Seeking Principles of Sustainability
A Forest Model Applied to Forest Gardens in Sri Lanka

By

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For Jerry in the spirit of Valle Amme

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CHAPTER 1

INTRODUCTION

The evidence of human destruction of the living environment is overwhelming. Scientists, journalists, physicians and farmers have documented rates of deforestation, soil erosion, species loss and air and water pollution all over the planet (Myers, 1979; Berry 1977; Caulfield, 1985; Eckholm 1982; Jackson, 1984). They tell us that if we are to survive for more than a few more generations, humankind must learn to live within the means of the earth's resources and to nurture rather than to consume her productive capacity. The message is clear and compelling. Sustainable livelihoods must become the goals for which we strive.

Among the most precious of natural resources is productive land. Good management can sustain and enhance its fertility, while poor management lays it to waste. Resource managers seek ways to sustain the production of a wide range of goods and services from the land. Yet, no two parcels of land are entirely alike, and the conditions affecting particular forms of land use at specific points in time are highly variable and not always well understood. It is therefore often difficult to make wise land use decisions.

One factor which contributes to this uncertainty is the absence of a commonly agreed upon definition of the basic objective -sustainable land use. If sustainable land use is to be a goal, then it is necessary to define criteria for distinguishing between sustainable and non-sustainable land uses and management. These criteria would help managers to evaluate the sustainability of one or another land use under a variety of circumstances. Such criteria emerge from implicit or explicit models about how ecosystems respond to human interventions. The absence of a commonly agreed upon definition of sustainabliity is due partly to the lack of explicitly stated models with which to estimate sustainability or non-sustainability.

Models which would make possible comparisons of the sustainability of various land uses could be useful to land managers in evaluating existing or designing new land use systems. The purpose of this thesis is to expand upon emerging models that are designed for the management goal of sustainable land use.

Among the categories of ecosystems for which explicitly defined models have been proposed, two are of particular interest for the purpose of this thesis. One is the tropical rain forest. The other is the traditional agroecosystem. Ecosystems in both categories have demonstrated their sustainability in their persistence over time despite significant variations in

environmental pressures (including human influences) upon them.

Tropical rain forests are believed to be among the oldest, most complex and diverse ecosystems on earth. Formalized scientific efforts to understand tropical forest structure and function have led to the emergence of a variety of ecosystem models (Aubreville, 1938; Richards, 1952; Holdridge, 1971; Janzen, 1975; Halle et al. 1978; Tomlinson and Zimmerman, 1978; Picket and White, 1985).

Traditional agroecosystems passed down for generations, provide farmers with sustained yields for their subsistence and often for sale in the market. Once of little academic interest beyond the realm of anthropology, studies which model these sustainable agroecosystems and their management by agronomists, ecologists and sociologists are increasingly common (Douglass, 1984; Altieri, 1983; Gliessman, et al. 1981).

Researchers have suggested that traditional agroecosystems often resemble natural ecosystems (Geertz, 1963; Marten, 1986). and that the sustainability of the agroecosystems result from this resemblance (Senanayake, 1987). Several researchers have analysed or suggested ways of testing these propositions for systems which incorporate trees, in particular Hart (1980), Ewel (1986) and Senanayake (1987).

Hart proposes that natural ecosystems be used as models for crop system design. First, potentially analogous units of vegetation would be defined then a model of the subsystem of the natural ecosystem which is analogous to the crop system would be constructed. Finally, a new crop system would be designed based upon the model (1980). Ewel demonstrates the importance of successional vegetation for nutrient cycling and storage in natural systems, as well as for protection against pests, and shows how many traditional agricultural systems use long fallow periods to provide these functions (1986). Senanayake proposes the concept of *analog forestry* to describe traditional agroecosystems in which perennial utility species replace natural forest species in systems which are architecturally analogous to the forest (1987).

This thesis draws on these ideas to present an additional approach to analysing the relationship between architectural similarity of natural- and agroecosystems, and the sustainability of agroecosystems. Based upon Hart's proposition, a model of the sustainable structure and function of a natural forest ecosystem is presented. The model uses ecological indicators of system function including several similar to those proposed by Ewel. The model is then used to analyse the structure and function of a long existing agroecosystem, a system which Senanayake calls an analog forestry system.

The thesis tests the hypothesis that if the model of natural forest sustainability fits the agroforestry system, then it can be argued that the model represents common principles of ecological sustainability in these systems. In this case there would be a connection between agroecosystem sustainability and the imitation of natural system structure. Such a finding would indicate the importance of applying an understanding of natural systems function to the design of ecologically sustainable agroecosystems.

If the model does not fit the agroforestry system, limits of the natural forest model would be revealed in assessing underlying principles of ecological sustainability in agroecosystems incorporating trees. Two explanations for this outcome are conceivable. First, the the boundaries, units and/or relationships which define the model are not representative of sustainability in a forest. Second, the model does represent sustainable relationships in the forest but there are alternative ways of achieving ecological sustainability other than those found in natural forest systems.

A detailed description of the model of sustainable forest structure and function is presented in Chapter 2. The methods used to test the model by comparing it to the forest garden systems of Mirahawatte, Sri Lanka follow in the third chapter. The results of the comparison are contained in Chapter 4. In Chapter 5, I conclude that the forest sustainability model does not fully represent sustainability in the agroecosystem. The

model adequately represents structural characteristics of forests and the forest garden system but fails in the description of the processes of change in the human managed system.

CHAPTER 2

SUSTAINABILITY

The concept of sustainability refers to the persistence of relationships at or above some minimum threshold over time despite variable pressures placed upon them. Sustainability can be understood in the context of systems. A system is defined as a set of elements together with relations among the elements and among their states (Hall and Fagan, 1956). Systems are defined to fit a variety of purposes. These purposes provide the basis for describing key relationships and characteristics of their sustainability in the system.

Systems may be termed **closed** if there are no connections across the system's boundaries with the surrounding environment, or **open** if such connections exist (Kitching, 1983:13). Open systems, being linked to their environment through flows of inputs and outputs, are subject to perturbations in their environment. A sustainable system is one within which the key relationships "weather" perturbations and persist into the indefinite future.

In this chapter, a model of ecosystem sustainability will be described for a particular vegetation system, the forest. Next, a continuum of forest and forest-like ecosystems subject to varying degrees of human influence will be presented as a range of land use systems for possible comparison with the

forest. Comparative hypotheses of the applicability of the model to the systems are outlined. Some of these systems have proven to be sustainable based upon their persistence through time. As a test of the model of forest sustainability, it will be applied to describe one of the sustainable systems from the continuum, the tropical forest gardens of the highlands in the Uva Basin, Sri Lanka.

