Forestry
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DANIDA

German
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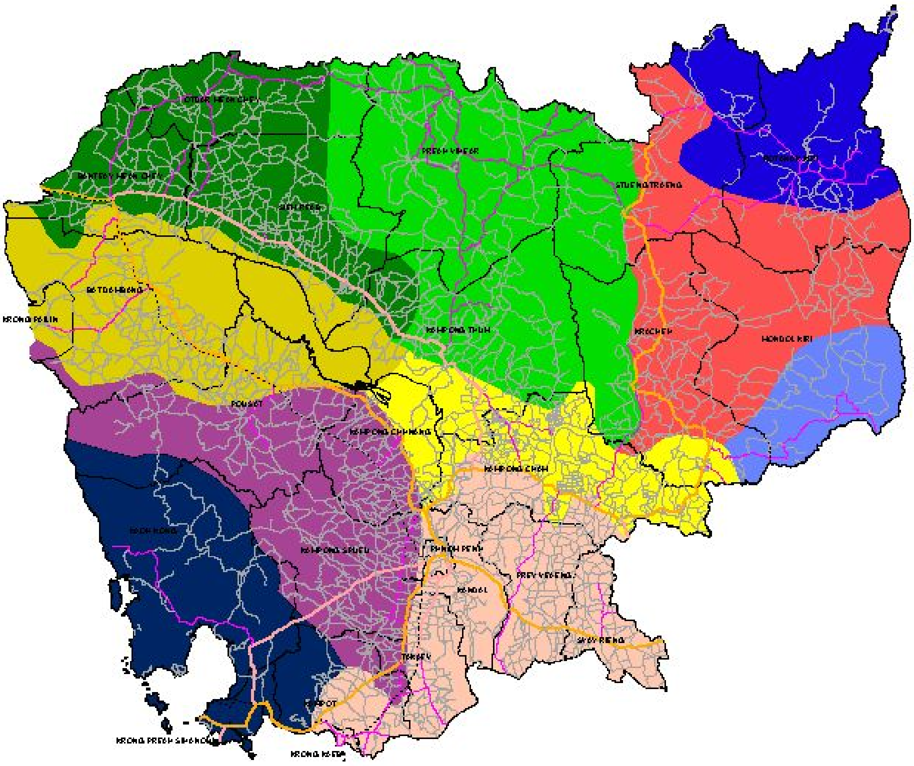
Gene-Ecological Zonation of Cambodia



December 2003

Cambodia Tree Seed Project
Institutional Capacity Building of the Tree Seed Sector

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Foreword

Success in the cultivation of commercially important trees on a national scale - whether in natural forests, degraded forests, plantation forests, or even villages and home gardens - will play an important role in the economic development of our nation.

We are all aware that the rehabilitation of degraded forests will pose a number of difficult challenges for Cambodian foresters in the future. Moreover, we recognize these include the identification and protection of remaining forestlands that produce high quality seeds. Fortunately, there is a strong desire and willingness on part of the Forestry Administration and local forest communities to develop a network of natural seed sources that can serve the needs of rehabilitation of Cambodia's forests. This report provides a useful foundation on which these activities can proceed with reasonable expectations of success.

The gene-ecological zonation model provides a useful planning tool for the conservation of forest genetic resources and a guide for the selection and use of suitable seed sources for planting programs within each Gene-Ecological zone throughout our country.

First and foremost, I would like to extend my gratitude to Danida and the Cambodia Tree Seed Project (CTSP) for recognizing the need for a Gene-Ecological Zonation System in the Kingdom of Cambodia. It was developed through the coordinated efforts of Forestry Administration, Cambodia Tree Seed Project (CTSP)/DANIDA, and German Development Service (DED). Special thanks are extended to the Cambodia Tree Seed Project Manager Mr. So Thea and Advisor Mr. Arvid Sloth and also in particular to Mr. Ignas Dümmer of DED for forming a core working group that was responsible for the creation of the zonation system and the publication of the present manual. Without their vision, initiative, and professional commitment, the useful outputs of this project would have never been realized.

Results that are presented in this report could not have been accomplished without the contributions of many people in the Forestry Administration and attached to this work. It is therefore a pleasure to express gratitude to the Cambodia Tree Seed Project Team, Mr. Ma Soktha, Mr. Sok Srun and to extend a special thanks to the consultants Ms. Sarah Burgess and Dr. Andrew McDonald for their inputs, and editorial works.

The Forestry Administration and the Ministry of Agriculture, Forestry and Fisheries are confident that all concerned parties will find this tool to be useful for sound forest rehabilitation and reforestation in the future.

Ty Sokhun

Chief of Forestry Administration

Abbreviations

CTSP	Cambodian Tree Seed Project
DANIDA	Danish International Development Agency
Dbh	Diameter at breast height
DED	German Development Service
FA	Forestry Administration
DoG	Department of Geology
DoM	Department of Meteorology
DTM	Digital Terrain Modal
FAO	Food and Agriculture Organization of the United Nations
GIS	Geographical Information System
IDW	Inverse Distance Weighting
IRRI	International Rice Research Institute
MoE	Ministry of Environment
MRC	Mekong River Commission
a.s.l.	Above sea level
UNESCO	United Nations Educational, Scientific and Cultural Organization
USDA	United States Department of Agriculture
UTM	Universal Transverse Mercator
WWF	World Wildlife Fund

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1. Introduction

With the support of Danida and in in cooperation with the Forestry Administration and the cooperation of the German Development Service (DED), the Cambodia Tree Seed Project (CTSP) has developed a database and geographical model to describe and predict natural genetic variation in Cambodia's important timber-tree species. The **Gene-Ecological Zonation** provides a series of updated maps that describe the present-day distributions of Cambodia's high-priority timber species, and affords a means by which to predict the suitability of distinctive genetic varieties of trees for reforestation programs. When applied to activities on the ground, the system can also be used to facilitate ongoing programs to locate and monitor existing seed sources. In short, the system establishes a conceptual framework in which silviculturalists, forest managers, and land-planners can be prioritize and improve upon existing plans and activities to regenerate the forests of Cambodia.

The Gene-Ecological Zonation System was developed as a tool to address a variety of questions and considerations that confront modern foresters. It is based, therefore, on a number of different of data-bases and information sources, all of which are integrated and cross-referenced by means of new and innovative computer methods. The system provides three distinctive outputs:

- A fixed Gene-Ecological Zonation Map
- A GIS model for species site-matching capabilities
- A user guide and documentation manual

The GIS manual is based on ArcExplorer software, and can be updated periodically as new meteorological data become available. Use of the GIS model is facilitated by an introductory user-level course in ArcExplorer, but general instructions to the use of our system, in both theoretical and practical terms, is provided in the manual. Like all models, the usefulness of the gene-ecological zonation system will depend greatly on the manner in which it is applied to practical questions. Due to the relatively flat and often homogenous topography of Cambodia's central lowlands, *we recommend to pay close attention to detail in their collection, application, and analysis of their ecological and forestry data.*

Readers and users who want additional information on the development of this model, or who have any critical comments on the manual, are kindly requested to contact the Cambodia Tree Seed Project or FA.

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2. Forest Seed and Gene Conservation

Given that native Cambodian trees are the product of selective forces which have operated in local ecological settings for millions of years, there is reason to assume that there is substantial genetic variation within and between populations of Cambodian plant species. It is therefore the goal of the Forest Gene Conservation program to identify and protect as many of these genetic races of plants as possible, in recognition that their genetic and phenotypic attributes are responsible for their competitive success in distinctive environments.

2.1 Gene-Ecological Zonation

Gene-ecological zoning is a simple and cost-effective tool to organize and prioritize action plans for the conservation and dissemination of important timber-tree species. Even though genetic information on most wild plant species is lacking at the moment, we are able to locate and protect distinctive population types on the basis of their present-day preference for natural environments. This general method can be applied immediately to reforestation and silvicultural programs by simply matching the environmental characteristics of a given seed-source with the environmental characteristics of a landscape for re-planting. The logic behind this method is based on the general assumption that the genes of one specific ecotype, regardless of its specific geographical source, are better suited for habitats that approach the general characteristics of its original homeland.

Definition of Gene-Ecological Zones:

> **"An area with uniform ecological conditions that produces distinctive phenotypic or genetic characteristics within a tree species."**
>
> **This concept is "based on a compromise between the variation in ecological factors and expected gene flow" (Graudal *et al.*, 1997).**

A gene-ecological zone is an area that exhibits ***uniform ecological conditions and limited degrees of gene flow between surrounding regions***. Each gene-ecological zone should be circumscribed in a manner that reflects the genetic homogeneity of plant populations. Yet in practical terms, it should also be large enough to be of practical use (Theilade *et al*., 2001). Various pragmatic decisions must be made before one is able to formalize the boundaries of these gene-ecological zones on a national scale.

The delineation of gene-ecozones is often complicated by the historical impacts of human communities on natural landscapes. Due to recent expansions of human populations, and their tendency to fragment woodlands, we are often unable to define the original distribution of plant races. Isolated populations of important timber tree species in the present day may have been established by a random dispersal event, in which case we expect to encounter populations that maintain minimal genetic variation, and ones which may or may not represent the optimal population of a given ecozone. On the other hand, isolated populations might also represent the last relics of a widespread race, in which case they are more likely to express considerable genetic variation and attributes that are optimally suited for a given environment. Since we have very little information on the genetics and geological history of Cambodian trees, we can only make an educated guess on their suitability to reforestation programs by considering their present-day distributions and environmental requirements (or preferences).

Because seed sources often occur near, or directly upon, the border of two distinctive ecozones, users of the gene-ecological zonation system must exercise caution in determining the specific nature of their seed sources. Seeds that occur on transitional zones may grow optimally in only one of bordering ecozones, or they might be better suited for a intermediate environment that shares the characteristics of two different habitats. Our system is devised to accommodate some of these outstanding questions through the use of its detailed databases. For example, if soil types are important in delimiting the abrupt transition between two eco-zones (such as basaltic flows over alluvial plains or sandstone plateaus that arise abruptly from lowland clays), a study of the specific substrates of a transitional region might indicate the presence of a singular soil type. On the other hand, if a determinant environmental factor varies gradually over large spatial expanses, as is often the case with water regimes and topography, then continuous plant populations are likely to express *clinal variation* (i.e., a continuum of genetic or phenotypic variation over space). In such cases, the use of this manual might be hard-pressed to specify a population's specific requirements.

General Objectives of a Forest Gene Conservation Program. The Gene-Ecological Zonation System has been developed to serve a variety of objectives in forest gene conservation.

A. **Gene Conservation Planning.** Identification of unique habitats in which ecotypical races of specific timber trees can be conserved in perpetuity.

B. **Germplasm Sources**. Establishment of seed production zones in native forests for the procurement of seed for the local needs of reforestation activities.

C. **Planning of Germplasm Sources**. Quantitative and qualitative assessments of seed-source sites for the planning of future needs and plans for forest improvement on a long-term basis.

D. **Plant Breeding .** Assessment and use of local genotypes for use in plant breeding programs (i.e., improvement on domesticated varieties).

E. **Distribution Potential**. Establishment of productive seed-source sites for the sale and dissemination of germplasm on a national or international scale.

2.2 Biological Rationale Behind the Conceptualization of Gene Ecozones

Since the turn of the 20th century, Cambodian economies have been dependant on timber resources as their principal source of trade revenue. As a consequence, governmental agencies have long been interested in assessing the relative values and abundance of their lucrative timber-producing species and forest ecosystems. Most of these studies were published by French botanists during the first half of the 20th century, and usually in the form of forest inventories (Bejaud 1932; Lecompte, 1926; Maurand 1938, Maurand & Dang-Phuc-Ho, 1937) and floristic treatments (Forbé & Trojani 1930; Lecompte 1907-1942). During the 1960s and 1970s, various detailed studies on species compositions and community structure of different vegetation types were published, including analyses of lowland evergreen forests near the seaport of Sihanoukville (Dy Phon, 1970, 1971, semi-evergreen forests on Phnom Kulen of Siem Reap (Bov Bang Eav 1970, Boulbet, 1979), and various types of vegetation in the Elephant Mountains of Kampot (Dy Phon, 1970, 1971). These comprehensive studies afforded insights into the general character of Cambodia's productive forests on a national scale (Dy Phon 1981, 1982; Legris & Blasco 1972; Rollet 1972). Unfortunately, many of the latter studies can be described as outdated, since the specific forests which they describe are now extinct or severely degraded.

Forestry studies of Cambodia have tended to focus on the diversity, distributions, and general structure of plant communities rather than the biological character of plant species which comprise them. Consequently, emphasis has always been placed on the merits of different classification schemes for plant communities, based on comparative assessments of species composition, dominant plant groups, and general life-history traits of different vegetation types. Most modern syntheses on forests of Cambodia include maps that circumscribe the geographical distribution of distinctive vegetation zones, and they tend to correlate the distribution of each vegetation type with the distribution of various climatic and environmental parameters. Because various environmental factors are responsible for determining the general characteristics of plant communities (such as stature, stratification, timing of germination, development, flowering and fruiting, etc.), they are of utmost importance to foresters and land-use managers that are interested in optimizing the economic output of regional forests.

A variety of selective forces have been operating in the native woodlands of Indochina since their origin some 70 million years ago. These forces of nature have given rise to natural variation in plant and animal populations throughout Cambodia. Very few studies in the past have addressed these issues, but modern-day foresters often find themselves in need of this base-line information when securing suitable germplasm for re-planting programs.

Since individual tree species do not recognize the natural boundaries of plant communities, the natural distributions of distinctive vegetation types are unable to account for the natural distribution of plant species, or the natural variation which is expressed by a species on a geographical scale. Many important timber tree species exhibit natural distributions that cut across environmental gradients and distinctive vegetation zones, and therefore express genetically-based characteristics that are adapted to one or another natural environment. A cursory examination of the vegetation studies by Legris & Blasco (1972), Rollet (1972), and McDonald et al. (1997) indicates, for example, that many important timber trees of Cambodia inhabit a variety of different vegetation types (Table 1). It is reasonable to assume, therefore, and predict, that populations which thrive in evergreen forests will exhibit different growth forms and developmental behaviours from those that grow in dry-deciduous and/or flooded forests. The full extent to which these populations differ from one another has yet to be explored by Cambodian biologists and forest ecologists, but we can be certain that natural variation exists between these populations, and that this variation can be put to use by foresters.

Knowledge of ecotypical variation between populations of desirable tree species is of utmost importance to Cambodian foresters, as different ecotypes of a given species will express characteristics that allow for their optimal growth and competitiveness in different environmental settings. This variation is sometimes expressed in the general morphology of plant races, in different physiological attributes, behavioural characteristics, and ecological associates. For example, discontinuous populations of *Albizia lebbeck* (L.) Benth. and *Peltophorum ferrugineum* Benth. are known to inhabit evergreen forests, deciduous forests, and flooded forests (Table 1).

Hence we are given to assume that these populations must respond to these distinctive environments in various ways. Populations that inhabit the flooded forests of Tonle Sap Lake, for example, which are submerged by floodwaters during the rainy season, must drop their leaves during the height of Cambodia's annual precipitation cycles. Hence they must develop and photosynthesize when their canopies are exposed to the sun during dry seasons of the year (December-July). On the other hand, populations that live in typical evergreen and deciduous forests of Cambodia consistently drop their leaves during dry seasons, when water stress is severe on upland sites. And conversely, these populations produce foliage during or just after the onset of the rainy season. We suspect that flowering phonologies of evergreen and flooded forest species must also be out of synchrony, and that these behaviours would serve as a genetic isolating mechanism between populations of the same species.

TABLE 1. Ecological Versatility of Some Cambodian Timber Trees

Evergreen Forest (EF); Deciduous Forest (DF); Savannah Woodlands (SW); Flooded Forest (FF)	**EF**	**DF**	**SW**	**FF**
Albizia lebbek (L.) Benth.	**X**	**X**	**X**	**X**
Anisoptera cochinchinensis Pierre		**X**	**X**	
Dipterocarupus alatus Roxb.		**X**	**X**	
Dipterocarpus costatus Gaertn. f.	**X**	**X**		
Dipterocarpus intricatus Roxb.		**X**	**X**	
Dipterocarpus obtusifolius Teysm.		**X**	**X**	
Dipterocarpus tuberculatus Roxb.		**X**	**X**	
Lagerstroemia spp.		**X**	**X**	**X**
Peltophorum ferrugineum Benth.	**X**	**X**		**X**
Shorea obtusa Wall. ex Blume			**X**	**X**
Sindora cochinchinense Baillon	**X**	**X**	**X**	

(Based on Legris & Blasco 1972: 73-133, Rollet 1972; McDonald *et al*. 1997)

Because species distributions do not correlate directly with the natural distributions of different vegetation types, many timber trees of Cambodia occur in a variety of vegetation zones (Table 1). And as a rule, their widespread populations can be expected to exhibit different developmental traits under different ecological conditions. Biologists have coined a term to describe different races of living creatures: namely '***ecotypes'***. And it is generally recognized that knowledge of these natural races of organisms can be employed by users of natural systems (i.e., foresters). At this point in time, we have very little data on the genetic basis of ecotypic variation in Cambodian seed plants, but we can presently recognize and characterize the different natural environments in which individual tree species occur, and regard these populations as unique ecotypes on a theoretical basis.

In the present report, we will refer to these different environments as '**Gene-Ecological zones**' (or **gene ecozones**), so as to acknowledge their influences on the genetic and adaptive features of their plant communities. We assume that variant ecotypes of plant species occur in each different gene-ecological zone.

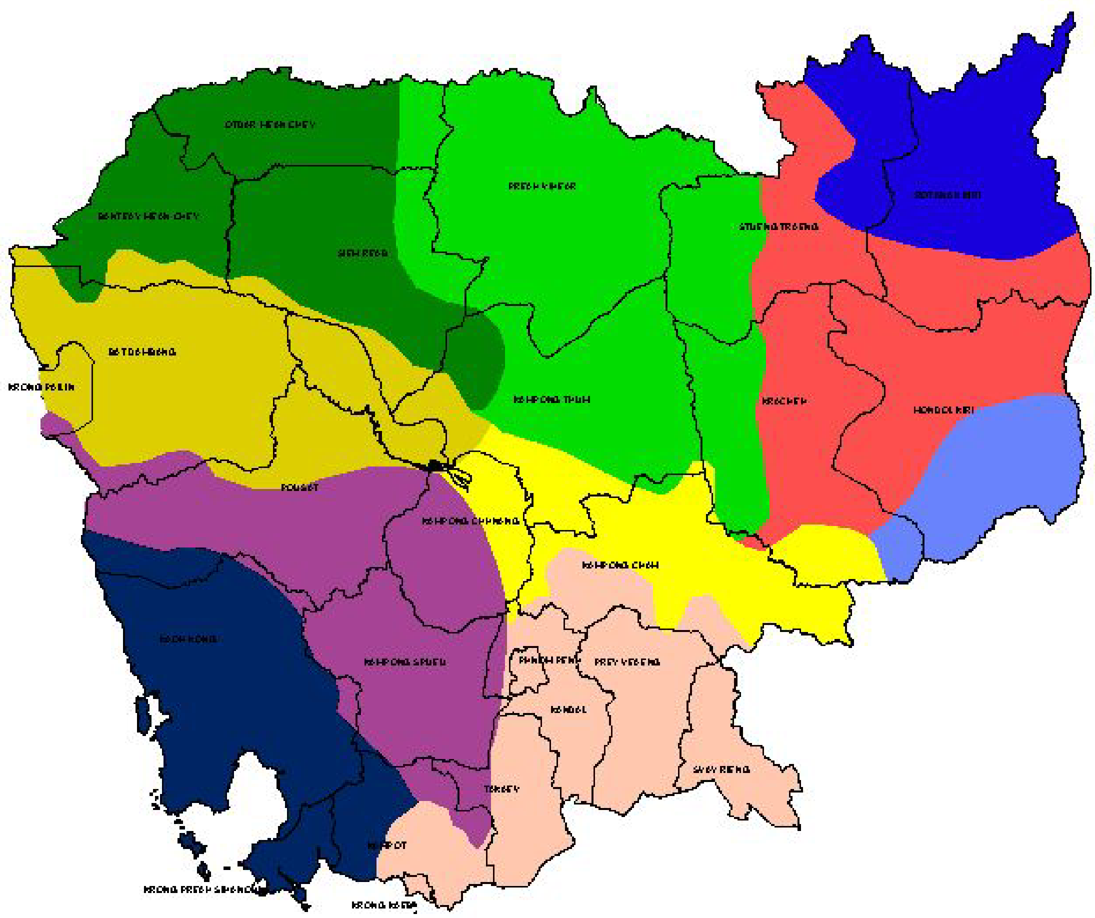
2.3 The Gene-Ecological Zonation Map and its Use in Gene Conservation

The Gene-Ecological Zonation system was created with a variety of environmental data-sets, including several that are based on records and interpolations from 123 meteorological stations within and around Cambodia (i.e., averages and ranges in temperature, rainfall, and length of dry seasons). This information was then correlated with databases that describe the topography of Cambodia, the age and chemical composition of its soils, soil fertility, and the natural distribution of vegetation types. Section 3 of the manual describes the general characteristics of each one of these databases, and the manner in which they were applied in the delineation of gene-ecological zones (see also Appendix vi for a general summarization of these data).

Based on the latter environmental factors, a general model and information system was created to serve the present needs of foresters in the following ways:

- As a planning tool to determine suitable planting areas.
- As a database to study the environmental characteristics of selected tree sites.
- As a means to identify areas which can be seeded with external sources of seeds.

Map 1. Gene-Ecological Zones of Cambodia



It may be noted that our gene eco-zones (Maps 1, 13) agree generally with a recently proposed system of 'Eco-regions' in Indochina, as defined by WWF in their 'Guidelines for Sustainable Forest Management' (Baltzer et al. 2001: p. 3, 68-69). Our model is more detailed for Cambodia, due to our interests in genetic variation between species populations instead of biogeographical origins and species compositions of plant and animal communities. It is only natural that these different schemes result in similar conclusions, as natural environments are the driving force behind evolutionary change and relationships between organisms.

2.3.1 Gene Conservation Planning

For the purpose of insuring a safe and reliable source for genetic variation in important trees, we recommended that at least ***two protected seed sources*** are conserved for every priority species that occurs in each eco-zone. If this general practice is followed, then the loss of a single seed source will not result in the extinction of a specific genotype. Guidelines for the conservation of seed sources have been published in the Forest Gene Conservation Strategy (FA/CTSP, 2003) in order to assure consistency in monitoring and enforcing the protection of these valuable natural resources.

2.3.2 Seed Zoning

Maps 1 and 13 can be used to recognize *seed sources that are most relevant and applicable to reforestation programs within a specific gene zone*. This does not preclude, of course, the possibility that seeds from one gene zone might be useful, for tree planting programs in an alternative zone. We recommend, however, that foresters test the success of inter-zonal transplantations before replanting programs are undertaken on a large-scale.

