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 20^{th} 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 20^{th} 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.

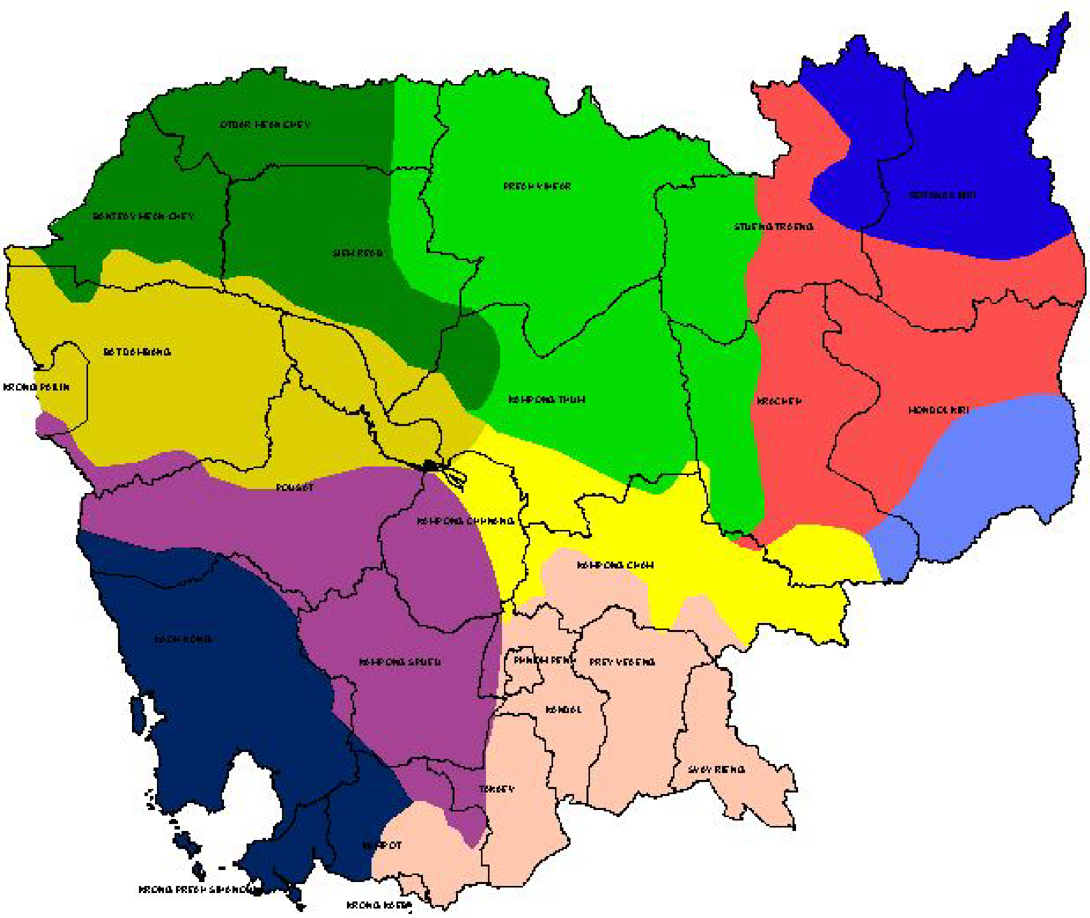
2.3 The Gene-Ecological Zonation Map and its Use in Gene Conservation

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.*