It is useful to distinguish between the interrelated ecological and socio-economic aspects of sustainability. *Ecological sustainability* (which will be discussed in detail below) is understood here as an ecosystem's capacity to maintain its overall productivity over time. *Ecological sustainability* is a function of the biological, physical and climatic environment of an ecosystem. Humans are one factor in a system's biological environment. *Socio-economic sustainability* is an important subcategory of ecological sustainability in systems modified or managed by people, which refers to the system's ability to meet human needs over time. Under such circumstances, the ecosystem is subject to the constraints and demands of human society. Socio-economic decisions influence the composition, structure and management of systems, and thus the overall ecological sustainability of many ecosystems.

Ecosystems are open systems fully exposed to their natural environments and few today, if any, can be said to be free of the influence of human societies. Therefore, a full study

of the concept of sustainability applied to ecosystems would address both the ecological factors as a whole, and the specific human socio-economic influences presented above. This thesis focuses on ecological relationships of sustainable systems, leaving aside socio-economic factors for future consideration.

ECOLOGICAL SUSTAINABILITY

An ecologically sustainable system is productive and resilient over time. Productivity is defined as the rate at which energy is stored by photosynthetic and chemosynthetic activity of producer organisms in the form of organic substances (Odum, 1953:78). Productivity is based upon the continued supply of energy to the system in quantities which exceed the output of energy; and upon the system's ability to capture and process energy, nutrients and water. Resilience is a measure of the capacity of the system to incorporate changes and still maintain the relationships that define the system (Holling, 1973:14.). It determines the persistence of relationships in a system.

A system's ecological sustainability is based upon its structure and function. System's function refers to physiological process. System's structure refers to the anatomy and morphology of the objects under study and to their location in space and time (Mueller-Dombois and Ellenberg, 1974). While the premises of productivity and resilience hold for all sustainable systems, systems' structures differ considerably.

The coral reef, the prairie and the rainforest are just three examples of the innumerable variations.

In order to operationalize the concept of sustainability it is necessary to understand in principle the underlying structure and function of a given ecosystem. A model of the system may be employed to reduce its complexity to a more easily conceptualized level.

> "A model is an imperfect and abstract representation of a real world system. Inadequacies of perception make it impossible to see and work with the real world itself. Perceptions can be illusory and be influenced by confounding from concepts and constructs. Models are neccessary due to our inability to deal with complexity (Schultz, 1983:45) ".

The complexity of a system is determined by the number of its distinct parts and by the number of recognizable states which these parts can assume. In a model, the number of states represented depends entirely upon the tools of measurement chosen. The investigator makes it as simple or complex as she wishes (Schultz, 1969 p. 82).

This thesis will develop a model for a sustainable ecosystem based upon a forest ecosystem. A forest has a distinctive structure and function based upon its dominant life form, tree. As the terrestrial ecosystem with the highest net

primary productivity[1] (Whittaker and Marks, 1985) and the highest biomass per unit area (Whittaker, 1975:224), the forest holds great potential as a production model for agroecosystems. The forest model will represent principles of sustainable structure and function of forest ecosystems.

The proposed model is based upon the following suppositions:

1) Principles of ecological sustainability underlying all ecosystems can be discerned.
2) These common principles are upheld through combinations of structure and function unique to each type of ecosystem.
3) Characteristics indicative of specific ecosystem function can be isolated.
4) Such indicators can be combined to present a model of the ecosystem's ecologically sustainable structure and function.
5) Beyond such a model of sustainable function, the long term persistence of an ecosystem through time in itself is an indication of ecological sustainability, and therefore, the natural forest ecosystem is assumed to be ecologically sustainable.

While the following discussion is relevant to forests in general, examples will be drawn primarily from tropical moist evergreen forest systems.

[1]Net primary productivity is defined as the sum of the net production of all individual plants in a unit area of the Earth's surface.

FOREST STRUCTURE AND FUNCTION

Solar energy, nutrients, carbon dioxide and water are the bases for biological production. All can be said to be equally important, as production would fail without any one of them, yet they are not equally available in all environments. How do systems' structure and function allow the forest to capture and process available energy, nutrients and water and withstand perturbation indefinitely?

Energy Capture

In forest ecosystems energy capture is achieved through the structure of forest canopies. The architecture of each tree allows it to maximize the amount of radiation which reaches its leaves. Leaf size, shape and placement vary with differential light capture strategies. It is common to find several layers of vegetation below the main canopy of a forest in which shade tolerant species survive on light filtered through gaps in the upper canopy. Species-diverse systems in particular, have been shown to have leaf tissue distributed at all height levels (Ewel, 1982).

Energy Processing

The processing of energy by plants in photosynthesis proceeds through carbon dioxide, water and nutrient uptake. Forest root systems extend far down into the soil to bring up nutrients and water. The more diverse the plant species are in

the forest, the more comprehensive is the exploitation of soil minerals as different species' root systems inhabit different levels of the substrata (Ewel, 1982). Also, mutualistic relationships such as nitrogen fixing associations of mycorrhizae with some plants, which may benefit others are most likely to occur in species diverse systems (National Research Council, 1982).

Nutrient Cycling

The maintenance of the productive capacity of the forest is achieved through nutrient cycling. Nutrient cycling is the process of mineral uptake and release by systems components. The cycling is strongly influenced by mean temperature and moisture levels. In a tropical moist forest for example, with high average temperatures and rainfall, productivity is high year round. Large quantities of leaf litter are produced, broken down, and their mineral components made available for plant uptake. The potential for loss of soil nutrients through leaching in the high rainfall environment is great but is counteracted by the great number of tree roots which extend into the soil and into the decomposing litter and dead wood above the ground (Jordan, 1985). Diverse systems have been shown to be more efficient in such nutrient recycling than monocultures (Glover and Beer, 1986).

System maintenance

Forest canopy, litter layer and root systems, so important for energy capture and nutrient uptake, are also among the most important structural features which promote nutrient cycle maintenance. The canopy and litter layers influence the forest microclimate. By shading and covering the forest floor, they dampen diurnal and seasonal shifts of temperature, thus protecting soil microorganisms. They further protect the soil from the erosive impact of heavy rainfall, the canopy by blocking the impact of precipitation (Greenland, 1977), and the litter by soaking up water. The litter layer and its microorganisms provide organic matter to the soil, improving its structure and its moisture and nutrient retention capacity (Brady, 1974:Ch 6). Together these features provide a slow release storage system for water and nutrients. Plant root systems help to drain the soil of excess moisture through transpiration, thus reducing the potential for soil erosion, particularly on steep slopes and after heavy rainfall. In addition to such features of physical structure which maintain nutrient cycling, *resilience* is a characteristic which promotes systems persistence.