During the process of seed-site matching, it should be recognized that trees are expected to react unpredictably along ecological gradients and borders that form transition zones between different gene-ecological zones. *As a general rule, the seed zonation system is a model that serves as a guideline, and not as a rule. The model cannot replace a forester's pragmatic decisions on the choice of seeds for planting programs. Rather, it is recommended that our zonation system and data-bases be used to assist land-planners in assessing the geographical distributions and ecological preferences of high-priority, timber-tree species.*

3. Theoretical Considerations

3.1 Climatic Influences on Plants

In principle, the boundaries of gene-ecological zones are determined by the discontinuous and often independent distributions of different environmental factors and parameters. Although each determinant factor can be qualified and quantified on an individual basis, their direct impact on biological systems is often influenced by, or inter-related with, other environmental factors. Organisms must contend with a host of selective pressures, the whole of which, over evolutionary time, are responsible for the adaptive features which we observe or predict in present plant populations. In the case of plants, many of these adaptive features relate in one way or another to a population's ability to photosynthesize and compete optimally in a given environment. Survivorship and success of plant populations depends greatly on their ability to make use of water and minerals, and these elements can vary in availability from one region to the next.

Figure 1 illustrates the manner in which differing temperature ranges and water regimes determine the structural features of plant species and physiognomic character of plant communities. Observable distinctions in tree morphology and community structures can be understood in terms of natural selection. Since most of the important timber species of Cambodia are tropical in nature, and occupy lowland environments that vary minimally in regard to temperature, their natural variability often relates to their response to different water regimes.

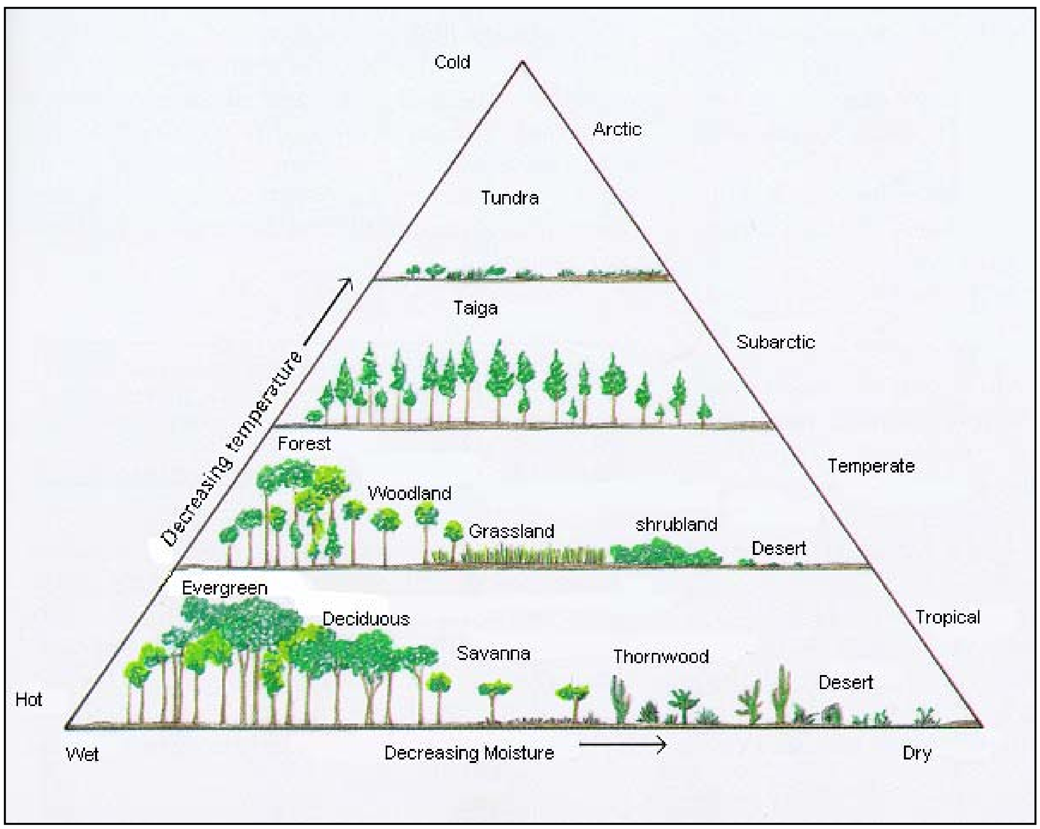


Figure 1. Influence of Water and Temperature Regimes on Vegetation
Source: Arms K. 1990

Generally speaking, the stature and productivity of tropical forests are determined by the availability of water. Plant communities that are tall (40-60 m), highly stratified, and evergreen, tend to occur in regions with a short dry season (< 2 months). Since water is always available in this environment, the limiting factor with which plants must compete is sunlight (hence large statures). As environments become drier, however, plants tend to be reduced in stature, and to produce small, deciduous leaves. These characteristics allow plants to reduce their surface areas, and hence transpiration rates (water loss) for prolonged periods of drought. As is often the case with adaptive features, there is a cost and benefit to either short or tall growth, the production of persistent or deciduous leaves, and the presentation of either large or small leaves.

Length and severity of dry seasons on a regional scale can also have considerable impacts on the timing of reproduction in plants and the behaviour of plant seeds and saplings. Plants that thrive in seasonally dry habitats tend to produce seeds that can withstand long and intense periods of drought, usually by means of long periods of dormancy. Moreover, their seedlings can be expected to be relatively hardy and pre-adapted to water stress. In contrast, plants that occur in evergreen forests tend to be heat intolerant, and generally produce seeds that are relatively short-lived. These plants tend to produce fast-germinating saplings that survive for extended periods of time in shaded understories, awaiting an opportunity for growth by the opening of light-gaps in the canopy.

In like manner, flowering phenology is also greatly affected by the length and intensity of rainy and dry seasons, as the movement of insect pollinators are substantially hindered by rainfall and cloud cover. Hence the flowering period of plant races in an evergreen forest may not be synchronized with flowering periods of neighboring populations in dry deciduous forest.

It is noteworthy that almost all of the priority species in the Cambodia Tree Seed Project (section 5) are native to 'Evergreen' and 'Deciduous' forest types. As a consequence, they tend to exhibit characteristics that are typical of plants that prefer high temperatures and significant quantities of water (Figure 1). We also encounter, however, forested savannahs (Figure 1) in regions of Cambodia that have low water retention (sandstones) and a long-lasting dry season, such as the lowland forests which lie East of the Mekong River (Map 11; section 5.1.8, the Lower Mekong Basis ecozone). And there are also 'thorn-wood forests' (Figure 1) which dominate the floodplains of Tonle Sap Lake (Map 11; section 5.1.3, the Tonle Sap Floodplain ecozone). Neither of these zones is particularly important, however, in the production of important timber trees (section 5).

Although the interactive influences of temperature and precipitation play a crucial principal role in determining the availability of water in woodlands, there are other mitigating factors that come into play. The availability of moisture is also regulated, for example, by topography, soil types, and in modern times, human influences on natural landscapes. All of these factors have a direct bearing on plant growth rates and forest productivity, since water is a basic ingredient of photosynthesis. Table 2 summarizes a variety of factors that have a direct impact on water availability and characteristics of plant communities.

Availability of water is also determined by temperatures, a factor that is important in regulating evapo-transpiration of individual plants and forests. The lower temperature limit for efficient photosynthesis is around 6^{o} C, whereas the upper limits depend greatly on the availability of water. As a general rule, the efficiency of photosynthesis begins to diminish when temperatures surpass 30^{o} C. It is notable that the lower temperature limits for photosynthesis do not exist in the tropical climates of Cambodia, and that the upper limits often prevail throughout the country for half the year. The coolest temperatures are to found, of course, in mountainous regions of Cambodia, and these conditions tend to correlate with an abundance of water.

Table 2. Factors Affecting Plant Growth

Climate	Site	Soil
• Temperature • rainfall • relation between precipitation and evapo-transpiration • wind velocity • air humidity • radiation	• slope • slope length • micro relief • external drainage • rocks and stones	• effective depth • texture • internal drainage • fertility • salinity • PH • Structure

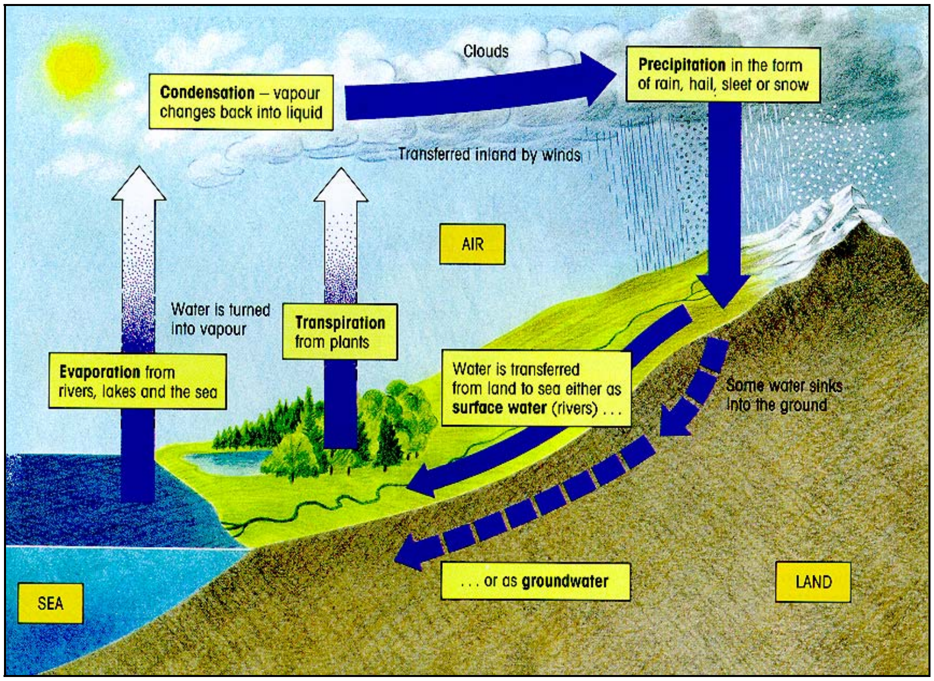
3.2 Topography

Due to the cooling effects of higher altitudes, and the condensation of water-saturated air in lowlands, topography is yet another important determinant factor of water availability. Mountainous terrain tends to receive larger amounts of annual precipitation in Cambodia, and for longer periods of time. Figure 2 illustrates the cyclical flow of water, and its complex interactions with the air and landforms.

As noted in Table 2, mountainous regions tend to be rocky, and therefore have soils that are less likely to retain water for plant communities. Furthermore, they are often defined by relatively steep slopes, which tend to drain the landscape of its water immediately after a rainfall. These same slopes can also affect evaporation rates of a forest, depending on the angle and pitch of slopes.

In contrast, the lack of relief can have the opposite of affect on water availability. Flatlands often receive precipitation that has fallen on nearby mountains, and then retain these waters in their shallow reliefs. This general scenario describes the physiography of Cambodia as whole, whose principal lowland forests are situated between the Dangrek and Central Annamite Mountains to the North and the Cardamom Mountains (*sensu lato*) to the South (Maps 2, 3).

Figure 2. The Water Cycle



(after Raven *et al*. 1993, from O'Brien, 2000)

3.3 Geology and Soil

The nature of soils and their underlying parent materials are equally important in determining the availability of both water and minerals. Alluvial sands, silts, and sandy soils are particularly common in floodplains, and these can serve to retain water in regions that experience a dry period during the year. As already noted, rocky soils and their underlying substrates are often incapable of retaining water and minerals. Consequently, they are often dry and infertile.

The fertility of soils is often determined by the nature of rock that characterizes a given region. The chemical characteristics of soil are often determined by the degree and manner in which regional rocks have decomposed over the geological course of time, and the character of rocks that serve as the parent material. Geological processes are influenced to varying degrees by climate, time, relief/topography, as well as biological processes that are determined by human and non-human organisms (animals/bacteria). All of these factors can have a direct or indirect bearing on a soil's acidity, colour, texture, structure, fertility, productive capacity, and permeability.

Soils are classified to a large extent by the size of their particles, from finest particles (clay) to coarse particles (silt, sand) to coarsest of particles (gravel). They are also influenced by the nature and content of their organic matter (humus). Soils are often formed by several distinctive horizons, each layer of which can be characterized in terms of their physical and chemical constitutions, or water-holding capacities.

They can also be characterized on the basis of their geological history and process of formation:

- sediments (e.g. sand, gravel)
- sedimentary rocks (e.g. sandstone, limestone)
- metamorphic rocks (e.g. schist, slate, quartzite)
- volcanic rocks (e.g. basalt)
- plutonic rocks (e.g. granite)

Table 3 summarizes the classification scheme of Driessen & Dudal (1989), which we cite in order to demonstrate their complexity, and the complicated processes that are involved in their formation.

Soils also have a direct impact on the adaptive features of plant species and communities. Soils that are comprised of inert, silicaceous sandstone or siltstone, for example, are often poor in water and mineral content due to leaching. Plant communities in these soils are often dominated by leguminous plants, owing to their symbiotic relationship with Nitrogen-fixing bacteria in their roots. Moreover, non-leguminous plants in sandy soils often require close associations with leguminous plants to obtain their needed allotments of nitrogen.

Various distinctive Cambodian plant communities have been defined specifically on the basis of their soil preferences types, as noted by Legris & Blanco (1972: p. 112; i.e., forests "terre rouge basaltiques", "Terre Grise", or limestone).

Table 3 – Soil Groupings of the FAO-UNESCO Systems (Driessen and Dudal, 1989)

Set	Dominant Identifiers	Main Soil Groupings
1	Organic soils	HISTOSOLS
2	Mineral soils in which soil formation is conditioned by **Human influences**	ANTHROSOLS
3	Mineral soils in which soil formation is conditioned by **Parent material** • soils developed in volcanic material • soils developed in residual and shifting sands • soils developed in expanding clays	 ANDOSOLS ARENOSOLS VERTISOLS
4	Mineral soils in which soil formation is conditioned by **Topography/Physiography** • soils in lowlands (wetlands) with level topography • soils in elevated regions with non-level topography	 FLUVISOLS GLEYSOLS LEPTOSOLS REGOSOLS
5	Mineral soils in which soil formation is conditioned by **limited Age**	CAMBISOLS
6	Mineral soils in which soil formation is conditioned by (**Climate and Vegetation**) in wet tropical and subtropical regions	PLINTHOSOLS FERRALSOLS NITISOLS ACRISOLS ALISOLS LIXISOLS
7	Mineral soils in which soil formation is conditioned by (**Climate and Vegetation**) in arid and semi-arid regions	SOLONCHAKS SOLONETZ GYPSISOLS CALCISOLS
8	Mineral soils in which soil formation is conditioned by (**Climate and Vegetation**) in steppes and steppic regions (prairies)	KASTANOZEMS CHERNOZEMS PHAEOZEMS GREYZEMS
9	Mineral soils in which soil formation is conditioned by (**Climate and Vegetation**) in subhumid forest and grassland regions	LUVISOLS PODZOLUVISOLS PLANOSOLS PODZOLS

4. Description of Ecological Factors in Cambodia

4.1 Criteria used in the Formulation of Gene-ecological Zones

Historical data and maps on the distribution of natural environments and agricultural lands of Cambodia have been maintained and updated by a variety of governmental departments. Our databases are derived from the following sources.

Datasets used in Delineating Gene-Ecological Zones

Geology (DoG)
Soil
- Soil map (IRRI)

Forest and land use cover:
- Forest and land cover 1993, 1997 (FA)

Climate data 1928-2002 (MoE, MRC, DoM)
- Rainfall data from 104 meteorological stations in Cambodia
- Rainfall data from 7 meteorological stations in Laos PDR
- Rainfall data from 9 meteorological stations in Thailand
- Rainfall data from 3 meteorological stations in Vietnam
- Temperature data from 9 meteorological stations in Cambodia

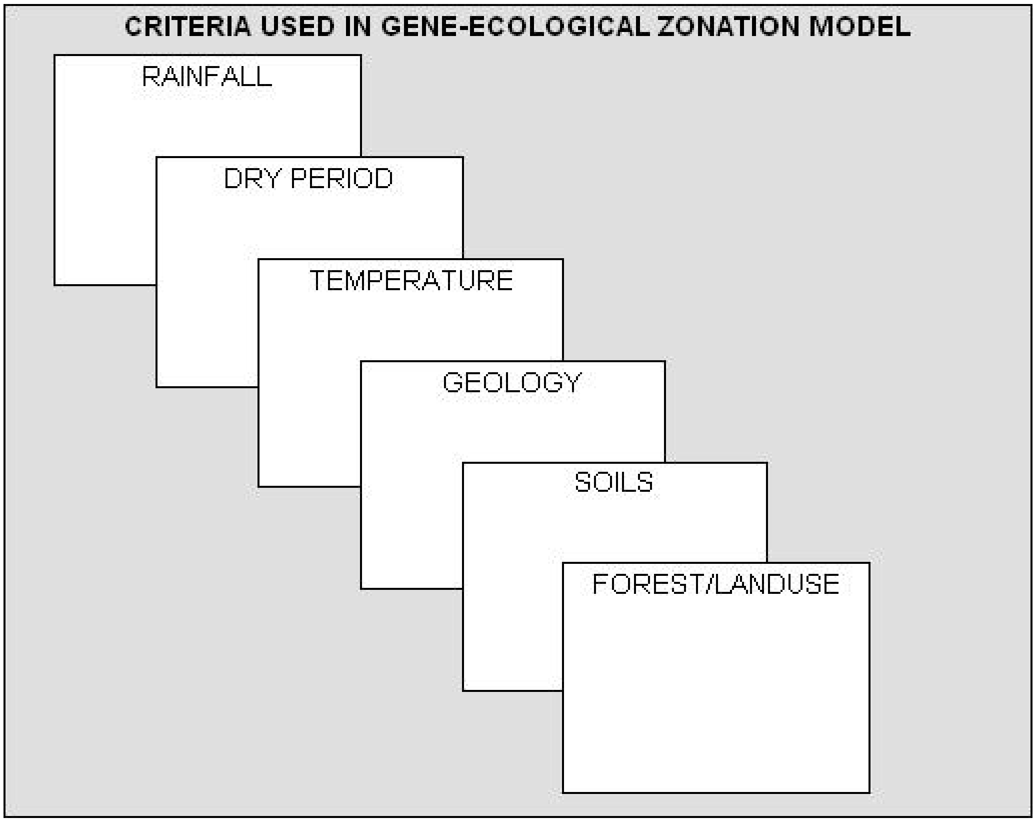
Elevation:
- Digital Terrain Model (MRC)

Because many of these datasets are much too detailed and cumbersome to use in the delineation of gene-ecological zones, the Cambodia Tree Seed Project has chosen to emphasize information that is most directly relevant to the processes of natural selection in the context of plant populations. These include the following environmental factors:

- Annual rainfall (using 200 and 600 mm range classes)
- Period of dry months (< 40 mm rainfall/ per month over a 4-month period)
- Temperature of coldest month (<16.5º Centigrade)
- Geological distribution of basalt, sand-siltstone, alluvial deposits, gneisses and schists, and complex substrates
- Soil Fertility (low, medium and high)
- Vegetation and Land Use (agricultural lands, shrub land, deciduous forest, evergreen forest and inundated/mangrove forest

In order to visualize these multivariate factors in a geographical context, each measurable environmental parameter, according to a biologically relevant interval, was mapped out for comparative purposes (Figs. 3). A comparative study of six different maps (Maps 4-6, 8, 10, 12) was undertaken, with the goal of recognizing an overall pattern to the occurrence of distinctive ecological zones in Cambodia.

Figure 3. Determinant Factors of Gene-Ecological Zones



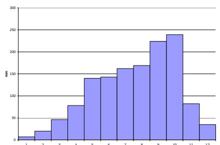
In this process, it became clear that around 10 distinctive zones could be delineated (Maps 1, 13), and that each of these zones could be characterized and distinguished on the basis of its geographical location and a definable range of environmental parameters.

4.2 Geography and Physiography of Cambodia

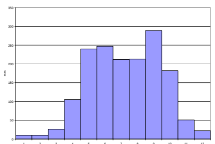
As would be expected, the boundaries of the gene-ecological zones of Cambodia tend follow the borders of important physiographic features of Cambodia. Included among these are the interconnected floodplains of the Mekong and Tonle Sap Rivers. These natural basins are confined in the North by the Dangrek and Central Annamite Mountains, and to the South by the Cardamom Mountains (including the Elephant Mountains; Maps 2, 3). These vast, low-lying alluvial plains surround Tonle Sap Lake in the western half of the country, and wind their way through the middle of the country following the course of the Mekong River. These two river basins can be recognized as a single body of water, the whole of which effects about 75% of Cambodia's land cover.

Map 2 - Distribution of Meteorological Stations in Relation to Elevation.

