to be high). [Note that the base-maps are a non-final version of the vegetation map]

9. Suggestions for further study

There is a vast amount of work that can be done in the areas, simply to understand some basic aspects of forest ecology and the relation of these forests to others in SE Asia. A short selection of topics that might be addressed by SHE staff follow:

- Which species is mraya proh essential oil produced from?
- What is the variation in density of commercial timber species in the various habitats?
- What is the distribution of *Pinus kesiya*?
- Are there any new species adapted to the conditions at the hot springs?

- What influences variation in the species composition of dipterocarp woodland?
- Produce a photo guide to ca. 40-60 tree species in the dipterocarp woodland?
- Develop a website for further botanical work in the Cardamoms.
- Investigate ecotypes and/or plasticity in widespread taxa.
- Interpret aerial photos for both parks to roughly map the extent of logging.
- Develop a plant checklist for the reserves.
- Visit the Paris herbarium to accelerate the rate of species determinations.

The SHE staff are very talented, and I encourage them to take on challenging projects.

10. Acknowledgments

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11. References and additional literature

Ashton PS. 1971. Forest Survey of Lowlands West of the Cardamomes Mountains, Cambodia, Final Report. Rome: FAO. 61.

Ashwell DA. 1997. Cambodia: A National Biodiversity Prospectus. Phnom Penh: IUCN.

Ashwell DA, Monyrak M, Bansok R, Eang Hourt K, Thol E, and Vong S. 1999. An Introduction to the Ecological Survey of Forest Vegetation. Phnom Penh: Ministry of Environment and IUCN Plant Resource Assessment Project.

Ashwell DA, Miller FR, Dümmer I. 2004. Ecology, forest cover and quality. Chapter 1 in Cambodia Independent Forest Sector Review. www.cambodia-forest-sector.net.

Blasco F, Bellan MF, and Lacaze D. 1996. Vegetation Map of Cambodia. Ecocart, Toulouse.

Boyce, P, Khou E, Ma, S, and Sar K. 2002. Higher plants. In *Social and Ecological Surveys of Phnom Aural Wildlife Sanctuary, Cardamom Mountains, Cambodia* (ed. J. Daltry). Cambodia Program, FFI and MoE, Phnom Penh.

Conservation International. 2002. Mini-RAP Assessment of Silver Road Logging Concession, Cardamom Mountain area, Cambodia. Washington, DC: Conservation International.

Daltry JC. 2002. Social and Ecological Surveys of Phnom Aural Wildlife Sanctuary, Cardamom Mountains, Cambodia. Phnom Penh: Cambodia Programme, Fauna & Flora International.

Dy Phon P. 1970. La vegetation du Sud-Ouest du Cambodge, Phnom Penh.

Dy Phon P. 2000. Plants used in Cambodia. Imprimerie Olympic, Phnom Penh.

Dy Phon P, and Rollet B. 1999. Lexiques des Arbres Forestiers du Cambodge. Office National des Forets, Fontainbleau.

FAO. 1971. Forest Survey of Lowlands West of the Cardamomes Mountains, Cambodia, Final Report. Rome: FAO. 61.

Forest Administration. 2002. Forest cover map, GIS layer. Forestry Department, Phnom Penh. Widely available GIS layer.

Fraser Thomas. 1999. Sustainable Forest Management Project: Review of Forestry Concessions. Phnomh Penh: ADB.

Gardner S, Sidisunthorn P, and Anusarnsunthorn V. 2000. A Field Guide to Forest Trees of Northern Thailand. Kobfai Publishing Project, Bangkok.

Global Witness. 1995. Forests, Famine and War. Phnom Penh: Global Witness.

Global Witness. 1996. Corruption, War and Forest Policy. Phnom Penh: Global Witness.

Global Witness. 1997. Just Desserts for Cambodia? Phnom Penh: Global Witness.

Global Witness. 1999. The Untouchables. Phnom Penh: Global Witness.

Global Witness. 2002. Preliminary Assessment of Strategic Forest Management Plans and Environmental Impact Assessment Reports. Phnom Penh: Gobal Witness.

Hozumi K, Yoda K, Kokawa S, and Kira T. 1969. Production ecology of tropical rain forest in southwestern Cambodia. Nature and Life in Southeast Asia 6: 1-54.

INRFSFFC. 1962. Forest and land-use statistics, Cardamome area, Cambodia: Institut National des Recherches Forestiers, Service des Faux, Forets et Chasse.

Le Billon P. Protected Areas in the Kingdom of Cambodia: IDRC/SSI.

Lecompte O. 1965. Droseraceae. Flore du Cambodge, du Laos et du Vietnam 4: 63-74.

Legris P, and Blasco F. 1972. Carte International du Tapis Vegetal: Cambodge. Pondichery: Travaux de la Section Scientifique et Technique del'Institute Francais.

Martin MA. 1973. Notes on the vegetation of the Cardamom Mountains, Cambodia. Singapore Gardens Bulletin 26: 213-222.

Martin MA. 1997. Les Khmers Daeum (Khmer de l'origine). Presses de l'Ecole Francais d'Extreme-Orient, Paris.

McDonald A. 1998. Herbarium Development and Forestry Inventory Capacitation in Cambodia. Phnom Penh: British Embassy and FORTECH.

Monney A, and Huber A. 1970. Inventaire forestier des Terre Basses du Versant Occidental des Monts Cardamomes. Rome: FAO.

Rollet B. 1972. La vegetation du Cambodge. Bois et Forets des Tropiques 144.

Rollet B. 1972. La vegetation du Cambodge. Bois et Forets des Tropiques 145: 24-38.

Rollet B. 1972. La vegetation du Cambodge. Bois et Forets des Tropiques 146: 4-20.

Rundell PW. 1999. Forest Habitats and Flora in Lao PDR, Cambodia and Vietnam. Hanoi: World Wide Fund for Nature.

Rundell PW. 2001. Forest habitats in Cambodia. In: Smith J, ed. Biodiversity, the Life of Cambodia: Cambodian Biodiversity Status Report.

Sloth, A, Dummer, I, and Thea, S. 2003. Gene-Ecological Zonation of Cambodia. Report of the Cambodian Tree Seed Project.

Smitinand T, Santisuk T, and Phengklai C. 1980. The Manual of Dipterocarpaceae of Mainland South-East Asia. Royal Forest Department, Bangkok.

UN. 1993. Cambodia. United Nations.

WB/UNDP/FAO. 1996. Cambodia Forest Policy Assessment. Phnom Penh: WB/UNDP/FAO.

Webb, CO, Sopeak, K, Sek Kaon, K. 2003. *Botanical survey of the southwest Cardamom Mountains, Cambodia*. Report to WildAid, Cambodia program, Phnom Penh.

Wikramanayake E, Dinerstein E, Hedeo P, and Olson D eds. 1997. A Conservation Assessment of Ecoregions of the Indo-Pacific Region. Washington, D.C.: WWF-US.

Appendix A: Maps/GIS ouput

ArcView project: On the MoE computers at the MIS lab: D:\ffi_final\main-dec04.apr
JPEGs: samkos_dec04.jpg, aural_dec04.jpg

Appendix B: Webb's annotated image collection

See photos directories on distribution CD. Open the file called *index.html* in a web browser. Photos from the overflight of 18-dec-04 are included on a separate CD (Disk 2).

Appendix C: Waypoints

See Excel file: webb_waypoints.xls for general survey waypoints, and cam_flighttrack_18dec04.xls for flight track. The latter can be used to accurately place the photos taken on the flight, since the camera clock was synchronized to GPS time before the flight.