Resilience

Resilience is the system's capacity for recovery after disturbance. Structural features which underlie this capacity in most forests include a certain degree of species diversity and of

redundancy in the occupation of niches within the ecosystem. The species diversity of many tropical forests protects the systems as a whole from pest or disease outbreaks which might decimate more simplified systems or make them susceptible to severe destabilizing cycles of population increase and decrease (Risch, 1981; Karel et al. 1982). As described above, species diversity contributes to systems' ability to exploit radiation, soil water and nutrients (Brown, 1982; Ewel et al. 1982; Christanty, 1981). Redundancy on the other hand, is the replication of function by several different species. Should one species fail, its function may be picked up by others and the maintenance of the system ensured (Odum, 1971).

While this summary of the energy capturing and processing, nutrient cycling and resiliency maintaining functions of the forest structure is not comprehensive, it does demonstrate that it is possible to isolate indicators of systems function which represent the underlying sustainability of the ecosystem. These indicators describe a link between a concept of sustainability and its application to ecosystems. A variety of combinations of indicators might adequately describe systems function. This model employs the following combination as a group of variables sufficient to represent sustainable systems function.

INDICATORS OF SUSTAINABLE FOREST STRUCTURE AND FUNCTION

Dominant Life Form

The tree as the dominant life form defines the forest. In vegetation ecology, dominants are defined as members of a plant community which have a determining or controlling influence on the rest of the vegetation belonging to it (Richards et al, 1939). Dominants receive the full impact of climate. They are the species best adapted to climate, the most abundant in density and weight, and the most stable in reproduction. They directly affect the microclimate, modifying water and light relations on the ground (Clements and Shelford, 1939). This characteristic of forests is quite obvious - trees are the building blocks of forest structure. At the individual tree level, work has been undertaken to model the architecture[2] and growth dynamics of tropical species (Halle et al. 1978). A tree's architecture and its influence upon the system extends into vertical and horizontal space above and below ground.

Density and Cover

The abundance of trees and their stand architecture determine the degree to which they dominate space and affect the microclimate of their surroundings. Thus two other indicators of forest structure are density, or the number of

[2] Tree architecture is defined by Halle et al as the visible, morphological expression of the genetic blueprint of a tree at any one time (1978, p. 74-75).

trees per unit area (Mueller-Dombois and Ellenberg, 1974:69); and cover, or the vertical projection of the crown or shoot area of a species to the ground surface (*Ibid*::80). As indicated, the degree of canopy closure is a function of density and cover which greatly influences forest structure by determining the site conditions including light, temperature and moisture regimes for the growth of other species beneath the canopy, as well as the soil's exposure to precipitation and erosion.

Tiered Structure

Forests are often described as mosaics of vegetation reflecting cycles of decay and regeneration and the effects of past perturbations (Aubreville, 1938; Oldemann, 1976:556). Forest canopies are not uniform. In theory, different horizontal layers or canopy strata can be identified in the vertical dimension of wet evergreen forests (Richards, 1952). The layers below the top canopy level are made up of juveniles and suppressed individuals of the tree species in the dominant canopy and of shade tolerant understory species which never grow to the height of the upper canopy (Oldemann, 1976). There is some debate over the concept of canopy layering and whether vertical structure is continuous or discontinuous. As the forest is in a constant state of flux, distinct layerings may be difficult to identify, particularly in pioneer stages of succession (Halle *et al*, 1978:333).

One way of distinguishing levels of vegetation is to base height classes on the average heights of mature individuals of the predominant species below the upper canopy. Canopy closure at each level can be measured. While distinctions between layers may have to be drawn arbitrarily at times, even evidence of partial layering or height class differentiation may be useful in describing forest structure. For example, the degree to which the canopy is structured in layers of vegetation at different heights may provide some insight into age class structure and/or successional stages in a forest. Some mature forests for example, have a cathedral like structure with a dense layer of canopy formed by the crowns of dominant trees which lets so little light through as to preclude the growth of all but a few very shade tolerant plants below, unless tree fall creates a gap in the upper canopy. By contrast, younger successional stages may have several levels of vegetation below a not yet completely closed upper canopy which allows more light to pass through to lower levels. In the lower levels might be mixtures of immature individuals of upper canopy species and mature individuals of more or less shade tolerant species (depending on the stage in the successional process) with smaller growth habits.

Species Diversity

The concept of species diversity combines two measures of species occurrence. It refers to: 1) the number of species in a community, the community's *species richness;* and 2) the

"mixtures of different crop species or varieties buffer against disease losses by delaying the rate of increase of the disease..." (Altieri et al., 1984:182)

These five indicators, *density; canopy closure; dominant life form; tiered structure* and *species diversity* can be used to define forest structure in vertical and horizontal space at a given point in time. In addition, it is neccessary to define indicators of adaptation to perturbations and of change in forest structure over time. Two primary processes are important in this regard, regeneration and succession.

Regeneration

Regeneration is the process of forest renewal and perpetuation in the basic cycle of life and death of individual plants. As one tree dies it is replaced by other plants in the process of gap phase succession, or system's maintenance (Watt, 1947, Whitmore, 1978; Hartshorn, 1976; Halle, et al.,1978,). In some forests, in the tropics for example, regeneration may be difficult to quantify, other than by studying these gaps. Because of the high species diversity in many tropical moist forests, the species of tree which ultimately takes the place of a fallen tree is unlikely to be of the same species as the first (Aubreville, 1938). A great variety of seed production and dispersal strategies can be found (Janzen, 1975). The degree of perturbation creating the gap and gap size greatly influence the success of individual

strategies and the selection of species which will occupy the site next and the rate of the forest's return to its closed structure (Denslow, 1980). In addition, the cycle of regeneration is affected by year to year variations in climate or other environmental factors (Miles, 1979:12).