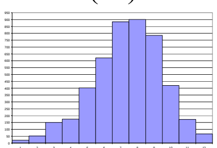
Battambang (6)



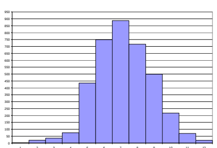
Baray (34)

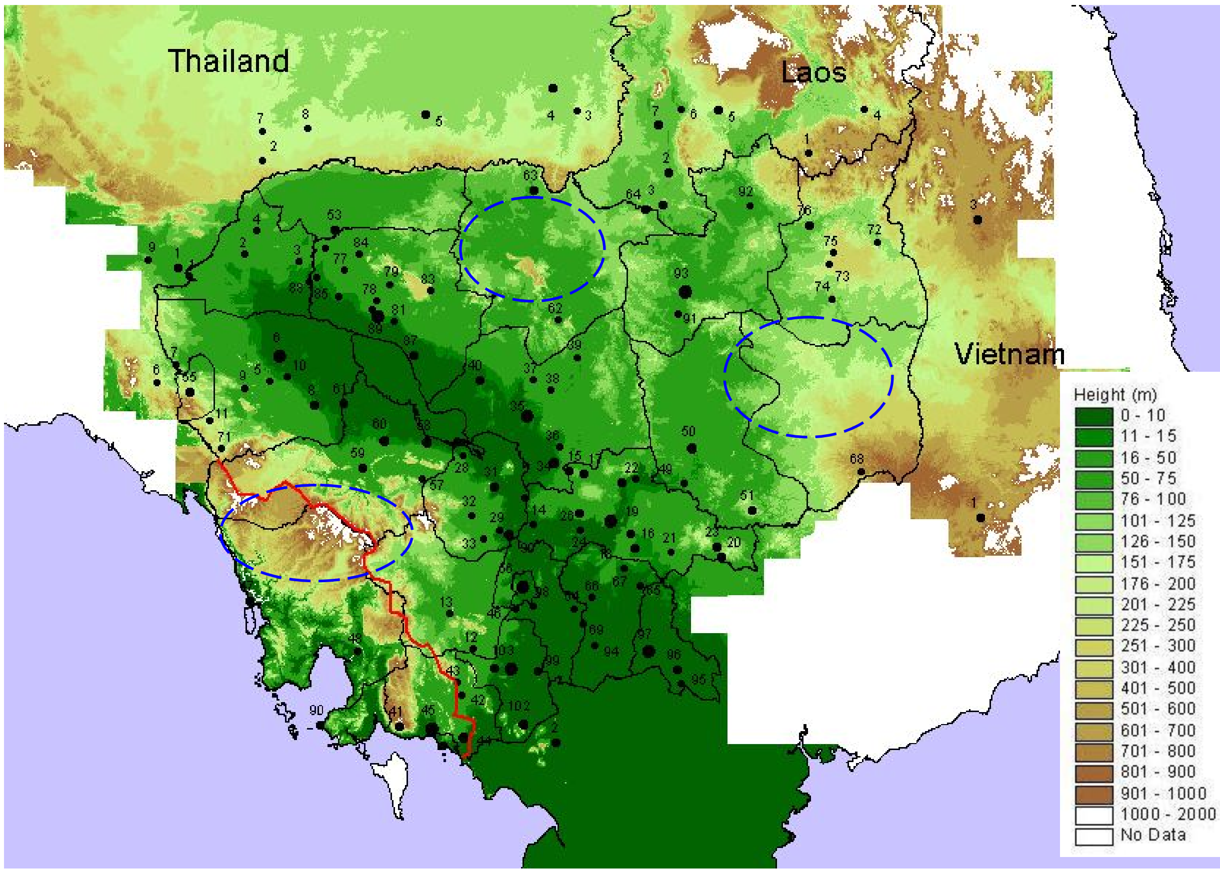


Bokor (41)

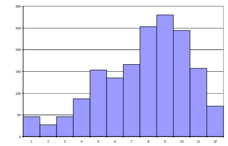


Chnong (49)

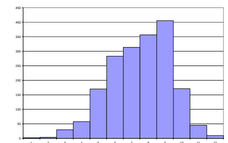




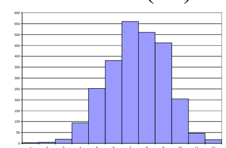
Leach (59)



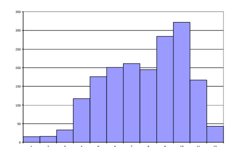
Chomksa (63)



Voeun Sai (76)



Svay Rieng (97)



Notes:

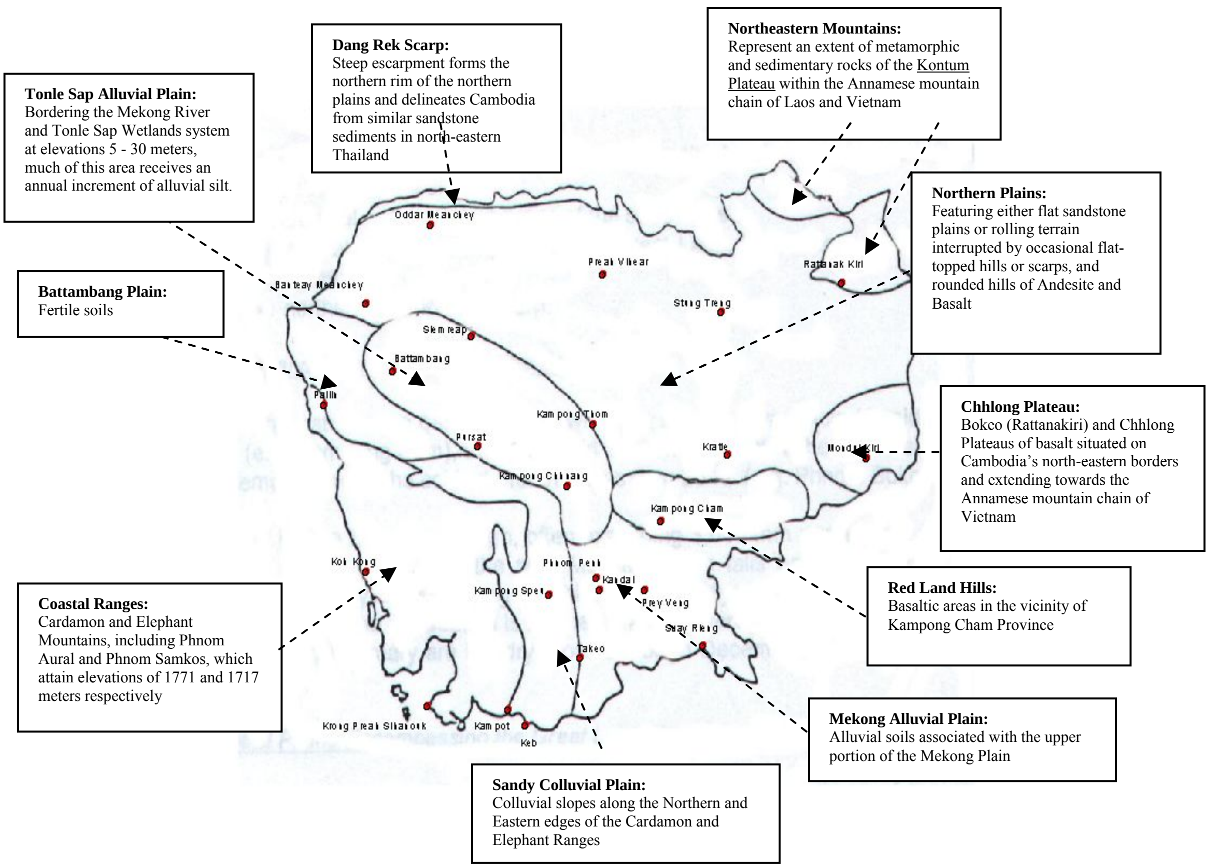
▲ Stations measuring temperature

- the dashed circle indicates a low density of stations, absence of stations, or only small amounts of data collection, and therefore, the interpolated data is of low accuracy.
- the size of the dot signifies the years of collection, where the bigger the dot, the higher the amount of years of data collection.
- the red line in the coastal zone marks the barrier for interpolation of rainfall data.
- the graph beside the figure shows the mean monthly rainfall of selected locations.
- the horizontal lines are divided in 50 mm classes.

For further details see *Appendix ii.*

Another prominent geographical feature of Cambodia is the southern coastal plain of the country. These lands fall within the southern regions of Cambodia's southern provinces (Koh Kong, Kampot, Sihanoukville and Krong Kep), and receive a substantial amount of water from the Sea of Siam. This region forms a narrow strip of land that is bordered on the north by another important geological formation of Cambodia, namely the Cardamom Mountains. These mountains and those to the East of the country (Southern and Central Annamites), enclose the central lowlands, and provide the home to distinctive types of plant life in their wetter habitats, low temperatures, and rockier terrains. Thus, when viewed as whole, Cambodia can be divided into four distinctive mountain regions, and a variety of closely linked floodplains (Map 3).

Map 3. Major Physiographic Zones of Cambodia (after Wharton 1968)



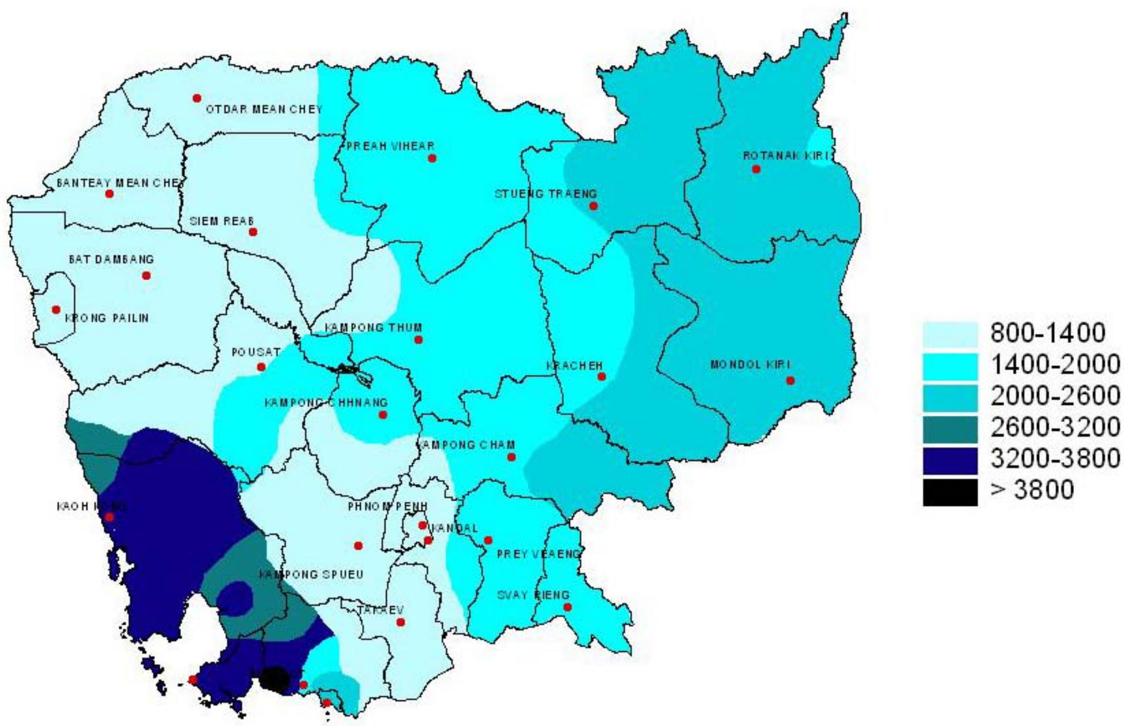
4.3 Simplification of Databases and Generation of Mapping Systems

Owing to the complexity of databases on the climatic, geologic, and biological characteristics of Cambodia, various subjective decisions were made to recognize those environmental parameters which have a direct bearing on the genetic constitution of plant populations. Only those parameters that were deemed most influential to the development of plants were utilized in the process of delineating gene-ecological zones. The following discussion describes the environmental conditions which we believe are especially important to the process of natural selection in Cambodia's tropical environments, and to conservation of genetic diversity in timber trees.

4.3.1 ANNUAL RAINFALL

The climate of Cambodia is classified as 'humid-tropical' in general terms, or more specifically, as 'tropical monsoon,' so as to underscore the importance of season droughts in the region. South-western monsoon systems bring high humidity, heavy rains, and strong winds into the country from May to October, while north-eastern winds from November to April are responsible for the dry seasons. Humidity is often high throughout the year, with a mean of 80.3 %. The average annual rainfall is 1,604 mm, although this figure rises considerably in coastal zones and highlands of Cambodia (> 3500 mm; Map 4).

Map 4. Distribution of Rainfall Regimes in Cambodia



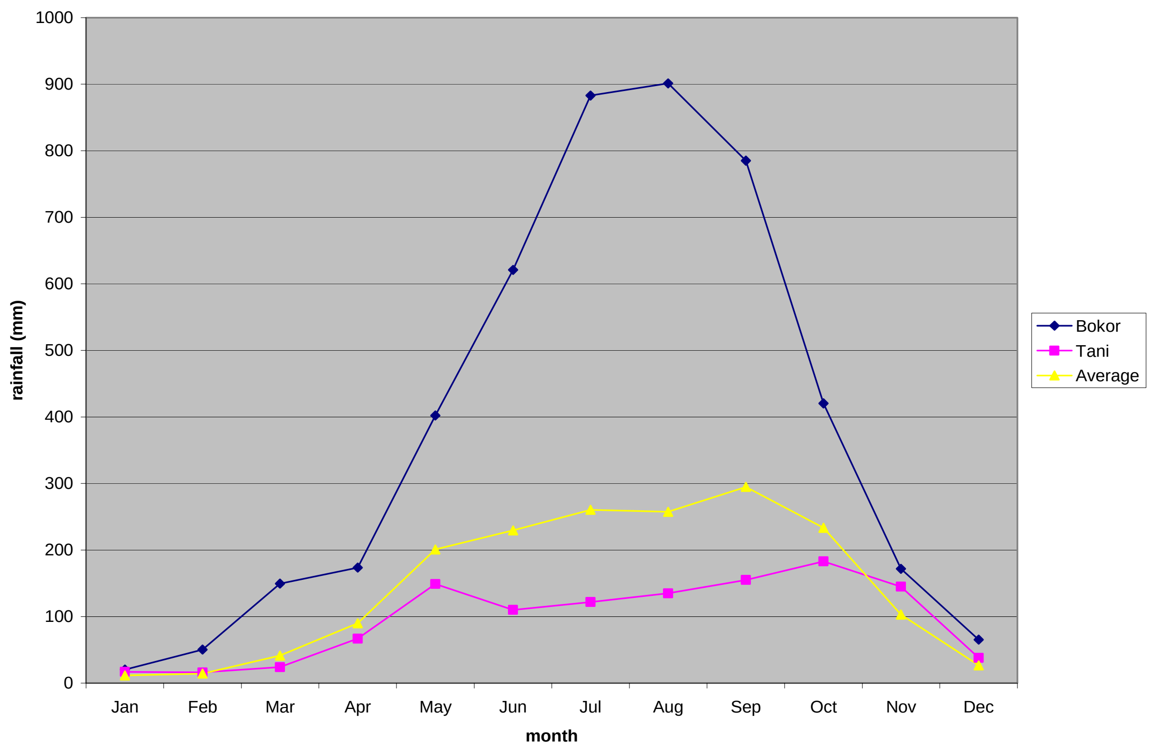
Based on climatic data from 59 stations, January is typically a dry month. In contrast, the month of September experiences an average of 19 rainy days. On a national scale, rain falls an average of 125 days per year (MoE). Details on the distribution of water regimes on the provincial and district levels is summarized in Appendix ii.

Map 4 describes the distribution of rainfall ranges in Cambodia. It may be noted that the windward slopes of the Cardamom Mountains receive the highest amount of precipitation, amounting to twice the rainfall in the second wettest region of the country, namely the East Mekong basin and the Central and Southern Annamite ranges (see sections 5.1.1, 5.1.7-9 and Maps 1 and 13). Although the Central and Southern Annamite Mountains on the eastern border of Cambodia probably receive more rainfall than our data suggest, meteorological stations and data are still lacking from these isolated regions of Cambodia to record the ranges of variation.

4.3.2 LENGTH OF DRY SEASON

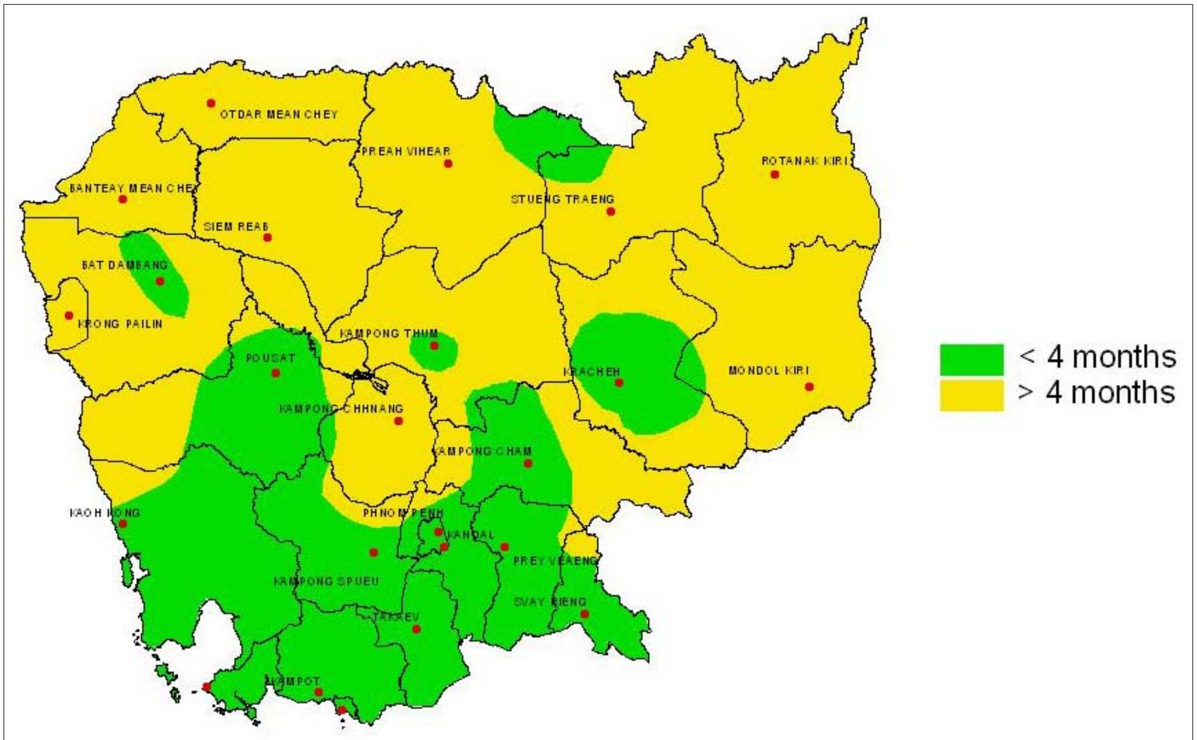
Although annual precipitation accounts for the total amounts of precipitation within a year, perhaps a more relevant parameter relates to the distribution of rainfall throughout the year. Seasonal droughts can place strong selective pressures on both young and adult trees; thus seasonality of rains is as important to plant growth as annual precipitation. Since some regions of Cambodia receive around 6 months of drought, and others only one or two months (Figure 4), we have chosen to recognize a 4-month dry period as in indication of extreme water stress (Appendix ii, Map 5).

Figure 4. Monthly Rainfall Variation and Average in Two Locations



It may be noted that part of the northern extensions of the Cardamom Mountains are seasonal, even though they receive high annual rainfall (Map 5). In like manner, regions around Battambang and Kampong Cham receive only moderate amounts of rainfall (Map 4), yet rain falls throughout the year in these areas. Generally speaking, two related gene ecozones are distinguished in part by their perpetual rainfall and evergreen forests of the Coastal Cardamoms and Northern Cardamoms (Sections 5.1.1, 5.1.2).

Map 5. Length of Dry Seasons in Cambodia

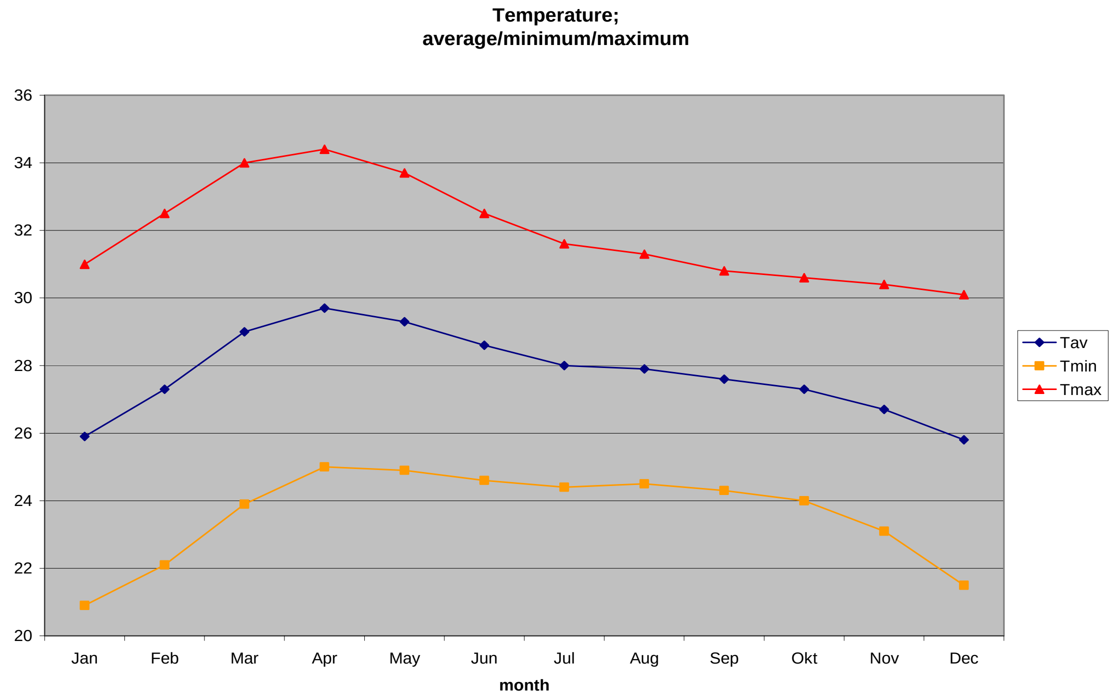


4.3.3 Temperature

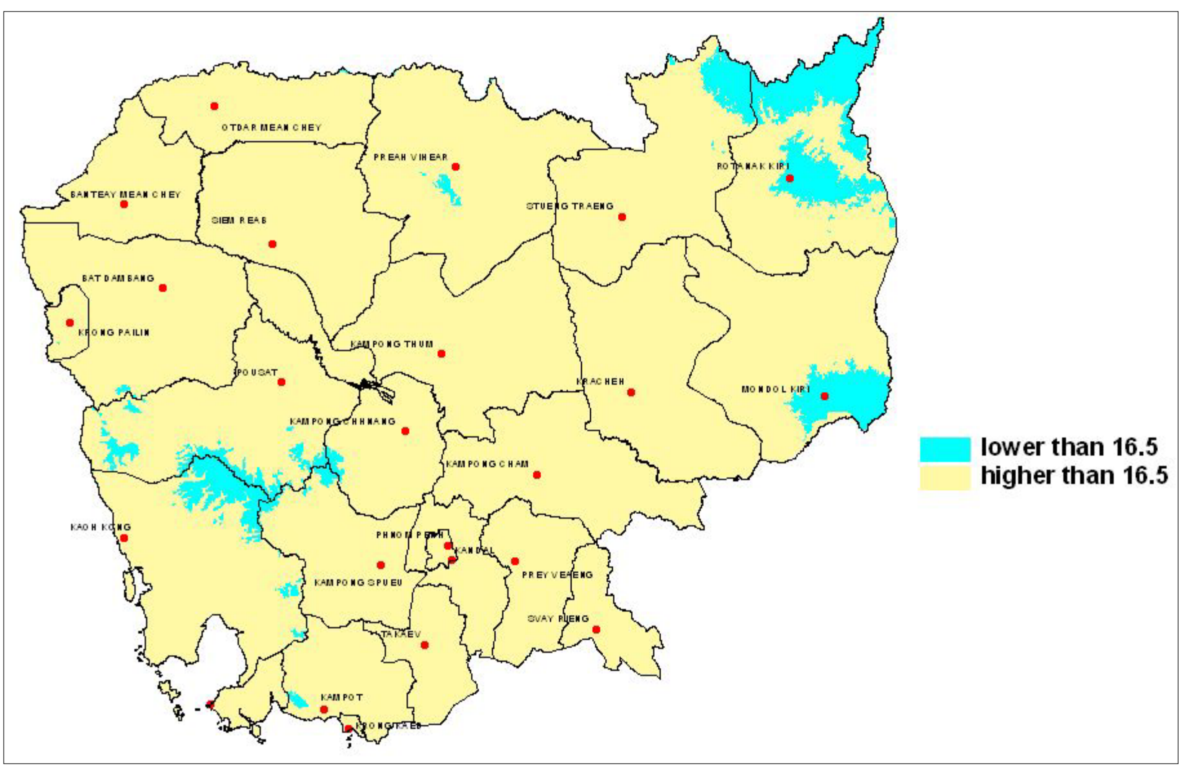
Temperatures vary less on an inter-regional basis than do other environmental factors and parameters. Most variation in temperature can be attributed to topography (i.e., local altitudes; Map 6) and the seasonality of cloud cover. On average, high temperatures reach to 34^{o} C in April, and 21^{o}C in January. Cambodia's annual average temperature of 28^{o} C (Figure 4, Appendix iii).