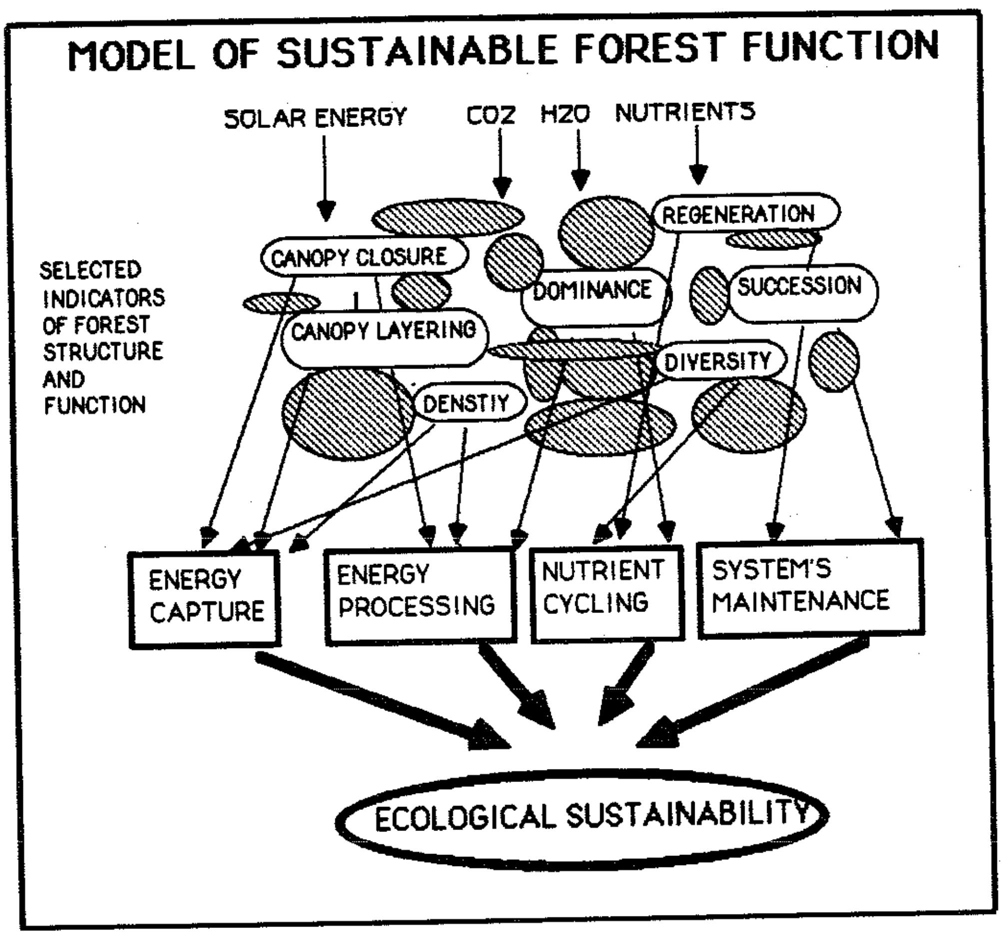
Succession

Succession is defined as directional change in the composition of a vegetation unit away from a mean within one stage of development and toward a state of relative homeostasis (Miles, 1979:11-20). As the structure and composition of vegetation change with succession toward a mature forest, Odum points out that the dominant tree species become more long lived; the stratification and pattern of system's structure are more organized and easily identifiable; and species richness and the evenness of species distribution increase. In addition, the overall biomass supported per unit of energy flow in the system increases and the amount of organic matter is high. System's resilience and the ability to resist perturbations increase (Odum, 1969). While certain aspects of Odum's views on succession have been criticized (Drury and Nisbet, 1983), overall his approach is instructive, proposing in effect, that sustainability increases with succession. Both processes, regeneration and succession, are at work at any one time and are interrelated.

A MODEL OF FOREST ECOSYSTEM SUSTAINABILITY

At the beginning of ths chapter it was assumed that forests are sustainable ecosystems and that certain processes are the basis of that sustainability. These were identified as *Energy capture, Energy processing, nutrient cycling* and *systems maintenance.* It was proposed that measurable structural and functional characteristics underlie these processes and may be used as indicators of sustainability.

FIGURE 1:



Seven indicators were chosen as *sufficient* to represent the processes of sustainable systems function (other combinations of forest characteristics are conceivable - the shaded elipses in Figure 1 - so long as they too give indications of the underlying processes of forest function). It is proposed that if all seven indicators (dominance, density, cover, tiered structure, diversity, regeneration and succession) are present and measurable within ranges expected for forest ecosystems, then the system is sustainable and a forest analog (Figure 1). The degree to which indicators are not present for the specified ranges in a system will indicate the degree to which the system is not sustainable or to which the model fails to represent the system's function.

Such a model might be used as a check list in evaluating the sustainability of various forest like systems. It is the purpose of this thesis to test the model itself, by applying it to an ecosystem which is already known to be sustainable. The degree to which the model fits the system will be an indication of its possible usefulness in analysing sustainability in a variety of forest and forest like ecosystems.

THE FOREST ECOSYSTEM CONTINUUM

On a continuum of ecosystems dominated by trees one can distinguish systems subject to varying degrees of human intervention. On one end lies the primary natural forest, on the other the monoculture, even-aged tree plantation. The primary

forest is the system from which the indicators of sustainability are drawn. As it has persisted through adaptation to perturbations, it is ecologically sustainable. On the other hand, the commercial plantation which maintains productivity in temperate climates, is not always sustainable without outside energy inputs in the moist tropics. Plantations of *Hevea brasilensis* in the moist tropical climate of Sri Lanka, for example, are heavily tapped for latex. Yields are kept high with fertilizer. Unless a steady supply of increasingly scarce (and therefore expensive) fossil fuel inputs can be guaranteed for them, such plantations are not sustainable in the long term.

Between these extremes lie other systems subject to varying degrees of human influence. Six systems are presented in Figure 2:

1) Primary forest.

2) Secondary forest: approaches maturity after a major disturbance caused, for example, by a fire or cyclone.

3) Managed secondary forest: Large areas in the Amazon basin have been shown to have been subject to human foraging. In these areas of minor disturbances, such as the removal of individual trees, regeneration is similar to gap phase succession. In some documented cases in Mexico and the Amazon, the species composition of the regenerating forest is selected for by local inhabitants (Alcorn, 1984; Denevan et al.,1984). This guiding of species composition is a form of

cultivation and marks the differentiation of human from all other biotic influences in the forest.

4) Shifting cultivation: Larger gaps are cleared and planted for short periods of time. There are numerous studies of such planting systems, primarily of annual or short-lived cultivars, and their various stages of tree fallow prior to complete recovery by the forest, beginning with Conklin's 1957 study of Hanunoo swidden agriculture in the Philippines. In extreme cases, induced for example by population pressure, fallow periods are reduced to the extent that forest land is converted completely to agriculture.

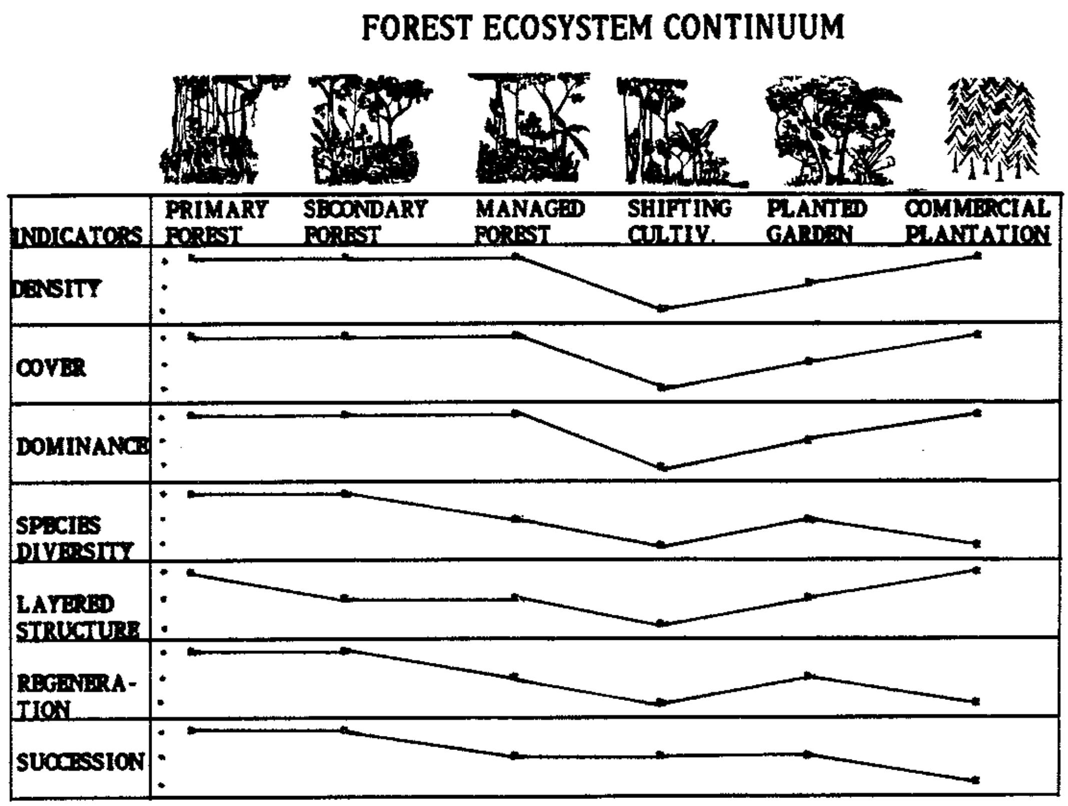
5) Planted Gardens: In parts of the tropics, permanent planted gardens of perennials are common. Such home or forest gardens may include "volunteers" of forest species but are dominated by more domesticated tree cultivars. These systems are no longer natural forests subject to varying degrees of human impact, but rather cultivated forest-like systems. They have been described in recent work from Costa Rica (Lagemann and Hueveldop, 1983); Mexico (Gliessman, 1984); Tanzania (Fernandes et al. 1984); Thailand (Kunstadter, 1983); India (Nair and Sreedharan, 1986); and Indonesia (Soemarwoto et al. 1985, Christanty et al. 1986, Michon et al. 1983).

6) Commerical plantations.

In Figure 2 the different systems along the continuum are compared with respect to the indicators of sustainable

forest structure on a hypothetical basis with a range of high, medium and low. One might expect for example, that all indicators would be measurable at a high level in a primary

FIGURE 2:



forest, but that canopy layering might be less distinctive in a secondary forest. Cover would be low in a patch of forest recovering from shifting cultivation, and species diversity would be low in most commercial plantations.

One system from the continuum, the planted garden, will now be more closely analysed with respect to the model. The

forest gardens of the Uva Basin in the South Central Highlands of Sri Lanka, will be introduced to test the relevance of the indicators of the forest sustainability model as presented here.

CHAPTER 3

RESEARCH METHODS

In the previous chapter a model of sustainable forest structure based upon seven indicators of forest function was proposed. One way of testing this model of "natural" ecosystem sustainability is to apply the model to a sustainable ecosystem designed and managed by people. Here the model will be applied to the forest garden systems of Sri Lanka, specifically of the village of Mirahawatte in the Uva Basin (Figure 3).

The Uva Basin lies in the South Central highlands of Sri Lanka at an elevation of 3,000-4,000 ft. Surrounding the large basin of rolling hills and steep valleys is a rim of mountains which reach peaks above 7,000 ft. Two rivers, the Badulla and Uma Oyas are the major drainages, both tributaries of the Mahaweli Ganga, the largest river in Sri Lanka.

Due to its particular location relative to the monsoon winds, the Uva is a drier region than either the mountains above or the Kandyan hills to the west but moister than the dry zone on the peneplain below. The average annual rainfall near the research site of Mirahawatte (measured at Diyatalawa, 3 km away) is 1743 mm. In the peak rainfall months torrential downpours are common, while there may be no rain at all in the dry months of July and August.