Since temperature ranges in the Northwest lowlands do not differ substantially from lowlands in the Southeast, the gene-ecological zonation system emphasizes the impact of high altitudinal temperatures. Hence the highlands of the Cardamom Mountains, Central Annamites, and Southern Annamites, all of which surpass altitudes in excess of 800 meters, sustain forests that are adapted to cool temperatures from December to February (< 16.5º C).

Figure 5. Monthly Mean Temperature (based on 9 stations)



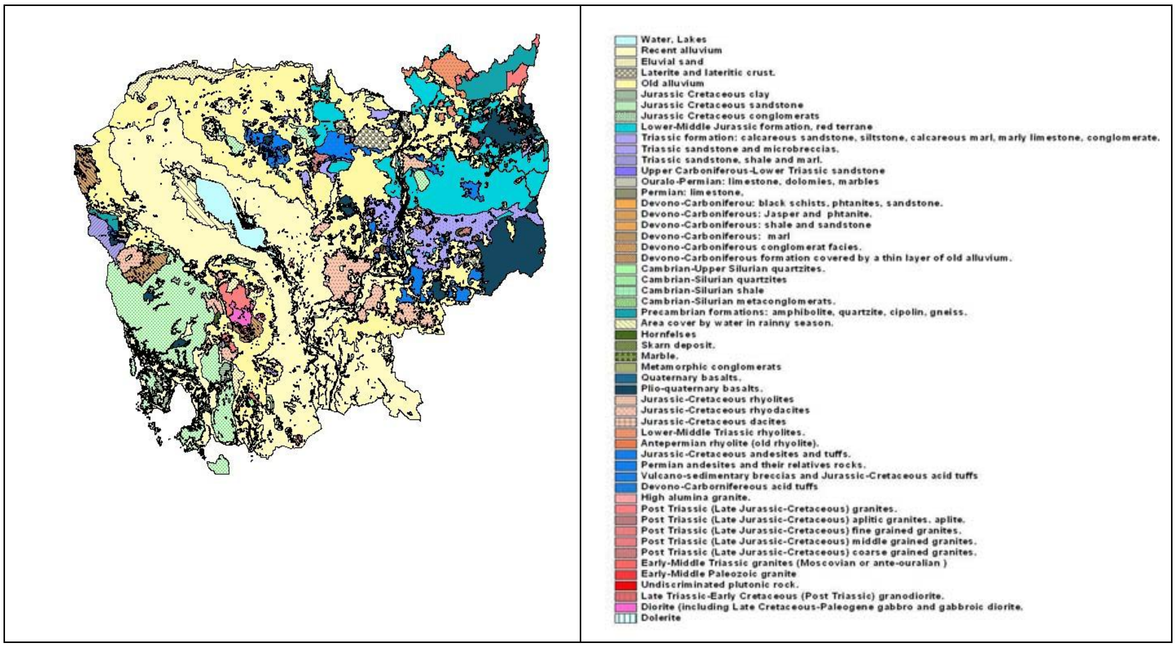
Map 6. Distribution of Low-temperature Regions of Cambodia



4.3.4 GEOLOGY

The geology of Cambodia is a complex subject, and one that has received little attention by botanists. This is unfortunate, as the age and chemical nature of substrates plays a decisive role in the natural selection of local plant races. Whereas the geological history of Cambodia is poorly known, the age and physical characteristics of the country's land surface have been sufficiently surveyed and mapped out to serve our purposes (Map 7).

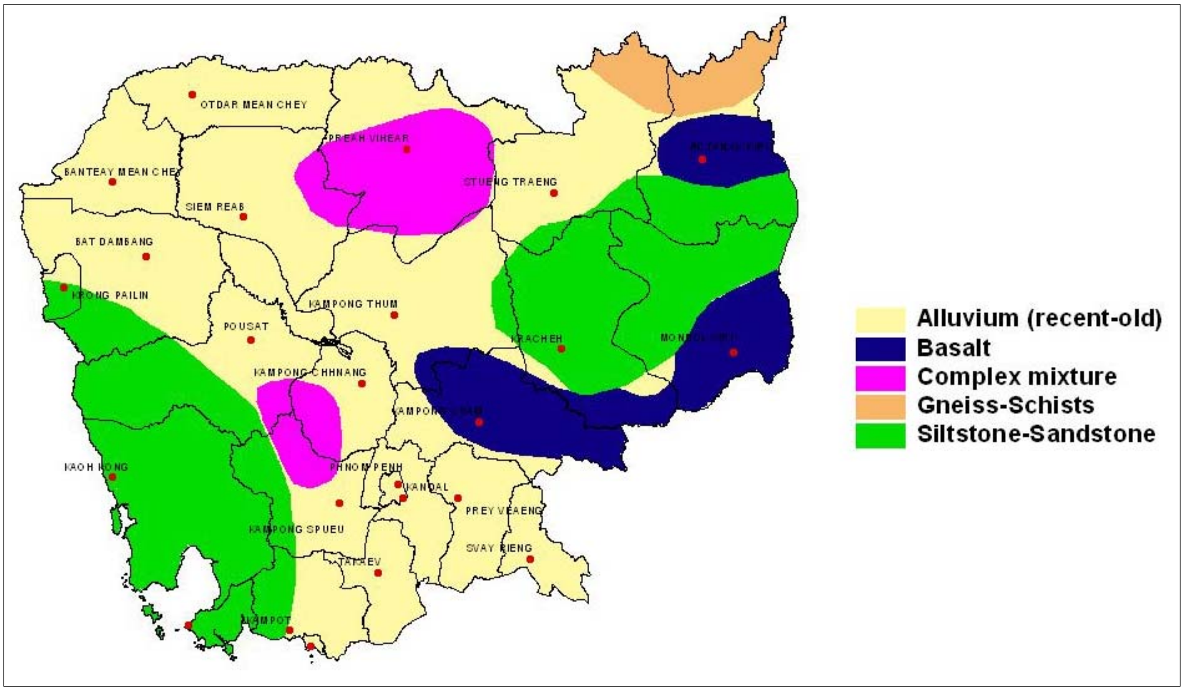
Map 7. Detailed Distribution of Geological Formations



Like most countries of Indochina, Cambodia is covered by a complex mosaic of different geological formations. In order to simplify this data, we have taken the chemistry and texture of different rocks into consideration, recognizing that plants must contend in different ways with these factors. We reason that the distribution of sandy, alluvial, basaltic, and rocky substrates (gneisses and schists) are highly relevant to the delineation gene-ecological, as these substrates vary considerably in their relative ages, water retention abilities, mineral retention, pH, and general chemical characteristics.

Alluvial soils in the Mekong and Tonle Sap River floodplains tend to retain water much better than rocky or sandy soils, and provide more minerals than the latter to soils. The upper layers of these soils are of relatively recent age, but older strata of similar character underlay the upper horizons. Conversely, basaltic soils characterize the low relief of the 'Redlands' ecozone (section 5.1.4) and the Eastern Mekong ecozone (section 5.1.8), and these tend to be much more acidic and fertile than alluvial soils. Plants that grow on both basaltic and alluvial substrates in the Redlands and Eastern Mekong floodplain, such as *Pterocarpus macrocarpus* (Table 5), are likely to exhibit very different racial characteristics. And in a similar vein, populations of *Diospyros crurnenata* that occur in basaltic regions of the Redlands and sandstones of the Northern Cardamoms (Table 5) are equally likely to exhibit distinctive characteristics.

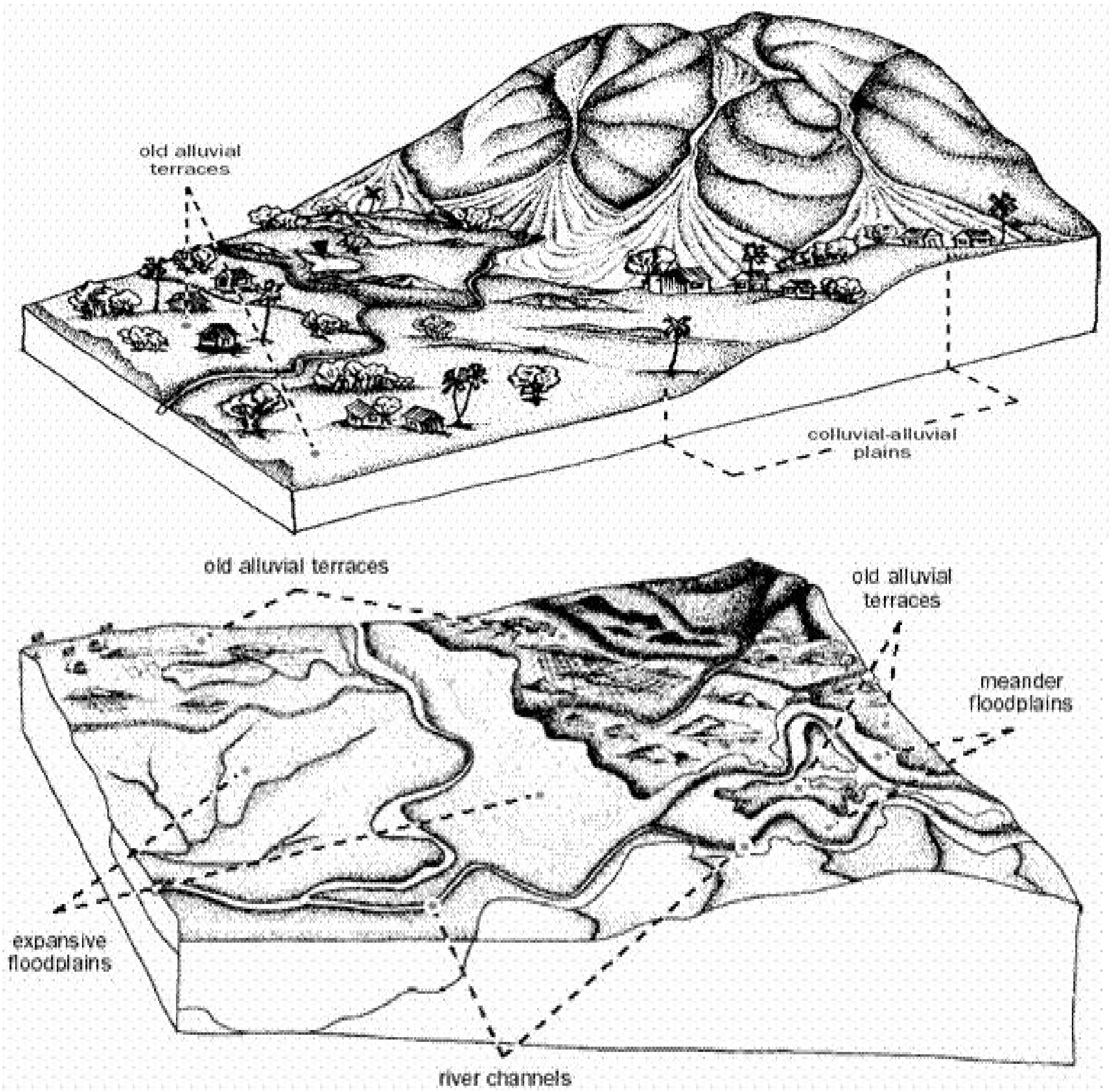
Map 8. Generalized View of the Geology of Cambodia



4.3.5 Soils

White and Oberthür (1997) recognize three fundamental physiographic regions in Cambodia on the basis of the age and general origins of soils. They distinguish regions that: (1) retain their original parent material (such as the Cardamom and Central Annamite Mountains; Maps 1, 7. 8, 13; see sections 5.1.1, 5.1.9), (2) are covered by ancient alluvial or colluvial plains (Figure 6 and Maps 7. 8; such as the Central Lowlands; 5.1.6), or (3) receive annual alluvial sediments (Tonle Sap Floodplain; section 5.1.3). Although the distributions of these three physiographic regions agree generally with the physiographic scheme that of Wharton (1968; Map 3), each of these physiographic categories is somewhat artificial in composition, as they comprise distinctive regions with various and sundry historical records and chemical characteristics.

Figure 6. Old Alluvial Terraces and Colluvial Floodplains



Crocker (1962) also recognizes three distinctive classes of soils in Cambodia, but circumscribes these classes of soil on the nature of their parent material, the impact of hydrological process on soils, as well as biological processes. He distinguishes these soil classes as follows:

1. Azonal: Soils without well-developed profile characteristics due to their youth, to conditions of parent material, and/or relief.

2. Hydromorphic intrazonal: Soils developed under the influence of the presence of excess water (marshes, swamps, seep areas, flats), due to the lack of drainage or high ground water.

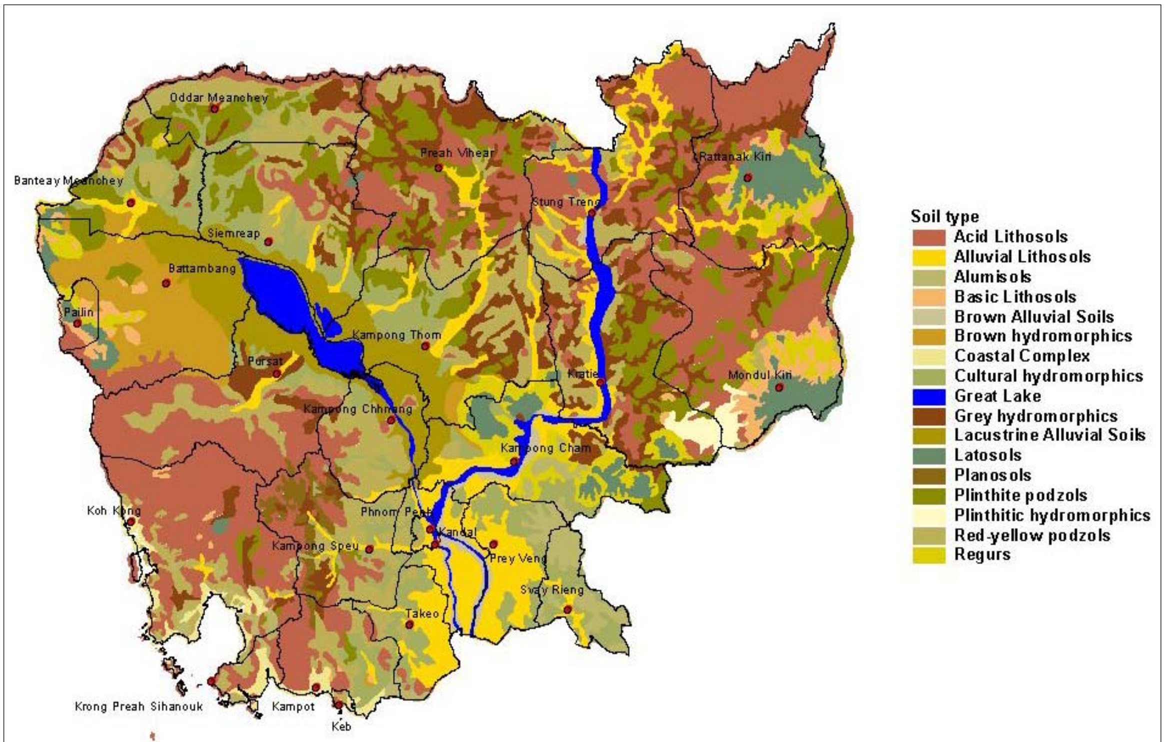
3. Lateric zonal: Soils having well developed soil characteristics that reflect the influence of active factors of soil formation, including climate, living organisms, vegetation, moisture, and such.

Within these three classes of soils, Crocker recognizes 16 subclasses (Table 4), and records their distribution in Cambodia (Map 9).

Table 4. Cambodian Soils by Formation

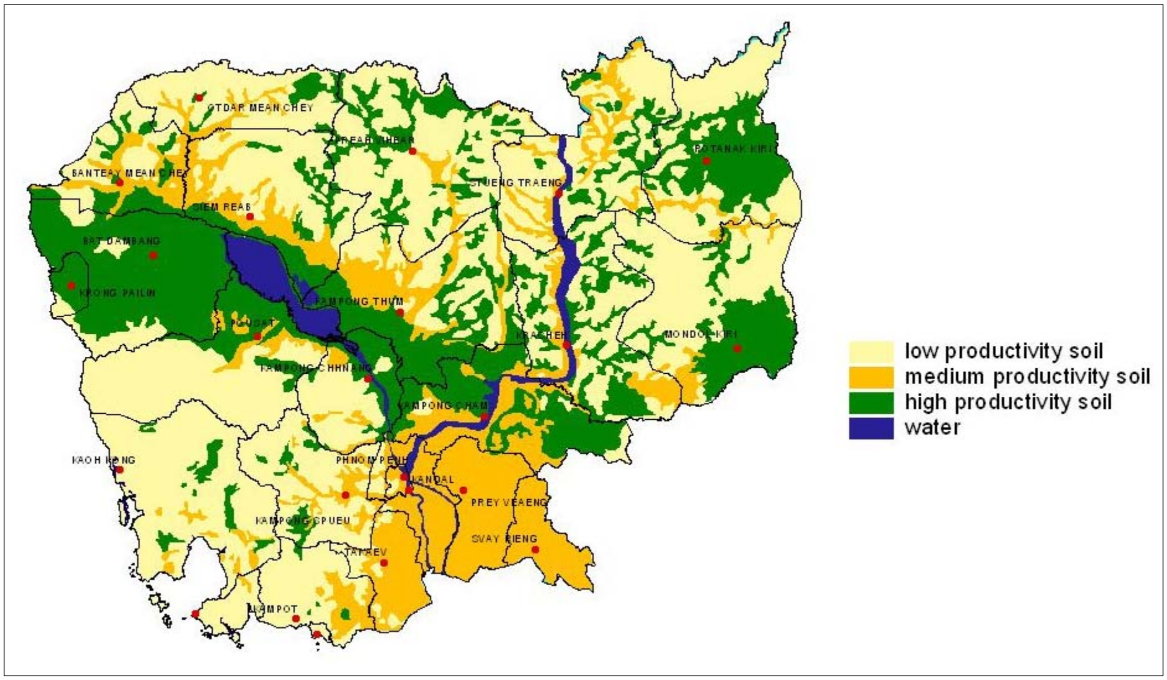
Azonal	Hydromorphic intrazonal	Lateric zonal
• acid lithosols • basic lithosols • alluvial lithosols • brown alluvial soils • lacustrine alluvial soils • coastal soil complex	• planosols • plinthite podsols • cultural hydromorphics • grey hydromorphics • plinthics hydromorphics • brown hydromorphics • alumisols • regurs	• red-yellow podzols • latosols

Map 9. Distribution of Soil Types in Cambodia (after Crocker 1962)



As is evident, soil types are often distinguished from each other on the basis of very subtle chemical differences or by varying degrees of alteration due to geological and biological processes. Hence classification schemes are often too detailed to be of direct relevance to our gene-ecological model. Nevertheless, plants often require distinctive types of soils, or otherwise demonstrate different growth rates on specific substrates.

Map 10. Generalized Distribution of Soil-fertility Classes



In order to simplify the complex system of Crocker (1962), we have used his data-base to recognize three distinctive types of soils in Cambodia. Based on Sanches FCC (1982), we provide a map that accounts for the distribution of soils that are fertile, moderately fertile, or infertile (Map 10). Appendix vi provides a conversion table that relates our fertility classification with Crocker's classification scheme.

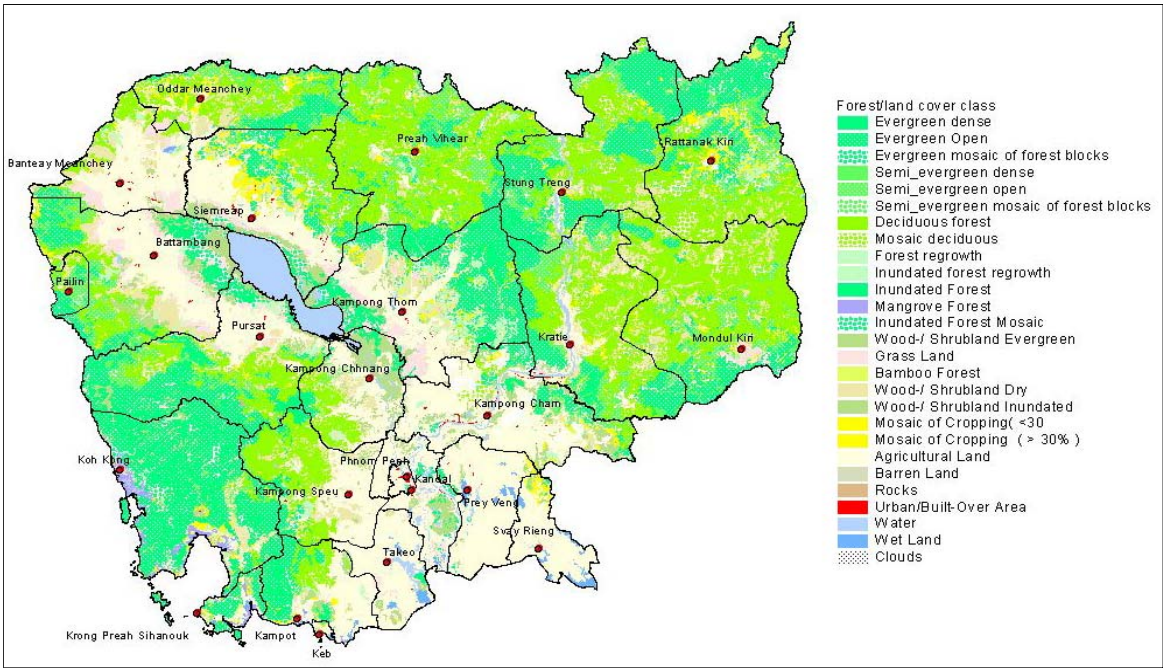
Since fertile lands are often invaded by human populations before infertile lands, this map provides an explanation for the distinctiveness of the Tonle Sap Floodplain and Redlands (sections 5.1.3, 5.1.4), both of which regions are now covered with highly degraded forests (Map 12). It also can be used to predict the eventual impact of a very important environmental factor, namely human populations.

4.3.6 Forest and Land Use Classification

The complexity of soils in Cambodia is equalled, if not exceeded, by the complexity of plant communities. Several generations of French botanists have attempted to develop classification schemes that account for Cambodia's diverse assemblage of plant communities, but no single scheme has emerged as a definitive system (see section 2.2). Different datasets and maps often refer to different categories of vegetation, and this poses a problem in comparing the results of these studies. Moreover, most datasets and maps are more than 10 years old, and somewhat obsolete due to the fast pace of deforestation.

The Cambodia Tree Seed Project has decided to make use of datasets on vegetation (1996/97), as the attendant maps to this study are the least dated. This study identifies 29 categories of vegetation, including 14 forested categories and 15 non-forested categories (i.e., land-use by human communities). Many categories that are defined by human activities (i.e., agricultural lands) have little bearing on germplasm sources or genotypic variation in timber-tree species.