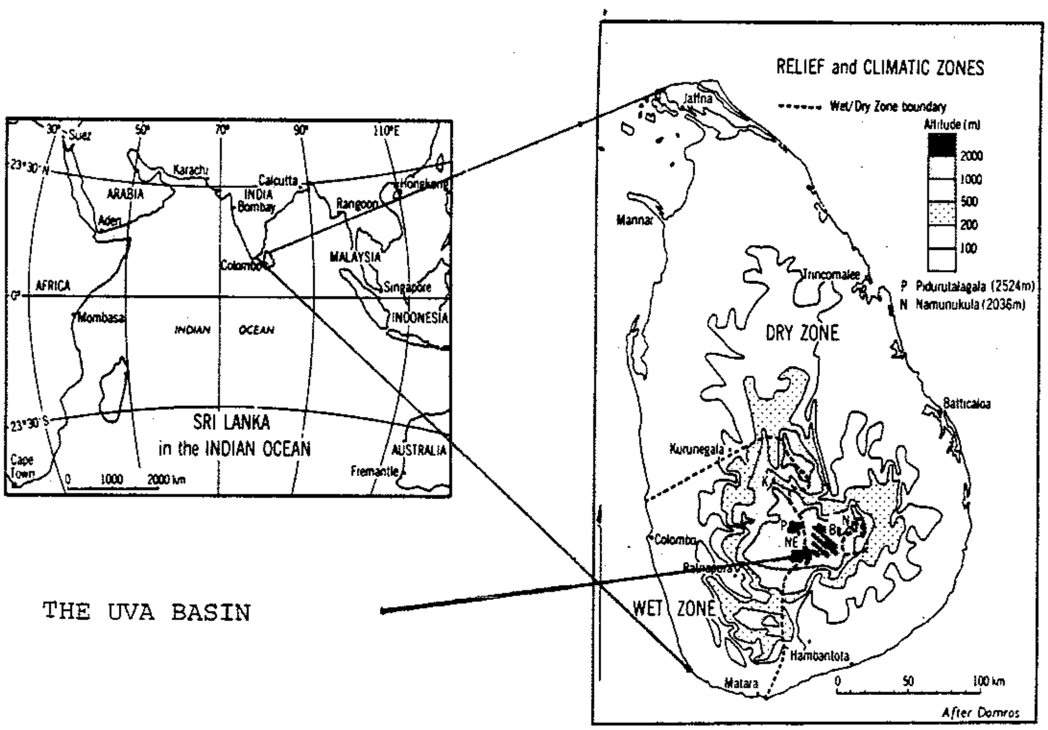
Climate is an important factor influencing soil formation in Sri Lanka. The boundaries of the major soil groups largely follow the

pattern of rainfall divisions even when they have developed on the same parent material (de Alwis et al 1981). The soils in the Uva are primarily red-yellow podzolics. They are derivatives from crystalline metamorphic rocks, typically well drained, and loamy to clayey in texture. The structure of the predominant grassland soils is described as follows:

> "Most of the A horizon in the grassland has been eroded with 0-12" of dark brown clay loam with quarz gravel inclusions remaining. The B horizon is typically 9-10" deep with quartz fragments and iron concretions. The C horizon is a10-18" layer of quarz sand with clay inclusions" (Perera, 1969).

In areas where the top soil has remained intact the basin's soils are thus quite fertile and well drained. However, the long history of vegetation disturbance has led to widespread degradation of the land.

FIGURE 3: SRI LANKA AND THE UVA BASIN



Adapted from Johnson and Scrivenor, 1981

THE FOREST GARDENS

The forest gardens of Sri Lanka are traditional agroforestry systems in which trees and perennial shrubs predominate. Typically located immediately around the owners' home, the gardens vary in species composition with elevation and climate. They are commonly one component of the larger farming system which may also include rice paddies, vegetable fields and/or plantation crops such as tea, rubber or coconuts. The gardens provide a wide variety of food, fuel, fodder, wood and medicinal crops as well as a cool and pleasant living environment.

The forest gardens of the Uva region, are deemed to be sustainable systems because they have persisted there, contributing to subsistence cultivation, for many decades if not centuries. It is difficult to say exactly how long the garden systems have existed in the Uva Basin. Irrigation works for rice cultivation indicate that the basin was inhabited by the 13th century (Holmes, 1951). I have not found a direct reference to the gardens. However, in the 1817-19 Uva Rebellion of the highland villagers against the British colonial power, the order was given to the British soldiers that

> "all men above 18 were to be killed; all houses pulled down and burned; *all trees bearing fruits of use to human beings* felled; all grain destroyed and confiscated; all irrigation tanks and canals breached; and all cattle belonging to the people which were in excess of the requirements of the army should be destroyed." (Vimalananda, 1970:13 - my emphasis)

The orders indicate that the area was settled and farmed in systems of rice and garden cultivation with some livestock as is common today. The extent of the destruction caused as the order was carried out is unknown. By 1859 however, the British historian, Tennent, refers to the "people of the Oovah" as skillfull farmers and irrigators and to local production of coffee, a common forest garden crop today (Tennent, 1859, Vol II:267). In the village of Mirahawatte many gardens predate living memory and elders talk about the gardens of their grandparents. This indirect evidence suggests that the garden systems of the Uva are very old, certainly existing by the early British colonial period.

RESEARCH HYPOTHESIS

The model of sustainable forest ecosystem function will be applied to this sustainable agroforestry system to test the following hypothesis:

If the natural forest model of sustainable function fits the sustainable forest garden system's structure and function, then it is a workable model of sustainable systems' function.

The degree to which the forest model of sustainability fits the forest garden systems will determine the validity of the forest model in representing sustainable ecosystem function. It will also indicate the degree to which the two systems are similar in structure and function, and thus whether the agroforestry system in some way is a structural equivalent or

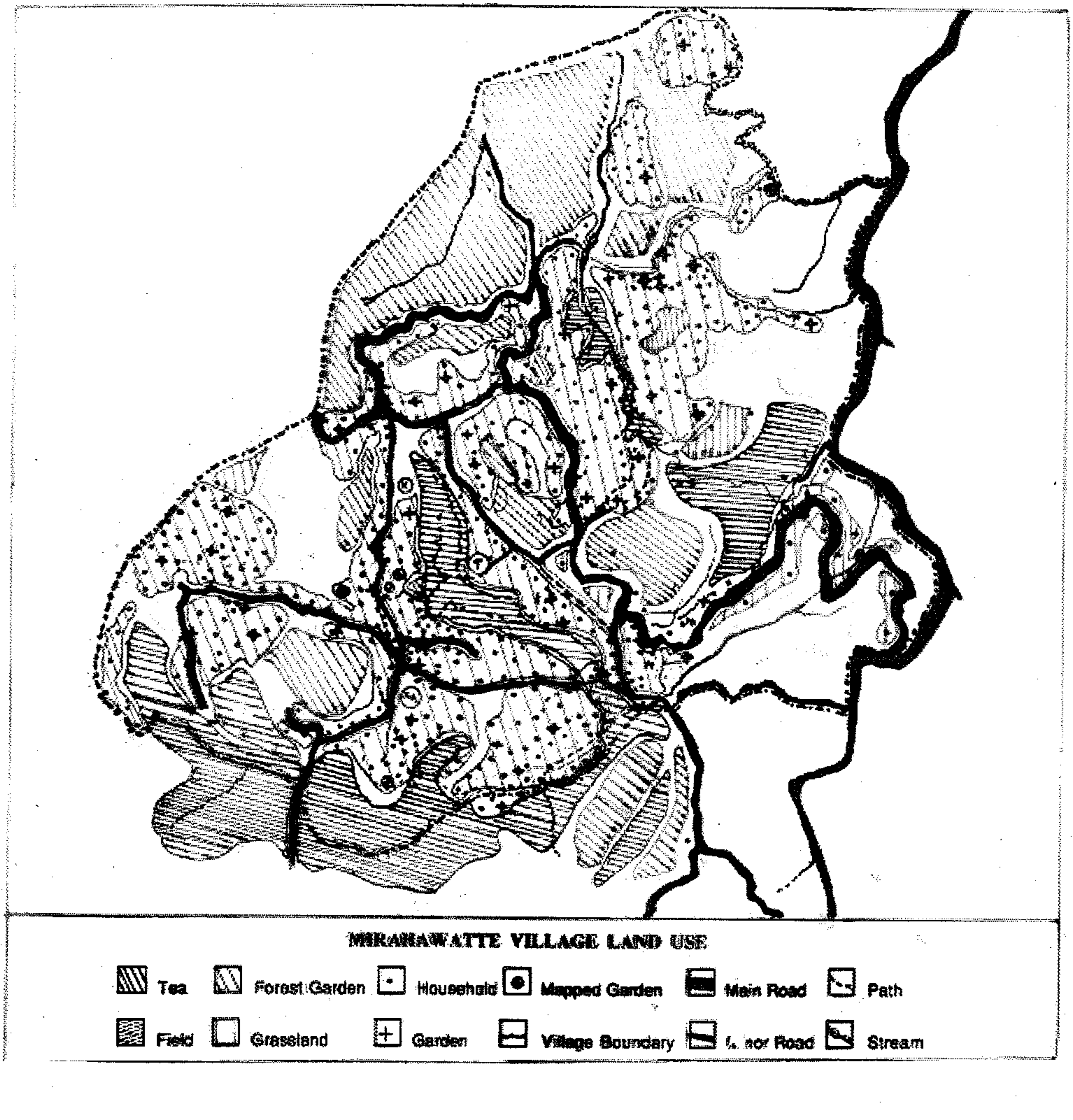
analog of the natural system. The degree to which the model does not fit the agroforestry system will indicate limitations of the natural forest model itself or its weakness in representing sustainable ecosystem function, for example, by failing to incorporate other attributes of sustainable structure which are found in systems managed by people.

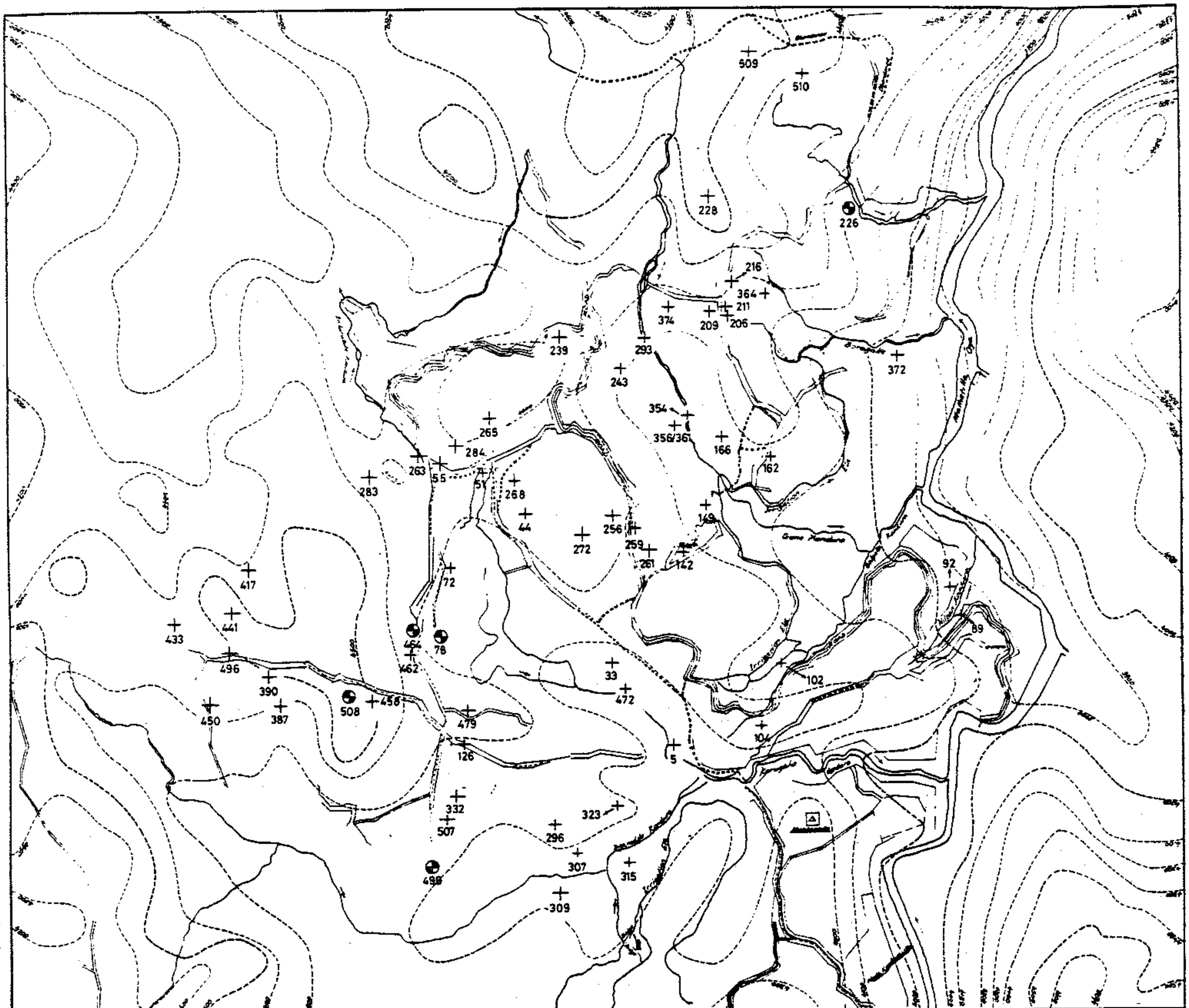
In the following pages, the methods used to identify and measure the seven indicators of forest function in the forest gardens of the village of Mirahawatte, Sri Lanka will be described. The study was conducted in Sri Lanka from November, 1985 - November, 1986.