Map 11. Detailed Map of Forest and Land Cover (1996-1997)

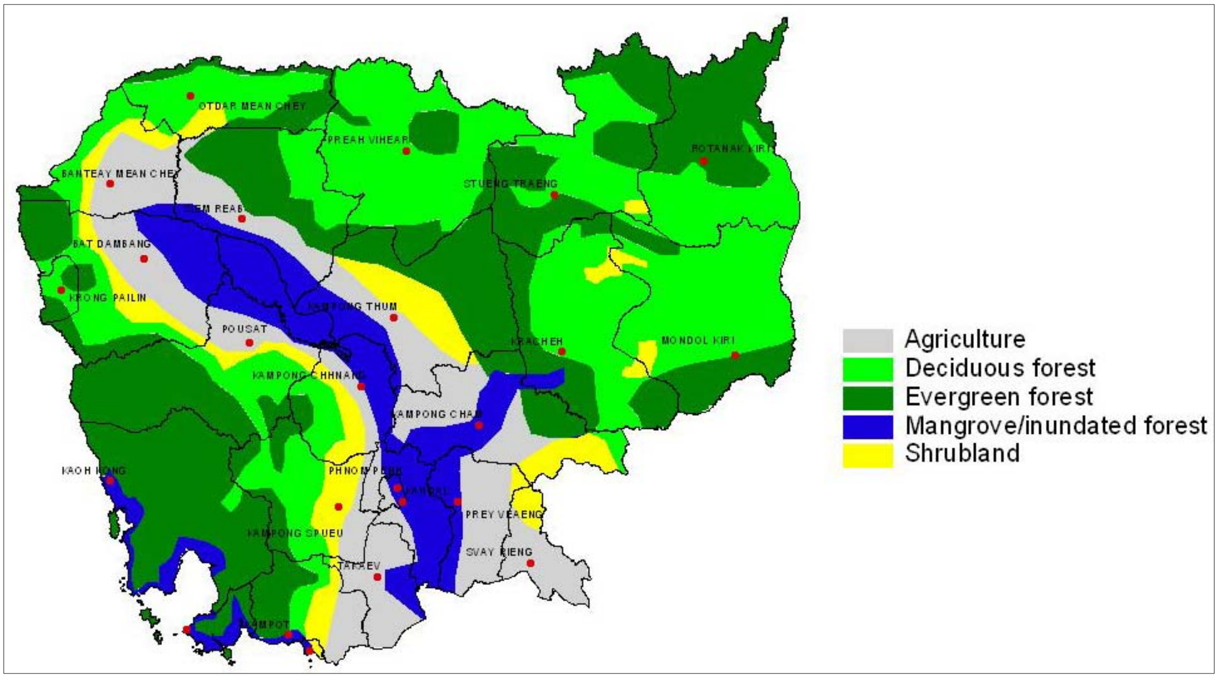


Source: DFW 1996-97

This particular classification scheme presents several difficulties in applying these data to our zonation system. It is difficult to say with certainty, for example, how one draws the line between a 'Semi-evergreen Dense' forest, 'Semi-evergreen Mosaic' forest, 'Open-evergreen' forest, or 'Wooded Shrubland Evergreen' Forest. As a consequence, we have attempted to simplify the classification by recognizing five general vegetative categories, including evergreen forest, deciduous forest, inundated forest (including mangroves), shrublands (both native and anthropogenic), and agricultural lands (Map 12). Appendix v provides a conversion table that translates the 1996 vegetation scheme into our simplified system.

Map 12 locates evergreen forests in mountainous terrains and along the northern boundaries of the Tonle Sap floodplain, while deciduous forests dominate lowlands throughout the country.

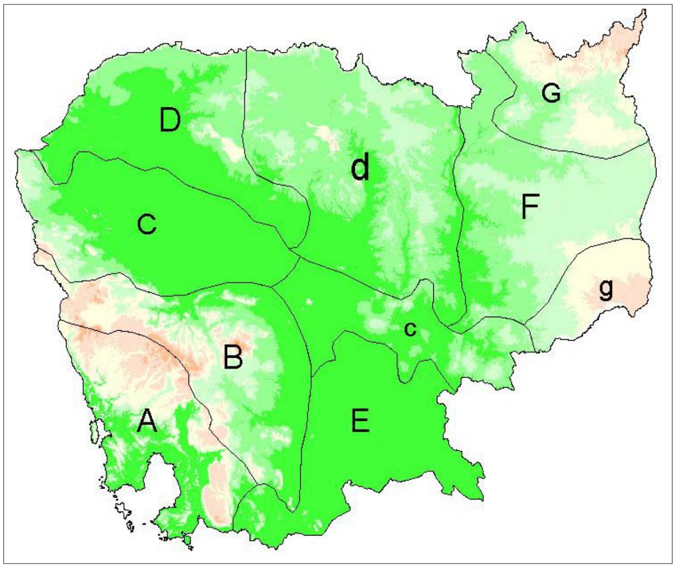
Map 12. Generalized Distribution of Vegetation in Cambodia



4.3.7 Delineation of Gene-Ecological Zones

As is evident, project resource persons have had to make a variety of pragmatic judgments on the weighting of ecological criteria in the process of delineating the boundaries of gene-ecological zones. These individuals include Mr. So Thea (Project Manager), Mr. Ma Soktha (Head of Reforestation Office), Mr. Sok Srun (Project Officer), Mr. Arvid Sloth (Danida Advisor), and Mr. Ignas Dümmer (DED Advisor). The decisions of these individuals were often made, however, after consultations with other resource persons. As a result, 7 distinctive Gene-Ecological Zones (and 3 sub zones) have been defined geographically (Map 13) and described in a biological/ecological context (Section 5).

Map 13. Distribution of Gene-Ecological Zones



5. Results of the Gene-Ecological Zoning System in Cambodia

Based on the foregoing, brief descriptions are provided for 10 gene-ecological zones of Cambodia, including commentaries on the geographical, geological, climatic, and biological character of each region. The descriptions include a listing of high priority tree species that occur in each zone, and a summarization of species distributions across gene-ecozonal boundaries (Table 5). As earlier noted, the Cambodia Tree Seed Project aspires to record at least two unique seed sources for every priority species that is represented in a gene-ecological zone. Thus, the forementioned table also indicates which gene-ecological zones include only a single seed source for a specific species, so as to encourage the search for additional germplasm sites.

5.1 BIOLOGICAL AND GEOGRAPHICAL CHARACTER OF GENE ECOZONES

5.1.1 <u>Coastal Cardamoms</u> (A)

Geography: The Coastal Cardamom Gene-Ecological Zone comprises only 9% of Cambodia's land-cover, yet it represents one of the more distinctive and species-rich ecozones of Indochina. This zone stretches across the coastal piedmont and windward slopes of the Cardamom Mountains, and encompasses a series of discontinuous, but geologically related ranges, including the Kravanh Mountains, Kirirom Plateau and Elephant Mountains (Phnom Damrei). The southern boundary of this zone follows Cambodia's southern coastal zone from Koh Kong to Kampot, while the northern boundary is defined by high ridges and slopes that drain rainfall into the Gulf of Thailand (Maps 2, 3, 13). This zone is now gazetted for protection, owing primarily to high species diversity in the region. Nevertheless, the lower coastal foothills have suffered extensive degradation during the past two decades.

Determinant Environmental Factors: The Coastal Cardamom Gene Ecozone is delineated on the basis of its high-montane topography, high annual precipitation (2600-3800 mm, or more), and sandstone or sandy conglomerates. The region is colder than other regions of Cambodia, owing to the height of these mountains, various ridges and peaks of which reach from 1000-1700 m. These regions are lost in a mantle of dense cloud cover during most of the year, and are inhabited by vegetation that has yet to be characterized. The soils of this zone are very poor in retaining water and minerals, but abundant and continual precipitation in the region provides ample water for tall and dense, evergreen forests. The only other ecozone in Cambodia that compares in altitude is the Central Annamite ecozone (see below), but this massif is distinguished by its distinct substrates and a well-defined dry season.

Plant and Vegetative Characteristics: Important timber trees of the lowland Evergreen Forests include a diverse assemblage evergreen forest species, including members of the following genera: *Anisoptera*, *Calophyllum*, *Hopea*, *Lithocarpus*, *Palanquium*, *Pterospermum*, *Syzygium*, *Shorea* (Boyce, P., Eanghourt K., & Sophal M, 2002). These plant groups are replaced by a different assemblage of plants on the upper slopes of the mountains (>700 m), including species of *Castanopsis*, *Lithocarpus*, *Syzygium*, and *Tristania*. These elements characterize the wet-montane Evergreen Forests of the zone. The lowland forests of the Coastal Cardamom Mountain Ecozone once engendered some of the largest trees and forest canopies in Cambodia, but only residues of this productive habitat now exist due to clear-cutting practices. Although the coastal zones of the Cardamoms are now secondary, we are safe in assuming that they still conserve a variety of young 'priority trees' (see below). This region is likely to produce plants whose seeds, seedlings, and adult plants exhibit little resistance to drought.

Priority Species: *Afzelia xylocarpa* (Kurz) Craib., *Albizia lebbeck* (L.) Benth. (one source), *Aquilaria crassna* Pierre, *Dalbergia cochinchinense* Pierre (one source), *Diospyros bejaudii* Lecompte (one source), *Dysoxylon louriei* Pierre, *Fagraea fragrans* Roxb., *Hopea odorata* Roxb., *Pinus merkusii* Jungh et de Vries, *Shorea cochinchinense* Pierre.

5.1.2 Northern Cardamoms (B)

Geography: The Northern Cardamom zone ranges across the leeward side of the Cardamom Mountains. The region is bordered to the North by the Tonle Sap Floodplain, and to the South the cloud-laden highlands of the Coastal Cardamom Ecozone. The eastern boundary is marked by the low alluvial plains of the Lower Mekong Floodplain Ecozone, where agricultural communities have removed all traces of its original woodlands. The Northern Cardamom Mountain Ecozone is slightly larger than the Coastal Cardamoms, covering around 12% of Cambodia's land surface.

Determinant Environmental Factors: The Northern Cardamom ecozone is distinguished from the Coastal Cardamoms on the basis of lower annual rainfall (800-1400 mm p.a.), and an extended dry season that often lasts for more than 4 months. A mixture of different soils can be found in this region, most notably Cretaceous sandstones. Nevertheless, a large granite outcrop dominates the highest and eastern-most reaches of the range (i.e., Mount Aural and environs). Like the coastal regions of the Cardamoms, the soils of the Northern Cardamoms are poor in retaining water and minerals.

Plant and Vegetative Characteristics: In response to drier climates and soils, the vegetation of the Northern Cardamoms is less robust and diverse than that of the coastal plains. Most forests are deciduous, and drop their foliage for over 4 months of the year. They produce timber trees of both primary and secondary quality, including species of *Anisoptera*, *Dipterocarpus*, *Ficus*, *Guttifera*, *Irvingia*, *Pahudia*, *Tetrameles*, and *Shorea* (Boyce, P., Eagnhourt K., & Sophal M, 2002).

Priority Species: *Afzelia xylocarpa* (Kurz) Craib., *Aquilaria crassna* Pierre, *Cananga latifolia* (Hook. F. & Thomson) Finet & Gagnep. (one source), *Dalbergia cochinchinense* Pierre (one source), *Dalbergia oliveri* Gamble (one source), *Diospyros bejaudii* Lecompte, *Diospyros cruenata* Thwaites (one source), *Dysoxylon loureiri* Pierre (one source), *Fagraea fragrans* Roxb. (one source), *Gardenia angkorensis* Pit., *Hopea helferi* (Dyer Brandis), *Pinus merkusii* Jungh et de Vries, *Pterocarpus macrocarpus* Kurz, *Shorea cochinchinense* Pierre (one source).

5.1.3 Tonle Sap Floodplain (C)

Geography: The Tonle Sap floodplain includes the largest wetland habitat of Southeast Asia and extensive 'flooded forests.' Only vestiges of a once expansive semi-evergreen forest remain on the outer boundaries of contemporary floodplains (Maps 11, 12). Due to strict controls over the flooded forest of Tonle Sap Lake by fishery concessionaires, very few people inhabit the floodplain of this important body of water. As a consequence, vast flooded forests surround and sustain one of the world's most productive freshwater fisheries (McDonald et al. 1997). The boundaries of the Tonle Sap Floodplain ecozone extend from the northern base of the Cardamom Mountains to the southern boundary of the Northwestern and Central lowland zones. The region comprises about 11% of Cambodia's land surface.

Determinant Environmental Factors: Seasonal rains are a determinant environmental factor on the Tonle Sap Floodplain. The region receives only 800-2000 mm per year, this falls exclusively during the wet season. This water-source is negligible, however, to the vast amounts of water which pour into the region from the Mekong River. Rising Mekong River floodwaters wash over this central region of Cambodia on an annual basis, and thereby inundate a highly specialized forest that is adapted to seasonal floods. In the process, Tonle Sap Lake rises in depth by a factor of seven, and doubles its area by a factor of two. Extensive short-tree forests that surround the Tonle Sap Lake are submerged by floodwaters from 2-6 months a year. When this occurs, native trees drop their leaves, and suspend all growth until the lake-waters recede. As such, most woodlands of the Tonle Sap floodplain are deciduous forest, but of a type that is quite distinct from the lowland deciduous forest that dominate Cambodia. While most of Cambodia is flourishing due to the yearly onset of rains, the Tonle Sap floodplain goes dormant. And while most of Cambodia is suffering drought, the Tonle Sap floodplain is springing to life. Hence the phenology of the flooded forest is out of synchrony with other types of forests in Cambodia.

Although the productive nature of this region is governed primarily by annual floodwaters, most of the zone is also susceptible to *drought* for at least six months of each year. The soils of the Tonle Sap Floodplain gene-ecozone are distinctive from its mountainous southern boundaries, as they are covered by alluvial soils, the upper surface of which is obviously of relatively recent origin. These soils are relatively rich in nutrients, which accounts, albeit indirectly, for the substantial fish production of the region.

Plant and Vegetative Characteristics: This zone consists of high forests in the Battambang, Pailin and Pursat areas. However, considerable part of this zone is made up by the flooded vegetation of the Tonle Sap Floodplain and is represented by different types of forest. One observes a tall, riparian forest (or marsh-forest) along the minor tributaries and lower floodplain of Tonle Sap Lake. Timber trees in these regions are few in number (i.e., *Barringtonia*, *Coccoceras*, *Combretum*, and *Diospyros*; McDonald et al. 1997). On the other hand, the upper floodplain produces a thorn-forest of short stature, co-dominated by *Gmelina*, *Hymenocardia*, and *Vitex*. These trees are employed in the region as an energy source for smoking fish. Paradoxically, these flooded-forest plants are adapted primarily to dry conditions, as they are exposed to a combination of light and water for only two or three months of the year. Hence, the trees are small in stature (1-4 m tall), branch from the base, and tend to produce small leaves and thorns. These trees are employed in the region as an energy source for smoking fish, but various timber-trees of considerable significance to local communities are also present.

Priority Species: *Afzelia xylocarpa* (Kurz) Craib.

5.1.4 <u>Redlands</u> (c)

Geography: The Redlands Gene-Ecozone can be interpreted as an eastern extension of the Tonle Sap Floodplain Ecozone. This region has a geological history that is more complex to the Tonle Sap floodplain, however, and lacks extensive aquatic habitats. The Redlands conserve only remnants of its original forests due to incursions of agricultural communities. The zone's northern borders are defined by the mountains and woodlands of the Central Lowland Ecozone, the Eastern Mekong Basin Ecozone, and Southern Annamite Ecozone. Its southern boundary is bordered by the Lower Mekong Floodplain, with which it shares many general landscape features (i.e., rice paddies!). It is distinguished, however, from the Lower Mekong Floodplain by virtue of its predominant igneous, fertile soils (Maps 8, 10). This gene-ecozone covers a mere 7% of Cambodia's land-cover, only minor portions of which still retain some forest cover.

Determinant Environmental Factors: The Redlands Ecozone is characterized generally by the interactions of three over-riding environmental factors: a monsoon climate, alluvial soils of the Mekong River, and relatively recent igneous flows that have transformed the chemical character of the soils. The region receives more water than other lowland regions of Cambodia (1400-2600 mm p.a.), which makes the region conducive to rice agriculture. The main characteristic that distinguishes this region, however, are igneous (basaltic) intrusions that render the soil more fertile, and therefore more desirable to agriculturalists. Still, about half of the region is covered with alluvia that also characterize the floodplains of the Mekong River (Map 7).

Plant and Vegetative Characteristics: Rice fields dominate this region of Cambodia. Although there are no detailed botanical descriptions of this zone in the literature, vestiges of once widespread forests in the eastern portion of the zone still exist.

Priority Species: *Diospyros bejaudii* Lecompte (one source), *Hopea helferi* (Dyer) Brandis (one source), *Hopea odorata* Roxb. (one source), *Pterocarpus macrocarpus* Kurz (one source), *Shorea cochinchinense* Pierre (one source).

5.1.5 Northwestern Lowlands (D)

Geography: Comprising about 11% of Cambodia's land-cover, the Northwestern Lowland Gene Ecozone forms part of an extensive lowland landscape that lies between the linear Dangrek Mountain chain on the northern frontiers of Cambodia, and the upper-most reaches of the Tonle Sap floodplain. The southwestern corner of this region generally follows the floodplain of Tonle Sap Lake, while the eastern boundary is demarcated (somewhat arbitrarily) by the Central Lowland Ecozone.

Determinant Environmental Factors: A defining factor that determines the boundaries of the Northwestern Lowlands is water availability. This region experiences a relatively long and intensive dry season, and therefore tends to engender slower-growing forests that are adapted to water stress. The region receives only 800-1400 mm of precipitation annually. Due, however, to the ancient alluvial soils that have settled in the basin, agricultural lands and forests coexist in this isolated region of Cambodia. Human populations have played a substantial role in this ecozone, as rice fields predominate in the southern regions of the zone.

Plant and Vegetative Characteristics: Lowland semi-evergreen forests in this region of Cambodia are dominated by *Irvingia*, *Mimosops*, *Pahudia*, *Pterocarpus*, *Shorea*, *Sindora*, and *Vitex*. Lowland deciduous forests are dominated by various *Diospyros*, *Dipterocarpus*, *Irvingia*, *Lagerstroemia*, *Pterocarpus*, and *Tetrameles* (Legris & Blasco, 1972; Rollet 1972).

Priority Species: *Afzelia xylocarpa* (Kurz) Craib., *Cananga latifolia* (Hook. F. & Thomson) Finet & Gagnep., *Dalbergia cochinchinense* Pierre, *Dalbergia oliveri* Gamble, *Diospyros bejaudii* Lecompte (one source), *Diospyros cruenata* Thwaites, *Gardenia angkorensis* Pit., *Hopea helferi* (Dyer) Brandis, *Hopea odorata* Roxb (one source).

5.1.6 Central Lowlands (d)

Geography: The Central Lowland Gene-Ecozone includes some of the most important timber production zones of Cambodia, and comprises the largest gene-Ecological zone (ca. 18%). This lowland basis provides a natural reservoir for waters that drain into the Tonle Sap and Mekong Rivers. A network of slow-moving rivers wind their way through the region and provide a steady supply of water to semi-evergreen, deciduous, and marsh-forests. The northern boundary of this ecozone is defined by the narrow Dangrek Mountain-chain, while the eastern boundary of the zone is defined by the Mekong River. The southern border merges with the agricultural lands of the Redland gene ecozone. A poorly defined western border interfaces with the Northwestern Lowlands, the latter of which is distinguished primarily by its lower annual rainfalls and homogeneous soil types.

Determinant Environmental Factors: The tropical vegetation of the Central Lowlands is as complex as the distinctive water regimes (mostly 1400-2000 mm per year; Map 4) and soil types (Map 7, 8). Not unlike the Northwestern Ecozone, the Central Lowland Ecozone is covered primarily with fertile alluvial soils of various ages. Nevertheless, the heart of the region also includes substantial outcrops of sandstones and rhyolites (immediately S of Preah Vihear: Map 7). Numerous rivers that cut across the zone establish fertile riparian and floodplain habitats, and these tend to engender tall tropical forests that are very productive, and often classified as either evergreen or semi-evergreen vegetation. Unfortunately, forestry practices in this region have yet to prove sustainable.

Plant and Vegetative Characteristics: Lowland semi-evergreen forests in this region of Cambodia are dominated by *Irvingia*, *Mimosops*, *Pahudia*, *Pterocarpus*, *Shorea*, *Sindora*, and *Vitex*. Lowland deciduous forests are dominated by various *Diospyros*, *Dipterocarpus*, *Irvingia*, *Lagerstroemia*, *Pterocarpus*, and *Tetrameles* (Legris & Blasco, 1972; Rollet 1972).

Priority Species: *Albizia lebbeck* (L.) Benth., *Afzelia xylocarpa* (Kurz) Craib., *Cananga latifolia* (Hook. F. & Thomson) Finet & Gagnep., *Cinnamomum cambodianum* Lecompte (one source), *Dalbergia cochinchinense* Pierre, *Dalbergia oliveri* Gamble, *Dasymaschalon lamentaceum* Finet et Gagnep. (one source), *Diospyros bejaudii* Lecompte, *Dysoxylon loureiri* Pierre, *Fagraea fragrans* Roxb., *Garcinia hanburyi* Hook. f., *Gardenia angkorensis* Pit., Hopea helferi (Dyer) Brandis, *Hopea odorata* Roxb., *Lasianthus kamputensis* Pierre ex Pit., *Pinus merkusii* Jungh et de Vries, *Pterocarpus macrocarpus* Kurz, *Shorea cochinchinense* Pierre.

5.1.7 Lower Mekong Floodplain (E)

Geography: The Lower Mekong Floodplain Gene-Ecozone covers about 10% of Cambodia's land-cover and is known primarily for its agricultural lands. Only small remnants of an ancient lowland forest can be found in the region today. Large human populations have settled here on account of the regions fertile alluvial soils and predictable sources of water for crops (i.e., the Mekong River). Natural and anthropogenic grasslands (mostly comprised of rice) stretch from Kampong Cham to the Mekong River Delta system of southern Vietnam.

Determinant Environmental Factors: The strong influence of seasonal droughts and the constant flow of the Mekong River define the general character of this gene-ecozone. Although the region only receives from 800-2000 mm annually, human inhabitants are often able to make good use of waters from the Mekong River. Even though the Mekong River does not begin to branch out until its crosses the Cambodia-Vietnam border, the river's meandering flow over geological time has endowed the Lower Mekong Floodplain with moderately fertile, alluvial soils. At this point in time, many parts of this ecozone exhibit the aspect of a desert during the dry season, owing to deforestation and the inability of people to irrigate their agricultural lands. Substantial annual rainfalls allow, however, for a reliable harvest of rice once a year.

Plant and Vegetative Characteristics: Rice paddies dominate this terrain, but rivers, lakes, and aquatic sinks serve as refugia for native riparian tree species and assorted grasses and sedges.

Priority Species: *Dalbergia oliveri* Gamble.

5.1.8 Eastern Mekong Basin (F)

Geography: The Eastern Mekong Basin Gene Ecozone forms a natural continuation of the Central Lowland Ecozone, but it can also be distinguished by its high annual rainfalls and unique substrates. This ecozone is defined by two important physiographic features of Cambodia and Vietnam, namely the Mekong River and the Annamite Moutaints. Covering only 13% of Cambodia's land surface, the western boundary of the Eastern Mekong Basin is delimited by the Mekong River, the northern boundary by a westward extension of the Central Annamite Mountains, the southern boundary by a westward extension of the Southern Annamites, and the eastern boundary by the backbone of the Annamites in Vietnam. Indeed, eastern portions of this gene-ecozone encompass the foothills to this prominent mountain system. Like the Central Lowlands of Cambodia, this region has relatively low relief, and drains the water it receives toward the Mekong River by a complex system of slow-moving rivers. These waterways serve to distribute water throughout an otherwise seasonally dry region.

Determinant Environmental Factors: The region as a whole receives a considerable amount of monsoonal rains (2000-2600), but rains tend to operate on a rigid monsoonal calendar. As a result, the vegetation is leafless and dormant for over half the year, and often broken up by a patchwork of natural and anthropogenic grasslands. The western half of the zone is formed by alluvial soils that have been laid down by the Mekong River and its tributaries over the course of millions of years. The eastern-half is comprised primarily of shallow, sandstone and siltstone plateaus, which do not retain water. The strong seasonality of precipitation in this region, in concert with the dry-sandy soils, often engenders vegetation that is dominated locally by grasslands or woodland-savannahs, making the region unique not only in its vegetation but also animal life (i.e., substantial herds of grazers).

Plant and Vegetative Characteristics: Most of the forests of the Eastern Mekong Basin are deciduous, and important for the production of several luxury and primary timbers, such as *Dalbergia*, *Dipterocarpus*, *Pterocarpus*, and *Shorea*,. Other co-dominant trees include *Irvingia*, *Pentacme*, and *Terminalia* (Legris & Blasco, 1972; Rollet 1972).

Priority Species: *Dasymaschalon lamentaceum* Finet et Gagnep. (one source), *Diospyros cruenata* Thwaites (one source), *Pterocarpus macrocarpus* Kurz .

5.1.9. Central Annamites (G)

Geography: The Central Annamite Gene-Ecozone is defined by a western intrusion of the 'Kontum Massif.' This formation extends across the Central Annamites. The zone covers a mere 6% of Cambodia, but includes a very distinctive biological and cultural region of Cambodia. The ecozone is bordered on its North by Laos, to the East by Vietnam and the Annamite Mountains, and to the south by the East Mekong Basin Zone.

Determinant Environmental Factors: This ecozone is defined primarily by the distinct character of the Central Annamites. Cool temperatures prevail in higher altitudes (700-1500 m), and soils in the northern half of this region are comprised of gneisses, schists, and plutonic rhyolites. In contrast, the southern boundaries of the ecozone are characterized by basaltic flows. Substantial rains in the region (2000-2600 mm p.a.) account for its extensive forests. This range in precipitation probably exceeds the 2600 mm mark on a regional basis. These mountainous regions of Cambodia are affected by monsoonal cycles, however, and operate on a schedule that differs considerably from that of the Cardamom Mountains of Southwest Cambodia. The rocky substrates of the northern regions are poor in mineral content, and therefore undesirable for agricultural purposes. The southern regions are formed, however, by relatively recent igneous activities, and are therefore fertile and productive for farmers. Hence human populations are much larger in these regions.

Plant and Vegetative Characteristics: There are no available reports on the character of the forests in this region of Cambodia. Suffice to say that most of the forest is evergreen or semi-evergreen, montane forest, and are undoubtedly dominated by the same plant genera that are found in the Central Annamites of Vietnam.

Priority Species: *Albizia lebbeck* (L.) Benth., *Afzelia xylocarpa* (Kurz) Craib., *Cananga latifolia* (Hook. F. & Thomson) Finet & Gagnep. (one source), *Cinnamomum cambodianum* Lecompte, *Dalbergia cochinchinense* Pierre (one source), *Dalbergia oliveri* Gamble, *Dasymaschalon lamentaceum* Finet et Gagnep. (one source), *Diospyros cruenata* Thwaites, *Hopea helferi* (Dyer) Brandis (one source), *Pterocarpus macrocarpus* Kurz, *Shorea cochinchinense* Pierre, *Sterculia lycnophora* Hance.

5.1.10 Southern Annamites (g)

Geography: The Southern Annamite Ecozone is the smallest of all ecozones, covering only 3% of Cambodia. The zone is formed by a small mountain intrusion of Vietnam's Annamitic complex into the South-central corner of Cambodia. The region is bordered to the north by lowlands of the Eastern Mekong Basin, and to the South and East by the mountainous boundary of Vietnam.

Determinant Environmental Factors: Soil type and topography distinguish the Southern Annamite Gene Ecozone from others. Moderately high mountains (700-1000 m) are responsible for the cooler temperatures of this region, and substantial monsoonal rains that can amount to 2600 mm per year (Map 4). The region is also distinguished by large expanses of igneous rock that extend into the Southern Annamite Mountains of Vietnam.

Plant and Vegetative Characteristics: There are no existing descriptions of this region of Cambodia. Schmid's (1974: 66-70) vegetation studies on the basaltic regions of the southern Annamites are probably relevant here. Subdominant genera include *Dipterocarpus*, *Hopea*, *Lagerstroemia*, *Pometia*, *Pterospermum*, *Terminalia*, and *Tetrameles*.

Priority Species: *Aquilaria crassna* Pierre (one source), *Cananga latifolia* (Hook. F. & Thomson) Finet & Gagnep. (one source), *Dalbergia cochinchinense* Pierre (one source), *Dasymaschalon lamentaceum* Finet et Gagnep. (one source), *Diospyros bejaudii* Lecompte (one source), *Fagraea fragrans* Roxb., *Hopea helferi* (Dyer) Brandis (one source), *Hopea odorata* Roxb. (one source), *Pinus merkusii* Jungh et de Vries (one source), *Pterocarpus macrocarpus* Kurz (one source), *Shorea cochinchinense* Pierre (one source).

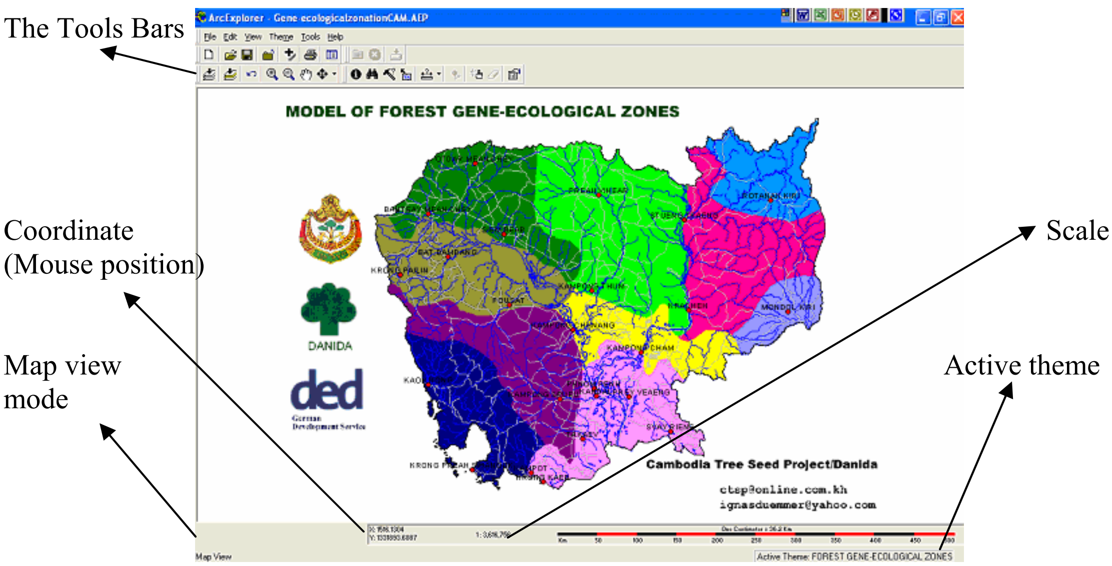
TABLE 5. Distribution of Priority Species in Gene Ecozones*

Species	Gene-Ecological zones									
	A	B	C	c	D	d	E	F	G	g
Afzelia xylocarpa	X	X	X	X	X	X			X	
Albizia lebbeck	**X**					X			X	
Aquilaria crassna	X	**X**				**X**				**X**
Cananga latifolia		X			X	X			**X**	**X**
Cinnamomum cambodianum									X	
Dalbergia cochinchinense	**X**	**X**			X	X			**X**	**X**
Dalbergia oliveri		**X**			X	X	X		X	
Dasymaschalon lamentaceum						**X**		**X**	**X**	**X**
Diospyros bejaudii	**X**	X		**X**	**X**	X				**X**
Diospyros cruenata		**X**			X			**X**	X	
Dysoxylon loureiri	X	**X**				X				
Fagraea fragrans	X	X				X				X
Garcinia hanburyi						X				
Gardenia angkorensis		X			X	X				
Hopea helferi		X		**X**	X	X			**X**	**X**
Hopea odorata	X			**X**	**X**	X				**X**
Lasianthus kamputensis						X				
Pinus merkusii	X	X				X				**X**
Pterocarpus macrocarpus		X		**X**		X		**X**	X	**X**
Shorea cochinchinense	X	**X**		**X**		X			X	**X**
Sterculia lychnophora									X	

* Dark '**X**'s denote a single seed source already established

6. Use of Gene-Ecological Zonation Model

This model generates information about specific locations in Cambodia. The information of this system can be selected by using series of queries, and exported to Excel or visualized on a screen. Much of the information relates to maps, and can be accessed or printed out in this format. As noted in section 5, information regarding annual average rainfall (classes 200mm/600mm/average), length of dry seasons (4 month intervals), minimum temperature (lower of higher than 16.5 ^{o}C), soil fertility (low, medium and high fertility), geology (sand-siltstone, gneiss-schists, basalt, old/ new alluvium, complex mixture) and types of vegetation (agriculture land, shrub land, deciduous forest, evergreen forest, mangrove/inundated forest) can be investigated according to Provinces, Districts and Communes. There are a total of 8220 specified areas in the model.

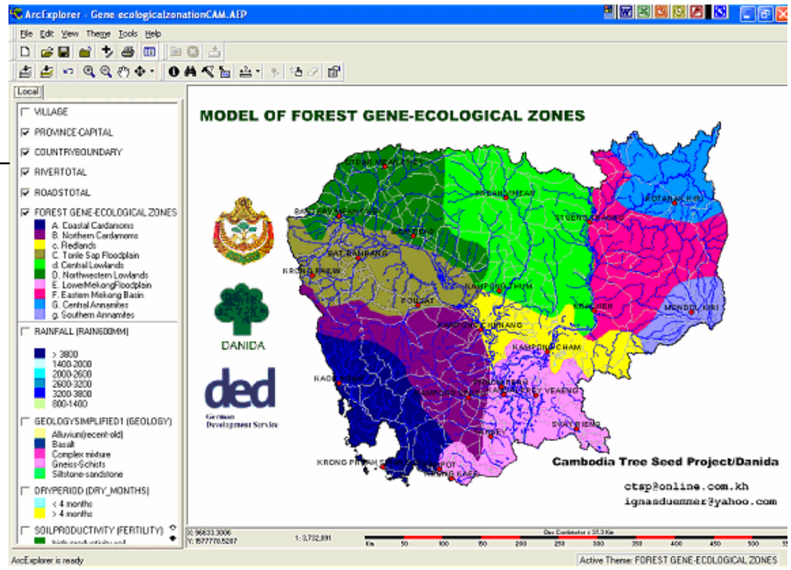


Screen 1. *Map view mode of the Forest Gene-Ecological-zoness model.*

The Map View mode is the section of the interface where you display, explore, query and analyze geographic data. The Tools Bars display buttons to generate a command. It allows for the use of standard tools, map tools, theme tools, and www tools. Coordinates are shown to the lower left bellow (in UTM, Indian Thailand). Details relating to the functions of the Tool Bars can be found in the help function within the ArcExplorer program.

Screen 2 displays the Explorer view mode (view, toggle legend), and allow the user to access maps that outline the gene-ecological zonation system. The model uses different features to visualize the maps, and the selection of one or more features is possible by using the query builder (the hammer symbol) (**"A query expression is a precise definition of what you want to select").**

Active theme



Screen 2: *Explorer view mode of the Forest Gene-Ecological-zoness model.*

The following pages will discuss the three possible ways in which to select areas of interest:
A. Selection of an area that employs the Query tool ( )
B. Selection of areas based on coordinates using identify option ( ).
C. Selection of areas based on tree specific characteristics (reports).

The feature/fields are as follows:

Name feature	Description	Comment
CODEKHUM	Commune unique number	(used for < and >)
CODESROK	District unique number	(used for < and >)
CODEDKHETt	Province unique number	(used for < and >)
COMMUNE	Commune name (in English)	
SROK	District name (in English)	
KHET_ENG	Province name (in English)	
DRY_MONTHS	Period of dry monts (more or less than 4 months)	Use = option in query buider
ECOZONE	Unique number gene-ecological zone	
ECO_ZONE	Name of gene-ecological zone	e.g. A. Coastal Cardamoms
FERTILITY	Low/medium/high productivity soil	
RAIN600mm	600 mm rain classes	

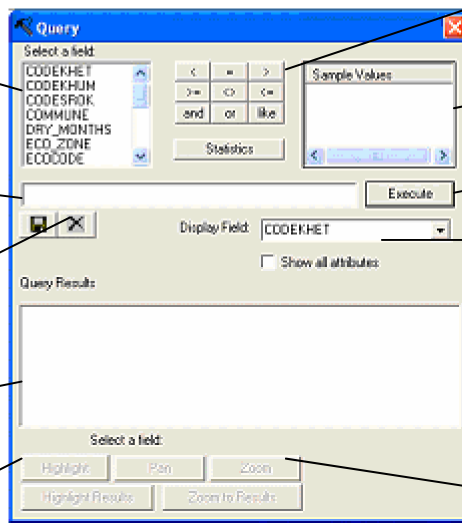
RAINFINE	200 mm rain classes	
RAINAV	Average rainfall	(used for < and > query)
MINTEMP	Temperature (average/month) (lower/higher than 16.5 ^{o}C).	
HECTARES	Area size in ha.	Area of smallest part

6.1 Selecting an area by using the Query tool ( )

Sample Question: Where are the areas with high fertility soils, high rainfall (> 2100 mm) with evergreen forest? And how does one calculate the cover area (by hectares) of this selected region?

1. Make sure that the theme (map layer) you wish to query is activated (see right corner). For this model, “Forest Gene-ecological Zones” should be active.

2. Click the Query tool ( ) and the Query builder opens.



The Query builder dialog

The Query Builder dialog lets you build the query expression by either clicking on fields, operators, or values. One may also type in these specific queries.

3. From the list of fields, click **FERTILITY** to enter it into the expression.

4. Click the Equal button and enter the ‘=’ operator into the expression.

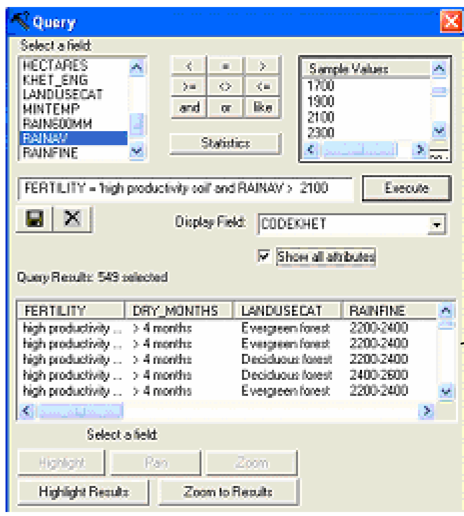
5. Click **“high productive soils”** from the Sample Values list.

6. Click the Execute button. Features that meet the query definition appear in the Query Results panel.

7. Click the Execute button. Press **Show all attributes** if you want to see the content of all selected areas.

Now you want to select areas with an average rainfall higher than 2100 mm within this high productive soil.

8. Adjust the query definition and add **and RAINAV** > **2100;** click the **Execute** button again.



All attributes are shown

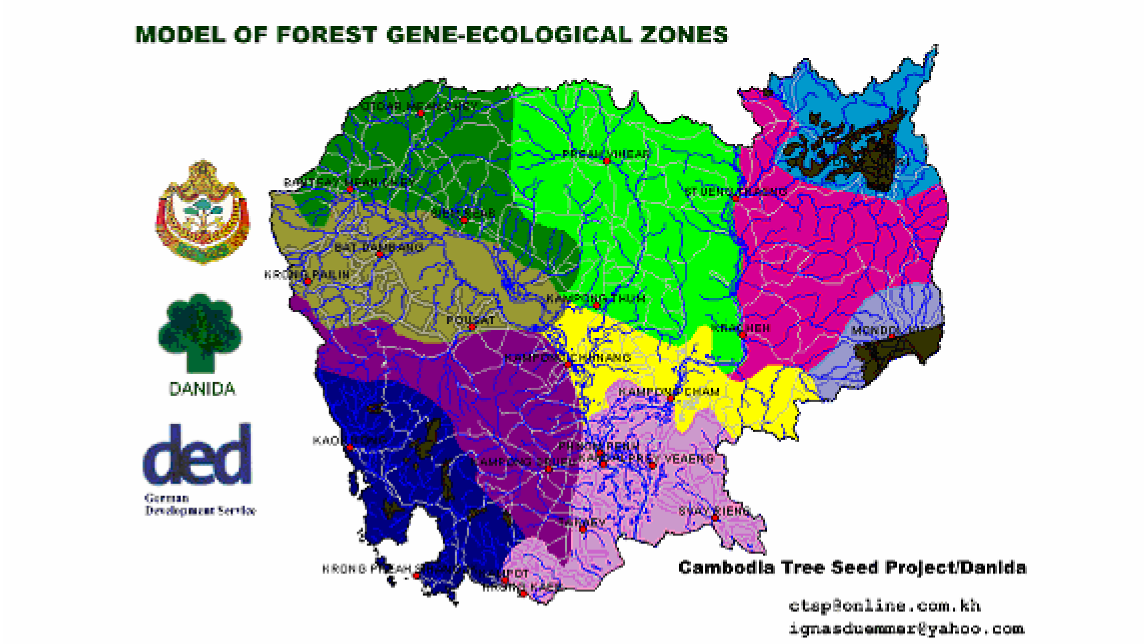
Result of query FERTITY = ‘high productivity soil’ and RAINFALL > 2100 mm

9. Press Highlight results and the selected areas will be shown on the map (→Some areas in the coastal zone and Ratanakiri/Mondulkiri)

10. Adjust the query definition and add **and RAINAV** > **2100** and click the **Execute** button again.

11. Press Highlight results again and the selected areas will be shown on the map (→Some areas in the coastal zone and Ratanakiri/Mondulkiri, but area is smaller than under step 9).

12. Map with selected areas (color dark red) of query**:** **FERTILITY** = ‘high productivity soil’ and RAINFALL > ‘2100 mm’ and LANDUSECAT = ‘Evergreen forest” (map exported).

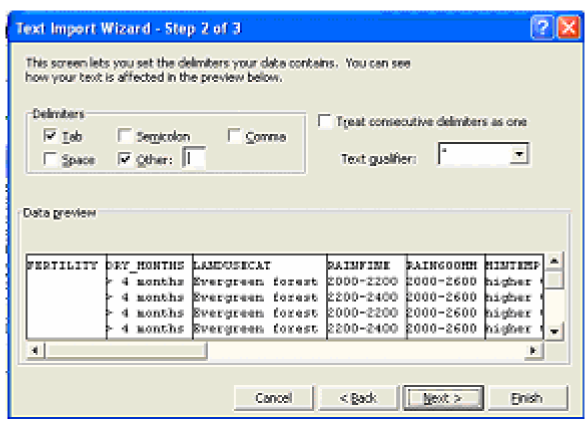


Dark red areas are areas which indicate the presence of high fertility soils, rainfall > 2100 mm, and evergreen forest.

13. Export results from the Query Builder to Excel for further processing:

The query result can be saved as a ASCII text file(delimited with "|"), and this can be opened in Excel using the delimiter option other ("|", this button you can find above the "\" button on the keyboard).

Screen shot of ASCII text file imported in Excel. Use the other option to delimits the columns.



Forest Gene-Ecological Zone	Area (ha)
A. Coastal Cardamoms Total	88464
B. Northern Cardamoms Total	47
F. Eastern Mekong Basin Total	3278
g. Southern Annamites Total	160868
G. Central Annamites Total	269802
Grand Total	522458

Final table prepared in Excel

Overview of Query options in ArcExplorer
- Boolean (Logical) Operators:
AND (only areas which are in both),
OR (both areas are includes),

- Relational (Conditional) Operators:
=, >, <, <> (not equal to)

More examples illustrating the syntax of query expressions

· **Strings** such as names are always single quoted in query expressions. Strings are case sensitive, so if a string field's value is 'c. Redlands', you can select this record with:

ECO_ZONE = 'c. Redlands'

· When querying strings, you can use % as a single or multiple character wildcard in conjunction with the like operator. For example, to select commune Kruos you could use this expression:

COMMUNE like 'Kru%'

· Use the And operator when **both expressions** must be true. For example, to find features with an area where the geology is basalt and the dry period is less than 4 months.

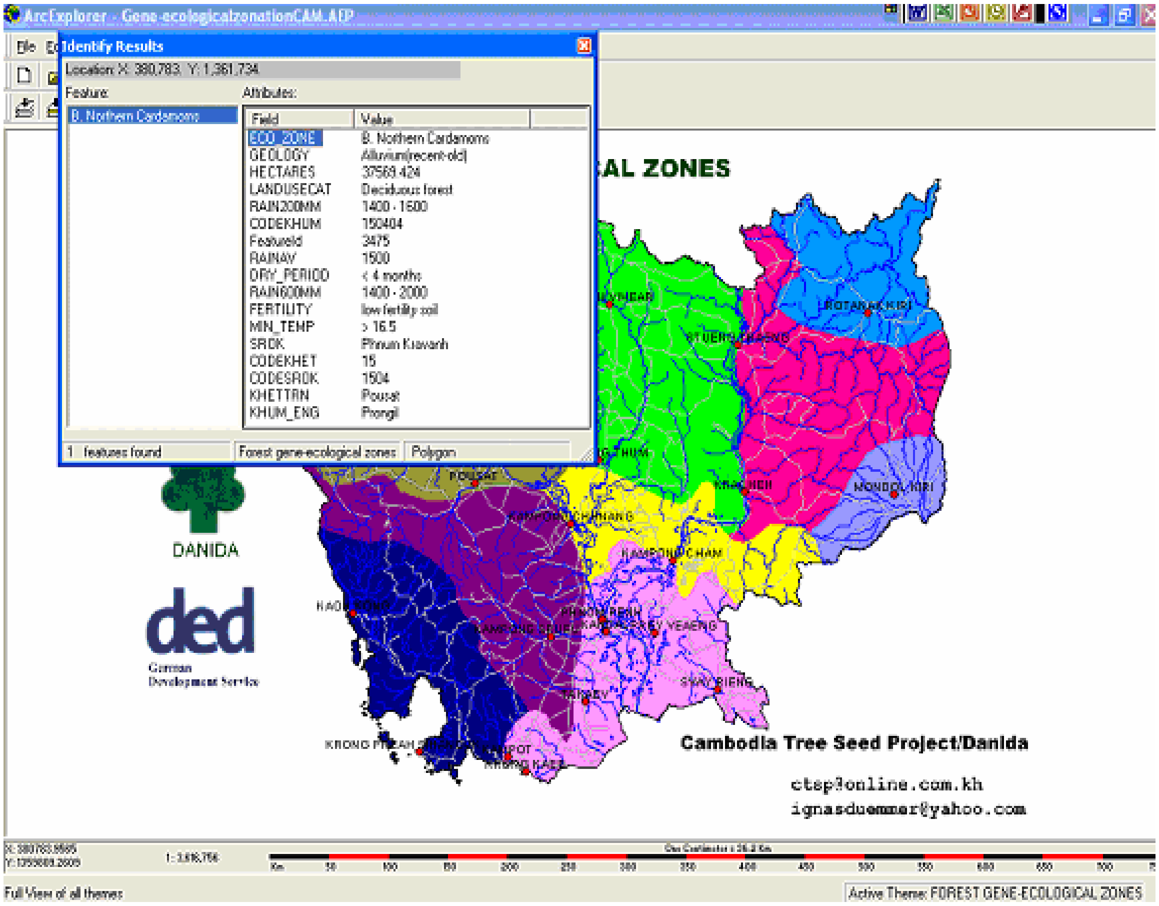
GEOLOGY = 'Basalt' and DRY_PERIOD = '< 4 months'

· Use the Or operator when **at least one expression** must be true:

HECTARES > '900' or RAINAV < '2100'

B. Selection of areas based on coordinates.

If you have coordinates of a specific location and you want to investigate specific parameters of this region, you can find this location in the model by using the mouse and scroll over the map until the coordinates in the left corner are matched. By clicking on the map (using the identify bottom,), an identify results table will appear with the information.
The model uses Indian Thailand as map datum and UTM as coordinate system. Your coordinates must have the same setting for collecting to use this model. Other settings need to be converted (use converter software/ArcView). Based on the identify result, it is now possible to find areas in Cambodia with same/similar conditions using the query builder.



Result of using the identify option on location x: 380,783 and y: 1,361,734

C. Selection of areas based on tree specific characteristics.

If you have the growth/site conditions of a specific tree based on literature, you can find these locations in Cambodia by using the Query builder directly. See section A on the use the query builder.

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APPENDICES

Appendix i. Table of Criteria for Gene-Ecological Zones

Conditions	**Criteria**
Rainfall (ranges)	800 -1000, 1000-1200, 1200-1400, 1400- 1600……, 4000-4200
	800-1400, 1400-2000, 2000-2600, 2600-3200, 3200-3800, > 3800
Rainfall (average)	900, 1100, 1300, 1500, 1700, 1900, 2100, 2300……., 4100
Period of dry months (< 40 mm)	< 4 months
	> 4 months
Minimum temperature of Coldest month	< 16.5 ^{o}C
	> 16.5 ^{o}C
Geology	Alluvium
	Basalt
	Sandstone-Siltstone
	Complex mixture
	Gneiss-Schists
Soil productivity (fertility)	Low
	Medium
	High
Forest cover/Landuse	Agricultural land
	Shrub land
	Deciduous forest
	Evergreen forest
	Mangrove/inundated forest

Appendix ii. **Climatic Data from 123 Meteorological Stations**

(Total Rainfall, Length of Dry Seasons, and Minimum Temperature)

No	STATION	X_COORD	Y_COORD	SNEWNAME	PROVINCE	COUNTRY	Z_YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	Z40_MM	TEMPMIN
1	O Chrov	238800	1509000		Banteay Meanchey	Cambodia	1													1143	4	
2	Svay Chek	280300	1525000		Banteay Meanchey	Cambodia	1													1943	4	
3	Phnom Srok	320400	1519500	Phum Srok	Banteqy Meanchey	Cambodia	7													1198	5	
4	Thmar Pouk	289600	1542400		Bantey Meanchey	Cambodia	2													843	7	
5	Banan	298600	1430500		Battambang	Cambodia	2													900	6	
6	Bat Dambo	293300	1466500		Battambang	Cambodia	73	7	20	46	78	140	143	162	169	224	239	82	35	1345	3	21.6
7	Komrieng	229000	1443100	Kamrieng	Battambang	Cambodia	3													612	8	
8	Maung Rus	331000	1412000	Moung Russei	Battambang	Cambodia	22	5	2	35	64	122	132	83	93	166	177	159	19	1056	4	
10	Rattanak Mondol	280400	1425700		Battambang	Cambodia	2													795	7	
11	Reangkese	311700	1434100		Battambang	Cambodia	4	9	3	62	79	139	152	106	112	247	153	134	10	1206	3	
12	Samlot	254901	1401406	Samlout	Battambang	Cambodia	3													1529	5	
13	Baset	449900	1232000	Basedth	K.Speu	Cambodia	7													1274	4	
14	Phnom Srouch	431900	1258100	Phnum Sruoch	K.Speu	Cambodia	7													1199	4	
15	Batheay	494400	1324800		Kampong Cham	Cambodia	11													1148	4	
16	Cha.andon	520203	1363982	Chamkar Andong	Kampong Cham	Cambodia	31	8	14	41	110	311	306	378	367	457	296	119	26	2433	3	
17	Chalang	569085	1305803	Chanlong	Kampong Cham	Cambodia	29	11	15	35	137	334	378	389	347	514	360	129	25	2674	4	
18	Chamkarle	530500	1360900	Chamcar Leur	Kampong Cham	Cambodia	30	4	17	36	78	200	195	235	218	219	198	59	17	1475	4	
19	Chup	565600	1317400	Phum chop Krau	Kampong Cham	Cambodia	31	6	13	44	119	295	291	301	304	358	281	107	30	2149	3	
20	Kam. Cham	550800	1325100		Kampong Cham	Cambodia	77	12	10	41	80	188	222	205	213	258	224	96	23	1573	3	21
21	Kntroy	632855	1299915		Kampong Cham	Cambodia	29	7	11	27	113	280	330	309	300	402	301	107	19	2206	4	
22	Krek	596000	1304000	Ponhea krek	Kampong Cham	Cambodia	17	3	10	36	166	339	336	407	327	427	317	128	35	2532	4	
23	Krouch Chmar	569600	1358000		Kampong Cham	Cambodia	3													1189	6	
24	Memot	629100	1307400		Kampong Cham	Cambodia	33	6	8	27	102	237	280	254	258	349	286	104	27	1938	4	
25	Peamchiko	528800	1320200		Kampong Cham	Cambodia	4			6	32	122	148	219	196	103	149	62	5	1041		
27	Prek chno	528100	1332600		Kampong Cham	Cambodia	29	12	9	41	119	304	338	350	306	386	340	137	27	2369	3	
28	Prek kak	558718	1354460	Preak Kak	Kampong Cham	Cambodia	34	8	17	44	112	234	251	278	265	340	245	84	16	1894	3	
29	Boribo	442100	1374900	Baribour	Kampong Chnang	Cambodia	3	0	0	1	30	61	224	294	293	246	240	124	34	1545	5	
30	K.trach	469300	1319800		Kampong Chnang	Cambodia	12	5	17	18	52	193	178	164	120	161	204	64	16	1191	4	
31	Kam. tral	475406	1316367	Kampong Tralach	Kampong Chnang	Cambodia	39	6	9	36	74	152	129	130	172	209	211	93	45	1265	3	
32	Kam.chnan	464600	1351900	Kampong Chnang	Kampong Chnang	Cambodia	32	11	23	37	75	187	247	287	291	283	257	113	37	1848	4	
33	S.achrome	448800	1331100	Tuek Phos	Kampong Chnang	Cambodia	11	4	7	27	44	239	176	154	245	215	161	90	21	1382	4	
34	Samaki Meanchey	457700	1313400	Sameakki Mean Chey	Kampong Chnang	Cambodia	7													1239	5	
35	Baray	509400	1370000		Kampong Thum	Cambodia	47	10	10	26	105	240	247	212	213	289	182	51	22	1607	4	
36	Kam. Thom	488243	1404132		Kampong Thum	Cambodia	59	2	16	51	80	168	217	178	190	323	235	68	17	1545	3	
37	Kompong Thmar	513823	1381706		Kampong Thum	Cambodia	5													1673	4	
38	Prasat Balang	494400	1431700	Prasat Balangk	Kampong Thum	Cambodia	3													1444	6	
39	Prasat Sambo	507400	1424000	Prasat Sambour	Kampong Thum	Cambodia	3													1345	6	
40	Sadan	527000	1448500	Sandan	Kampong Thum	Cambodia	4													1515	4	
41	Staung	453700	1430700		Kampong thum	Cambodia	27	2	7	28	72	136	140	156	196	262	162	54	10	1226	4	
42	Bokor	394186	1174013		Kampot	Cambodia	22	21	51	150	174	402	621	883	901	785	420	172	66	4644	1	
43	Chhuk	441000	1197700		Kampot	Cambodia	13	19	11	42	71	147	111	148	142	205	225	128	30	1278	3	
44	Chumkiri	437200	1207300	Chum kiri	Kampot	Cambodia	2													1292	3	
45	K.trach	442400	1166700		Kampot	Cambodia	47	19	15	80	96	187	185	302	293	245	258	164	53	1897	2	
46	Kampot	418500	1172100		Kampot	Cambodia	75	18	24	77	118	188	213	274	349	234	232	142	48	1916	2	21.7
47	Kandal	481300	1261200		Kandal	Cambodia	1													1325	3	
48	Kasmoul,K	283700	1266900		Koh Kong	Cambodia	21	2	21	36	75	434	748	887	716	499	217	70	20	3725	4	
49	Koh Kong (Ville)	299982	1264172	Kaoh Kong	Koh Kong	Cambodia	1													3882	3	
50	Sreambel	364000	1229700	Srae Ambel	Koh Kong	Cambodia	16	9	24	99	140	297	466	574	569	442	258	55	7	2939	3	
51	Chhlong	605200	1355000	Chloung	Kratie	Cambodia	11													2105	4	
52	Kratie,sa	611000	1381000	Kracheh	Kratie	Cambodia	47	6	18	57	89	200	257	293	290	289	172	57	15	1743	3	
53	Snoul	655300	1334500		Kratie	Cambodia	30	3	8	32	83	260	282	298	280	335	259	73	18	1930	4	
54	Kep	426500	1160000	Kaeb	Krong Kep	Cambodia	31	19	39	99	160	228	240	380	361	307	262	144	59	2297	2	
55	Chnong	346300	1542900	Ghnonh Kal	Otdar Mean Chey	Cambodia	30	7	19	48	86	269	245	301	258	307	217	64	8	1827	3	
56	Samrong	524400	1261100	Samraong	Otdar Mean Chey	Cambodia	18	0	20	20	70	195	207	220	247	344	168	28	23	1542	5	
57	Pailin	239265	1422417	Pailin	Pailin	Cambodia	24	9	29	78	101	133	92	130	118	195	186	94	13	1178	3	
58	Po.tong	484932	1276753	PochenTongAirpor	Phnom Penh	Cambodia	77	10	9	35	83	134	138	158	160	254	241	131	26	1381	4	21.3
59	Bamnak	411348	1357946		Pousat	Cambodia	11	4	13	47	94	153	151	130	158	224	176	93	13	1254	3	
60	KrakorPur	414700	1385100	Krakor	Pousat	Cambodia	53	13	12	36	75	178	155	173	190	229	264	128	23	1475	4	
61	Leach	367000	1365400	Leach, close to Phn	Pousat	Cambodia	23	46	27	46	87	153	135	166	253	280	244	157	70	1662	1	
62	Pursat	383000	1386400		Pousat	Cambodia	48	4	19	35	76	183	145	161	190	197	240	116	26	1392	4	19.4
63	Tani	352900	1413000		Pousat	Cambodia	33	17	16	24	67	149	110	122	135	155	183	145	38	1161	4	
64	Rovieng	512500	1476400		Preah Vih	Cambodia	2													1403	4	
65	Cheomksan	494300	1571500		Preah Vihear	Cambodia	24	2	4	30	58	170	283	313	356	405	171	45	10	1847	4	
66	Suong	576698	1557204		Preah Vihear	Cambodia	28	101	63	30	106	212	213	203	190	238	236	84	31	1708	2	
67	Kamchay Mea	572700	1279300	Kamchea Mear	Prey Veng	Cambodia	2													1280	4	
68	Kampong Leav	537300	1270500		Prey Veng	Cambodia	1													1470	3	
69	Kanchreach	561200	1292300	Kanhchriech	Prey Veng	Cambodia	2													886	4	
70	O Raing	736400	1363900	Ou Reang	Prey Veng	Cambodia	5													2512	4	
71	Peam Ror	531100	1250500	Peam Chor	Prey Veng	Cambodia	2													1617	3	
72	Cholkiri	487100	1343700	Chol Kiri	Pursat	Cambodia	1													1258	8	
73	Peam	263628	1381002		Pursat	Cambodia	2													1118	7	
74	Andoung Meas	749300	1534100		Ratanakir	Cambodia	1													1180	5	
75	Ban Lung	713000	1517700		Ratanakir	Cambodia	2													2450	5	

No	STATION	X_COORD	Y_COORD	SNEWNAME	PROVINCE	COUNTRY	Z_YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	Z40_MM	TEMPMIN
76	Lumphat	714700	1491900		Ratanakir	Cambodia	8													1758	5	
77	O Chum	716242	1525693	Ou Chum	Ratanakir	Cambodia	2													2248	5	
78	VoeunSai	697300	1545400		Ratanakiri	Cambodia	28	3	5	19	94	252	380	560	510	462	204	46	17	2551	4	
79	Angkor Chum	354200	1513000		Siam Reab	Cambodia	4													1156	5	
80	Angkor Watt	378000	1489800		Siam Reab	Cambodia	2													1119	6	
81	Banteay Srey	387900	1502700		Siam Reab	Cambodia	2													932	5	
82	Chanlasdai	333563	1507328		Siam Reab	Cambodia	1													1139	6	
83	Prasat Bakong	391300	1475400		Siam Reab	Cambodia	5													1282	5	
84	Srey Snam	340000	1529400	Srei Snam	Siam Reab	Cambodia	2													1134	5	
85	Svay Leu	418600	1497700		Siam Reab	Cambodia	2													1811	4	
86	Varin	365500	1525000		Siam Reab	Cambodia	2													1417	5	
87	Sasar Sdam	350063	1493115		Siam Reap	Cambodia	2													1082	5	
88	Baray Dan	374447	1483563	Baray Dankor	Siem Reab	Cambodia	10	2	5	24	66	146	179	191	183	273	191	116	14	1389	4	
89	K.khleng	405200	1449300	Kampong Khleang	Siem Reab	Cambodia	28	1	7	27	56	129	144	151	147	275	188	67	16	1208	4	
90	Kralanh	328700	1504300		Siem Reab	Cambodia	20	1	12	23	69	129	162	148	134	234	114	35	12	1073	5	
91	Siem Reap	378500	1477100		Siem Reab	Cambodia	63	15	11	26	55	143	198	195	206	280	227	79	13	1447	4	19.7
92	Kam. Som	336113	1174966	Sihanouk vill	Sihanouk vill	Cambodia	26	30	29	93	128	289	508	621	666	586	358	161	47	3517	2	23.3
93	Seam Bork	601700	1480800	Siem Bouk	Stoeg Treng	Cambodia	2													1661	4	
94	Siempang,	654000	1561200		Stoeng Treng	Cambodia	13	1	9	12	72	202	299	369	357	392	152	42	13	1920	4	
95	Stung Tre	605700	1495800	Stoeng Treng	Stoeng Treng	Cambodia	68	3	22	39	110	216	271	327	309	326	201	70	19	1913	4	18.8
96	Chipou	540046	1234061		Svay Rieng	Cambodia	10	30	9	17	80	156	225	195	172	192	202	97	37	1412	4	
97	Kam. Rau	603300	1206800	Kampong Rou	Svay Rieng	Cambodia	6	29	1	16	154	250	169	123	191	285	349	240	97	1902	3	
98	Soc noc	600734	1216463		Svay Rieng	Cambodia	23	23	12	32	78	196	197	208	164	219	299	143	35	1606	4	
99	Svay Rien	578400	1228600		Svay Rieng	Cambodia	67	15	16	33	117	176	201	211	195	284	322	167	43	1781	3	20.9
100	Takmau, K	494300	1264300		Svay Rieng	Cambodia	13	12	5	87	61	137	144	146	157	249	226	92	30	1346	3	
101	Angkor Borey	497800	1215000		Takeo	Cambodia	2													1302	4	
102	Angtassom	464455	1216991		Takeo	Cambodia	32	11	5	34	59	137	115	112	136	181	210	122	34	1155	4	
103	Bat Rocar	497665	1215860	Bot Rocar	Takeo	Cambodia	4	12	1	43	92	148	92	160	147	217	277	151	19	1359	3	
104	Kirivong	486500	1176500		Takeo	Cambodia	46	14	12	45	119	131	122	158	131	221	244	155	41	1391	3	
105	Takeo	477200	1216030	Doun Kaeo	Takeo	Cambodia	64	12	7	32	84	145	109	138	139	180	266	126	27	1261	4	
1	Attopeu	697424	1600247			Laos	14													2192	4	
2	Mounlapamok	593567	1584611			Laos	21													1844	5	
3	Muong Khong	589899	1561060			Laos	21													1737	5	
4	Muong Mahaxay	738928	1631906			Laos	13													2559	4	
5	Nonghine	630824	1631134			Laos	22													2714	3	
6	Pathoumphone	603798	1632678			Laos	9													2325	4	
7	Soukhouma	586231	1619938			Laos	22													2033	5	
1	Aranyaprathet	231067	1514070			Thailand	28													1384	4	
2	Ban Kruat	293922	1594768			Thailand	16													1280	5	
3	Buntharik	526285	1631265			Thailand	17													1816	4	
4	Det Udom	508037	1647891			Thailand	34													1659	5	
5	Khukhan	413551	1627615			Thailand	25													1272	5	
6	Pon Nam Ron	215657	1429316			Thailand	16													1643	5	
7	Prakhon Chai	293111	1615855			Thailand	17													946	5	
8	Prasat	326770	1618694			Thailand	16													1335	5	
9	Watthana Nakhon	209169	1520153			Thailand	16													1717	4	
1	Buon Me Thuot	825016	1328731			Vietnam	23													1895	4	
2	Chau Doc	510540	1162221			Vietnam	24													1312	4	
3	Pleiku	822525	1550371			Vietnam	24													2210	4	

Sources: Moe, MRC, DoM

No	Number station
Station	Name station
X_coord	x-position
Y_coord	y-position
SNEWNAME	New name (Gazetteer)
Z-YR	Years of collection
Total	Average total rainfall
Z40_MM	perod of month < 40mm
TEMPMIN	Temp. coldest month

Appendix iii. Temperature (Minimum, Maximum, and Average) from Nine Meteorological Stations in Cambodia

Tmean		**Station**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Okt**	**Nov**	**Dec**
		Po.tong	26.2	27.6	29.2	30.0	29.6	29.0	28.4	28.4	27.9	27.5	26.9	25.9
		Pursat	25.2	26.7	28.8	29.8	29.7	29.2	28.6	28.1	27.7	27.1	26.5	25.3
		BB	26.5	28.5	30.5	30.9	30.3	29.4	29.0	28.9	28.6	28.0	27.2	26.0
		K. Som	26.6	27.3	28.0	28.8	28.6	27.9	27.3	27.1	27.2	27.2	27.5	27.1
		Kampot	26.3	26.9	27.9	28.7	28.7	28.2	27.4	27.3	27.3	27.3	27.0	26.5
		Stung T	24.9	27.0	29.1	30.0	28.6	27.8	27.1	27.2	26.9	26.6	25.8	24.3
		Siem.R	25.4	26.9	29.0	29.8	29.3	28.7	28.3	28.1	27.8	27.2	26.6	25.3
		Svay R	26.3	27.5	29.0	29.8	30.1	28.4	28.0	28.0	27.6	27.5	27.1	26.4
		K. Cham	26.0	27.6	29.1	29.8	28.9	28.4	27.8	27.9	27.5	27.1	26.3	25.4
	Av		25.9	27.3	29.0	29.7	29.3	28.6	28.0	27.9	27.6	27.3	26.7	25.8
Tmin		Po.tong	21.3	22.5	24.0	25.1	25.0	24.8	24.5	24.6	24.4	24.2	23.4	21.8
		Pursat	19.4	20.9	23.2	24.5	24.6	24.5	24.2	24.1	24.0	23.7	22.9	21.0
		BB	21.6	23.6	25.2	26.7	26.4	25.5	25.7	25.5	25.3	24.8	23.7	21.8
		K. Som	23.3	23.9	25.0	25.7	25.7	25.4	24.7	24.8	24.7	24.6	24.5	24.0
		Kampot	21.7	22.6	23.7	24.6	24.7	24.6	24.1	24.2	24.1	23.8	23.3	22.4
		Stung T	18.8	20.8	23.5	25.0	24.3	23.9	23.6	23.7	23.6	23.0	21.5	19.0
		Siem.R	19.7	21.3	24.0	24.6	24.7	24.5	24.4	24.5	24.3	23.6	22.5	20.5
		Svay R	20.9	21.5	23.0	24.3	24.7	24.4	24.2	24.4	24.4	24.3	23.5	21.7
		K. Cham	21.0	22.3	23.8	24.9	24.4	24.2	24.0	24.4	24.3	23.9	22.7	21.2
	Av		20.9	22.1	23.9	25.0	24.9	24.6	24.4	24.5	24.3	24.0	23.1	21.5
Tmax		Po.tong	31.1	32.8	34.5	35.0	34.2	33.2	32.3	32.2	31.5	30.7	30.4	30.1
		Pursat	30.9	32.4	34.4	35.1	34.7	33.8	32.9	32.1	31.3	30.5	30.1	29.6
		BB	31.5	33.4	35.9	35.2	34.2	33.4	32.4	32.3	31.8	31.1	30.8	30.3
		K. Som	29.8	30.6	31.1	31.8	31.4	30.5	29.8	29.5	29.6	29.9	30.4	30.3
		Kampot	30.9	31.3	32.1	32.9	32.6	31.8	30.7	30.5	30.5	30.7	30.7	30.7
		Stung T	31.0	33.1	34.7	35.0	32.9	31.6	30.6	30.6	30.2	30.2	30.1	29.5
		Siem.R	31.0	32.5	34.0	34.9	34.0	32.9	32.1	31.7	31.2	30.8	30.7	30.1
		Svay R	31.7	33.4	34.9	35.2	35.5	32.4	31.7	31.6	30.8	30.7	30.6	31.1
		K. Cham	31.0	32.9	34.4	34.8	33.5	32.6	31.7	31.3	30.7	30.4	29.9	29.7
	Av		**31.0**	**32.5**	**34.0**	**34.4**	**33.7**	**32.5**	**31.6**	**31.3**	**30.8**	**30.6**	**30.4**	**30.1**
			Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Okt**	**Nov**	**Dec**
		Tav	25.9	27.3	29.0	29.7	29.3	28.6	28.0	27.9	27.6	27.3	26.7	25.8
		Tmin	20.9	22.1	23.9	25.0	24.9	24.6	24.4	24.5	24.3	24.0	23.1	21.5
		Tmax	31.0	32.5	34.0	34.4	33.7	32.5	31.6	31.3	30.8	30.6	30.4	30.1

Appendix iv. Conversion of Soil and Forest/Land Use Maps into a Soil Fertility Zonation Map

1. Conversion of Soil and Forest/Land Use Maps based on USDA classification, the classes are used for soils affected by rice cultivation.

SOILTYPE	HECTARES	%	Fertility Class	Subtotal % per class	
Acid Lithosols	4542131	25.3	1	25.3	
Coastal Complex	228465	1.3	1	26.6	
Planosols	166536	0.9	1	27.5	
Plinthite podzols	1816460	10.1	1	37.6	
Red-yellow podzols	2571678	14.3	1	51.9	51.9
Alluvial Lithosols	1523256	8.5	2	8.5	
Alumisols	329727	1.8	2	10.3	
Brown Alluvial Soils	132565	0.7	2	11.0	
Cultural hydromorphics	1419051	7.9	2	18.9	
Plinthitic hydromorphics[1]	118393	0.7	2	19.6	19.6
Basic Lithosols	348281	1.9	3	1.9	
Brown hydromorphics	681349	3.8	3	5.7	
Grey hydromorphics	1706815	9.5	3	15.2	
Lacustrine Alluvial Soils	1044566	5.8	3	21.0	
Latosols	663657	3.7	3	24.7	
Regurs	637896	3.6	3	28.3	28.3
Total	**17930824**	**100.0**			

[1]: A unique class, described by Crocker (1962) as a soil that had developed a thin, artificially compacted, impermeable horizon.

2. Regrouping of Soils into Three Fertility Classes
Based on the authors' interpretation of FCC (Sanchez, 1982), where :
Fertility class 1: Low fertility (yellow)
2: Medium fertility (orange)
3: High fertility (green)

Appendix v. Basis for Simplification of Vegetation Types

CONTINUOUS FOREST COVER		Code GIS[1]	Code new[2]
- Evergreen	- cover density: high	11	2
	- cover density: medium-low	12	2
- Mixed, evergreen and deciduous	- cover density: high	17	2
	- cover density: medium-low	18	2
- Deciduous		20	3
- Inundated forest		52	4
- Mangrove forest		53	4
- Forest plantations		54	0
- Other forests		55	0
- Forest regrowth		40	0
- Forest regrowth, inundated		41	4
MOSAIC OF FOREST COVER			
- Evergreen		13	2
- Mixed		19	3
- Deciduous		22	3
- Inundated		56	4
NON-FOREST			
Wood- and shrubland			
Evergreen type		61	5
Dry type		64	5
Inundated		65	4
Bamboo		63	0
Grassland		62	0
Mosaic of cropping			
cropping area < 30%		81	0
cropping area > 30 %		82	0
Agricultural land		91	1
Barren land		92	0
Rocks		93	0
Urban or built-over area		94	0
Water		95	0
Wetland		97	0
Other		96	0
Clouds		99	0

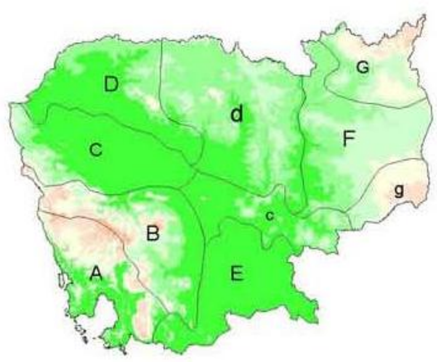
After Stibig (1999): A regrouped category based on old vegetation cover. Mixed (0), Agricultural lands (1), Evergreen forest (2), Deciduous forest (3), Mangrove/inundated forest (4), Shrubland (5)

Appendix vi. Summarization of Environmental Factors that Delineate Gene-Ecological Zones

Name zone	A		B		C		c		D		d		E		F		g		G	
Area (ha)	1628512		2106369		2045565		1238804		1979209		3226072		1873684		2294977		613262		1158609	
	9		12		11		7		11		18		10		13		3		6	
	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
Soil fertility *																				
low	1471320	90	1721345	82	68870	3	112976	9	1222013	62	1999658	62	179744	10	1605204	70	148810	24	595828	51
medium	65619	4	242254	12	81137	4	163089	13	582892	29	413151	13	1589487	85	190956	8	96065	16	55937	5
high	91574	6	142602	7	1626927	80	902138	73	174304	9	747815	23	27342	1	431074	19	368388	60	506844	44
Landuse global																				
Evergreen	1362954	84	833648	40	231962	11	225525	18	632385	32	1330350	41	4855	0	261101	11	300315	49	974996	84
Deciduous	29067	2	658115	31	318425	16	118110	10	574304	29	1601402	50	33827	2	1919798	84	312949	51	183613	16
Mangrove/inundated	236494	15	187	0	818298	40	347444	28	19101	1	30439	1	625183	33						
Shrubland			324082	15	162352	8	116481	9	203469	10	209675	6	178352	10	114078	5				
Agriculture			290287	14	514527	25	431244	35	549951	28	54206	2	1031467	55						
Dry period																				
< 4 months	1403488	86	1293755	61	403834	20	347965	28			483253	15	1701960	91	370038	16				
> 4months	225024	14	812564	39	1641732	80	890839	72	1979209	100	2742819	85	171725	9	1924939	84	613264	100	1727497	100
Temperature min.																				
< 16.5	145275	9	152580	7							18102	1					180601	29	534873	46
> 16.5	1483237	91	1953739	93	2045565	100	1238804	100	1979209	100	3207970	99	1873684	100	2508931	100	432661	71	623737	54
Rainfall cat.																				
800-1000					169406	8														
1000-1200			272939	13	807799	39			172237	9										
1200-1400	1024	0	1341874	64	891383	44	69561	6	1806961	91	45408	1	677707	36						
1400-1600	68	0	457259	22	176977	9	249976	20	12	0	1532743	48	626309	33					41205	4
1600-1800							449025	36			1364462	42	408842	22	194144	8				
1800-2000											142760	4	20995	1						
2000-2200							470243	38			140699	4	135201	7	1875569	82	275576	45	149159	13
2200-2400															225265	10	272732	44	574663	50
2400-2600																	64954	11	393583	34
2600-2800	23933	1	2151	0																
2800-3000	58603	4	2463	0																
3000-3200	338236	21	3641	0																
3200-3400	794020	49	25993	1									4631	0						
3400-3600	106321	7																		
3600-3800	276959	17																		
3800-4000	19008	1																		
4000-4200	10340	1																		

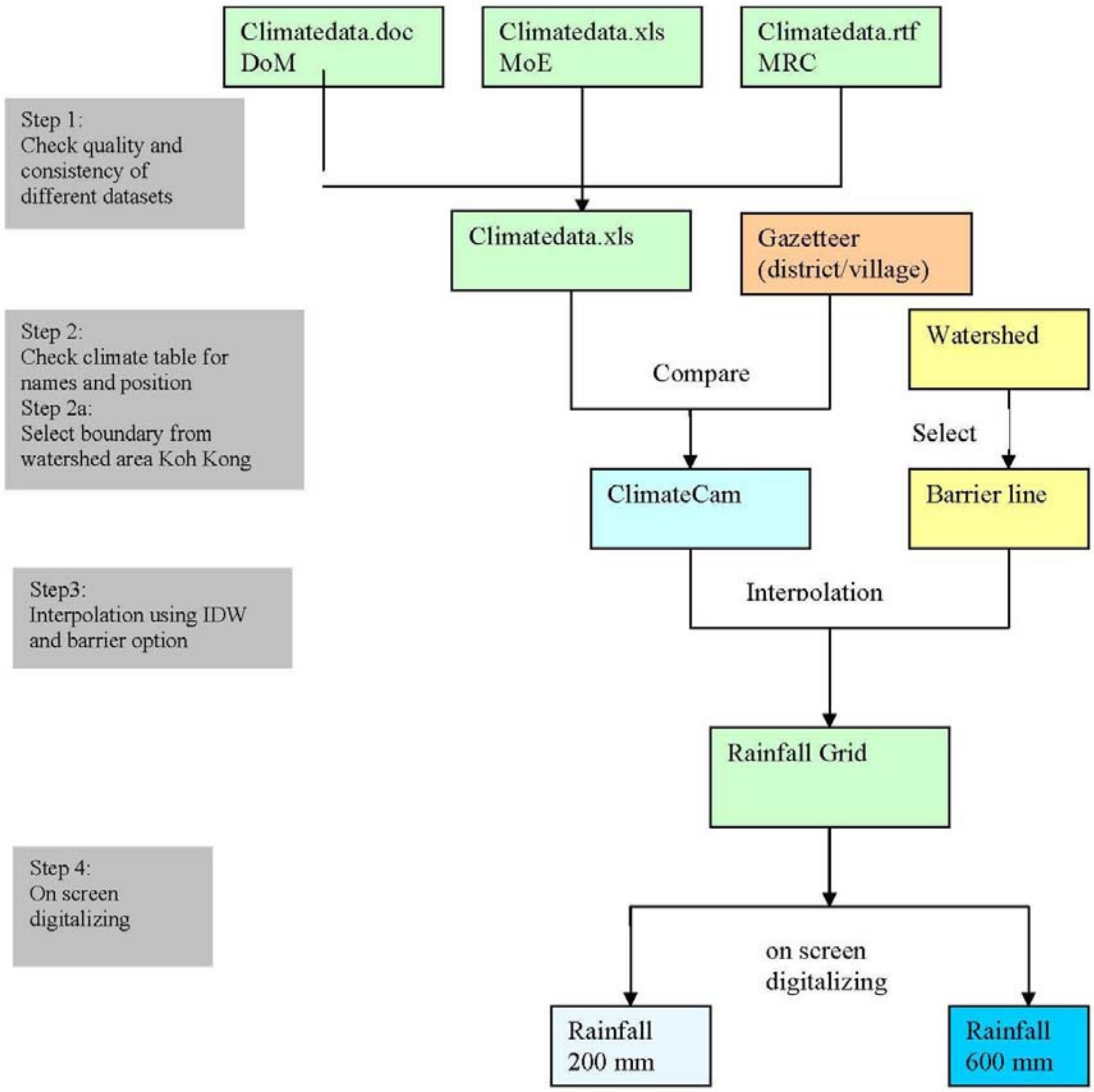
*: water excluded

Name zones
A. Coastal Cardamoms
B. Northern Cardamoms
C. Tonle Sap Floodplain
D. Northwestern Lowlands
E. Lower Mekong Floodplain
F. Eastern Mekong Basin
G. Central Annamites
c. Redlands
d. Central Lowlands
g. Southern Annamites

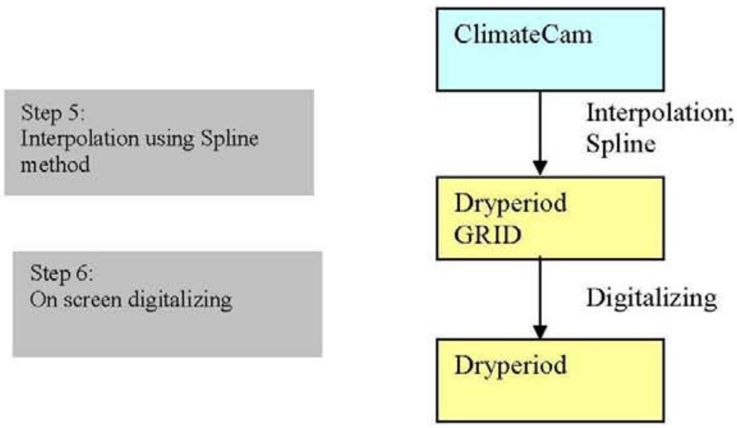


Appendix vii. Flow Diagrams of Gene-Ecozone Model

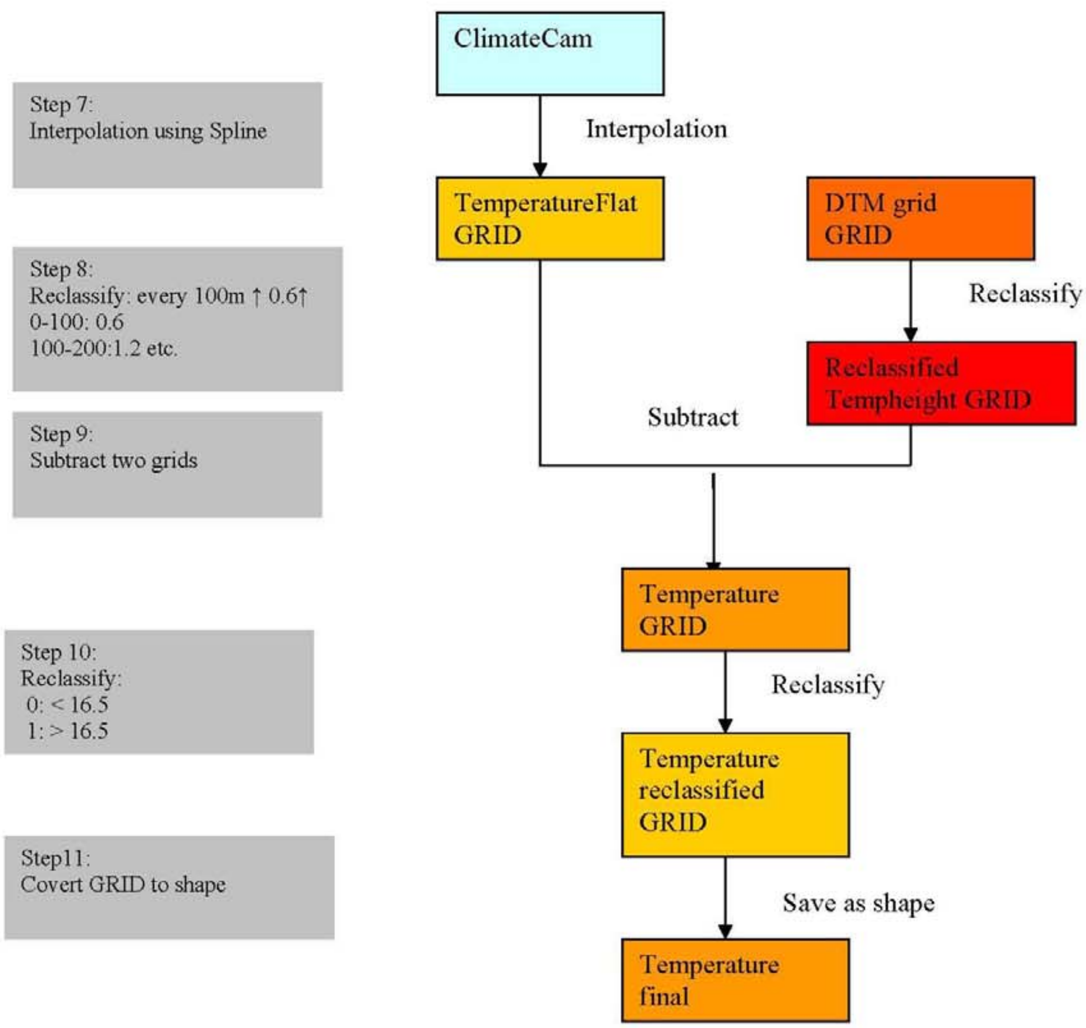
A. Average annual rainfall (200 and 600 mm classes) maps



B. Dry period (< 40 mm) map

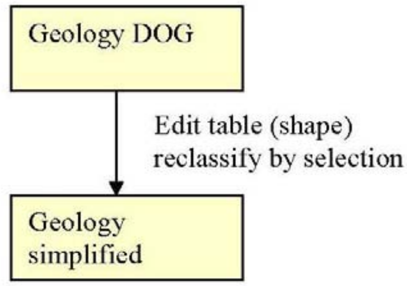


C. Average temperature of coldest month map



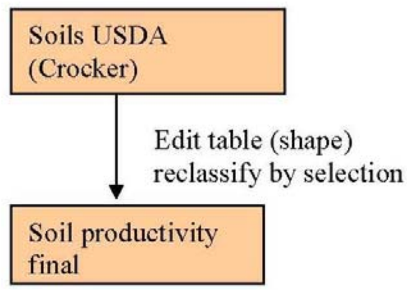
D. Geology map

Step 12:
On screen digitizing



E. Soil map

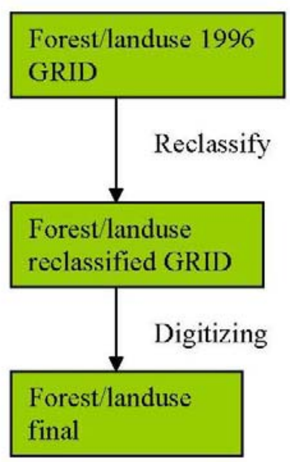
Step 13:
Reclassify, see soil-table for conversion



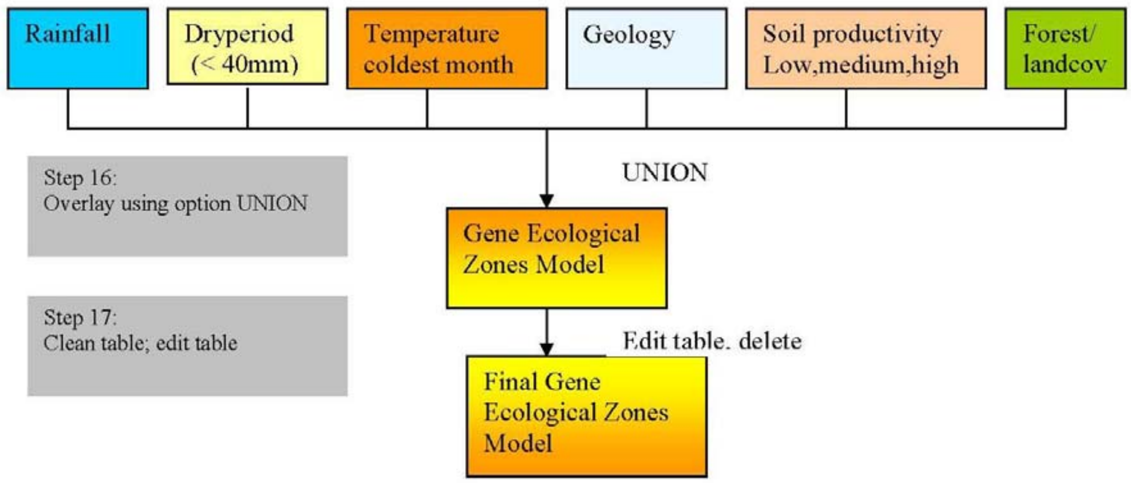
F. Forest/land cover map

Step 14:
Reclassify, see forest/landuse table for conversion

Step 15:
On screen digitizing



G. Finalizing gene-ecological model



Appendix viii. Flow Chart of Gene-Ecozone Model

(Based on ArcView 3.2., extension spatial Analyst, Geoprocessing)

A. Average Annual Rainfall Map

Step 1 Meteorological data (rainfall, temperature) from MoE, MRC, and DoM was used to create the climate table. The MoE dataset (54 stations) was used for the climate model (Excel). The actual number of meteorological stations is higher, but due to not all data seems liable some meteorological station data were excluded from the analysis.
Result: climateCam.xls (Excel table of average annual rainfall and temperature).

Step 2 Meteorological stations were transferred from longitude/latitude to UTM (X,Y) Indian Thailand. Station names and positions (x,y) on the map were checked with Province/District/Village position datasets from the Gazetteer (DoG). Names were changed to the Gazetteer system when appropriate. The periods of dry months and years were calculated a data set in Appendix ii.
Result: climateCam.dbf and ArcView shapefile.

Step 3 Rainfall data was interpolated by using the inverse distance weighting (IDW) method, and corrections were made for coastal, mountainous areas. The watershed boundary of the coastal zone was selected as the rainfall barrier, based on the assumption that rain measured in this region does not cross the Cardamom mountain range.
Result: Rainfall shown as a spatial pattern (grid).

Step 4 The final rainfall map was produced by smoothing; the interval lines were drawn by on-screen digitalizing (200mm and 600 mm classes). Stations with higher annual rainfall have higher weighting factors. A minimum of 20 years of data collection is generally considered necessary for statistical spatial analysis.
Result: Two maps: ″200 mm rain″ and ″600 mm rain″ interval as a shape.

B. Dry Period Map

Steps 5 and 6 Dry periods (<40mm/month) were determined by using climatic data from Appendix ii. These data were interpolated by using ArcView Spline, the best method for gently varying surfaces such as elevation. Interval lines were smoothed by on-screen digitalising to produce the map.
Result: Dry period map.

C. Average Temperature of Coldest Month Map

Step 7 The ArcView Spline method was used to interpolate climate data. In this step, Cambodia is viewed as a flat surface, and the height was corrected in Step 9.

Step 8 DTM height map (grid 250 meter) was used to show a 0.6 degree temperature decrease for every 100 metres in elevation (0-100=0, 100-200=0.6 etc).
Result: Temperature maps were corrected with elevation.

Step 9   Map interpolated in step 7 subtracted from map from step 8:
Result: Average annual temperature of the coldest month corrected for height.

Step 10 and 11 The grid map was reclassified as 0 : < 16.5 and 1 : > 16.5 (degrees Celcius) and saved as shape.

Result: Final temperature map of the coldest month for the two classes.

D. Geology Map

Step 12 The Geology map (1997) was reclassified to display the distribution of basalt, sand-siltstone, alluvium (old-recent), Gneisses-schists and complex mixture. Reclassification was necessary to simplify the data into 5 classes for the final model.
Result: Cambodia was reclassified into 5 geology types; on-screen digitalizing was used to smooth the lines and group into larger geology types.

E. Soil Map

Step 13 Complex soil types were reclassified to indicate low, medium and high levels of productivity. Conversion ratios are listed in Appendix iv.
Result: Map showing potential soil classifications.

F. Forest/Land Cover Map

Steps 14 and 15 Forest and land cover map (1997) was reclassified to include agricultural zones, shrublands, deciduous forest, evergreen forest, and mangrove/inundated. See Appendix v for conversion ratio. Reclassification was necessary to simplify the data into 5 classes for the final model.
Result: Cambodia reclassified into 5 land cover types, on-screen digitalizing was used to smooth the lines and group into larger land cover types.

G. Final Gene-Ecological Map

Steps 16 and 17 Maps were converted to shape maps and then combined into a single map. The union option was used to maintain all features/boundaries. Tabular data was cleaned.
Result: Final map including all criteria for gene-ecological zones