SURVEY

Mirahawatte was chosen because of its proximity to the NeoSynthesis Research Center[1].which supported my research. The village lies at an elevation of 4,000 ft. With 600 households it is above average in size but otherwise typical of the villages of the Uva Basin. Private land use is divided between agricultural fields (31.2%), gardens (49.2%), and tea plantings (19.6%)[2]. The surrounding grasslands, forest and tea plantations belong to the government. As a one inch to one mile topographical map was the only map available, I began work with mapping the village (Figure 4). When all known

[1]NSRC is a non-profit research organisation incorporated in California and Sri Lanka.
[2]Based upon the survey of 61 village households.


MIRAHAWATTE VILLAGE LAND USE
Tea
Forest Garden
Household
Mapped Garden
Main Road
Path
Field
Grassland
Garden
Village Boundary
Road
Stream



MIRAHAWATTE VILLAGE & SURROUNDINGS

Scale : 8 chains to an inch

(1 : 6,336)

NEO SYNTHESIS RESEARCH CENTRE

Forest Gardens Project 1986

NOTE: This drawing was compiled from enlargements of relevant parts of the Nuwara Eliya 1 inch to one mile sheet and Final Village Plans nr. 54 [illegible], 62 [illegible], 63 Mirahawatte, 69 [illegible] & 72 [illegible].

10th September 1986

NSRC, Topography Dept

village households had been located on the map, a random survey of 10% (n=61) of the village households and gardens was carried out. The survey was done with the help of a research assistent who spoke fluent English and Sinhala. For each household visited, garden structure and composition were inventoried and the family was interviewed on species uses, garden management, land tenure and general household information (Appendix 1 is a copy of the inventory sheet used).

Five gardens of particular interest were selected from the original survey for closer study. These five gardens were notable because they were particularly diverse, produced cash income, were located on especially good or poor sites, and/or belonged to owners who were most willing to allow us to study their gardens and to tell us about their management practices. A professional surveyor and I mapped these gardens in detail, including every perennial tree or shrub. Ten additional gardens were selected from the survey to represent (together with the first five gardens mapped) all size and age classes of gardens found in the village. The boundaries of these ten gardens were measured and the placement of their component species noted in sketch maps. A second round of interviews focusing on specific management information was carried out with members from the 15 households with gardens mapped or sketched.

MEASUREMENTS

Dominance, Density and Diversity:

In the course of field data collection, the indicators of dominance, density and diversity were described in the following manner. The garden, as the individual unit of analysis, was bounded by property lines. Garden boundaries and size to the nearest quarter of an acre were determined in the household interview. Ocular estimates were used to judge the reliability of the acreage responses. (Informant response on garden size was accurate in the subsample of the five gardens which were measured by the surveyor). In each garden the species of all woody perennials and the number of individuals per species were noted (Appendix 2 is a list of species found in the gardens). These data provide the basis for the determination of the dominant life form present in each garden; for density as the number of individuals per acre; and for species diversity.

Cover and Layered Canopy:

The degree of cover and the layered canopy structure of the gardens were measured in two steps. In the 61 garden inventory the height of each tree and shrub was estimated as belonging to one of five classes. The height classes were: (1) <2m; (2) 2-5m; (3) 5-15m; (4) 15-25m; and (5) >25m. In addition each individual was placed in one of the following five age/vigor class categories: (1) seedling; (2) juvenile; (3)

mature/juvenile; (4) mature; (5) over-mature or deteriorating. The difficulty of determining age classes for tropical tree species has been noted (Hartshorn, 1976), therefore the data reflect relative age/vigor of the trees in the sample. In this case, however, the purpose of gathering height and age class estimates is to gain a sense of the average size and therefore canopy placement of vigorous, mature individuals of each species, a purpose for which these data are quite sufficient. The data on canopy layering were supplemented with information gathered in the five mapped gardens.

As mentioned above, the perennials in the five gardens were surveyed in detail for horizontal distribution. In addition, one two meter wide transect line was chosen for each garden to represent all categories of vertical vegetation structure from open to very dense and shaded. All tree heights along this line were measured with an abne level. (The accuracy of the previous height estimates in the five classes for the trees on the line cross-checked well with these more precise data.) The height and species data were used to create views of vertical garden structure and levels of vegetation for these gardens. The transect drawn for garden No. 464 is appended (Appendix 3).

In addition, the canopy extension of each perennial was measured to gain an indication of cover or canopy closure in the five gardens. The crown diameter method described by Mueller-Dombois and Ellenberg (1974) was adapted to the

existing field conditions as follows: Each crown was measured with a tape from one side of the crown perimeter across the center to the other side, resulting in one diameter reading. Because crowns are rarely circular, it is common practice to measure crown extension in the described fashion in at least two directions. This double measure was not feasible due to the limited time available for work with the surveyor. Therefore, only one canopy diameter per tree was taken. This measure was, however, always taken at a 90 degree angle from the chain lines which had been laid out to survey the garden. The chain lines had been placed to measure the dimensions of the gardens independently of their vegetation. Thus, this measure of crown extension is based upon a systematic collection procedure independent of the variable in question. The large sample size of over 100 trees and shrubs in each garden should ensure adequate representation of extension. Therefore, while the actual shape of the individuals crowns is not known, the approximate cover throughout each garden can be estimated with the resulting circular crown facsimiles. These circle diameters were used to create overlay maps representing tree canopies and the degree of crown closure in each garden as a whole, and at four above ground heights of (1) 0-2m; (2) 2-5m; (3) 5-15m; (4)15-25m (the above 25m category was not represented). The percent canopy closure created by the circular crown representations was measured for all layers and for each layer independently with a

plenimeter (Figure 5 is a reduction of the map of garden No. 464 with two overlays).

Regeneration and Succession:

The indicators of regeneration and succession were addressed with garden inventory data, with information from interviews on management and from the literature on the natural vegetation of the area. Regeneration and succession are two processes strongly influenced in systems where composition is managed by people.

Regeneration

Regeneration in a forest garden may occur as it would in a natural forest with a root sucker or a seed by chance arriving in a suitable place and beginning to grow. But the majority of woody perennials in the gardens are planted. Someone has taken the care to select a given seed or seedling and place it in a desired spot, perhaps even adding compost or water to give the plant's roots a head start. The survival rates of such carefully nurtured individuals is expected to exceed the natural rate of survival. The species planted may not be a species which would normally occur at that site. A young, tolerant tree, normally needing shade, may survive the seedling stage with the extra water supply added by the farmer. Both the processes of natural and planned regeneration (planting) were studied in the gardens.

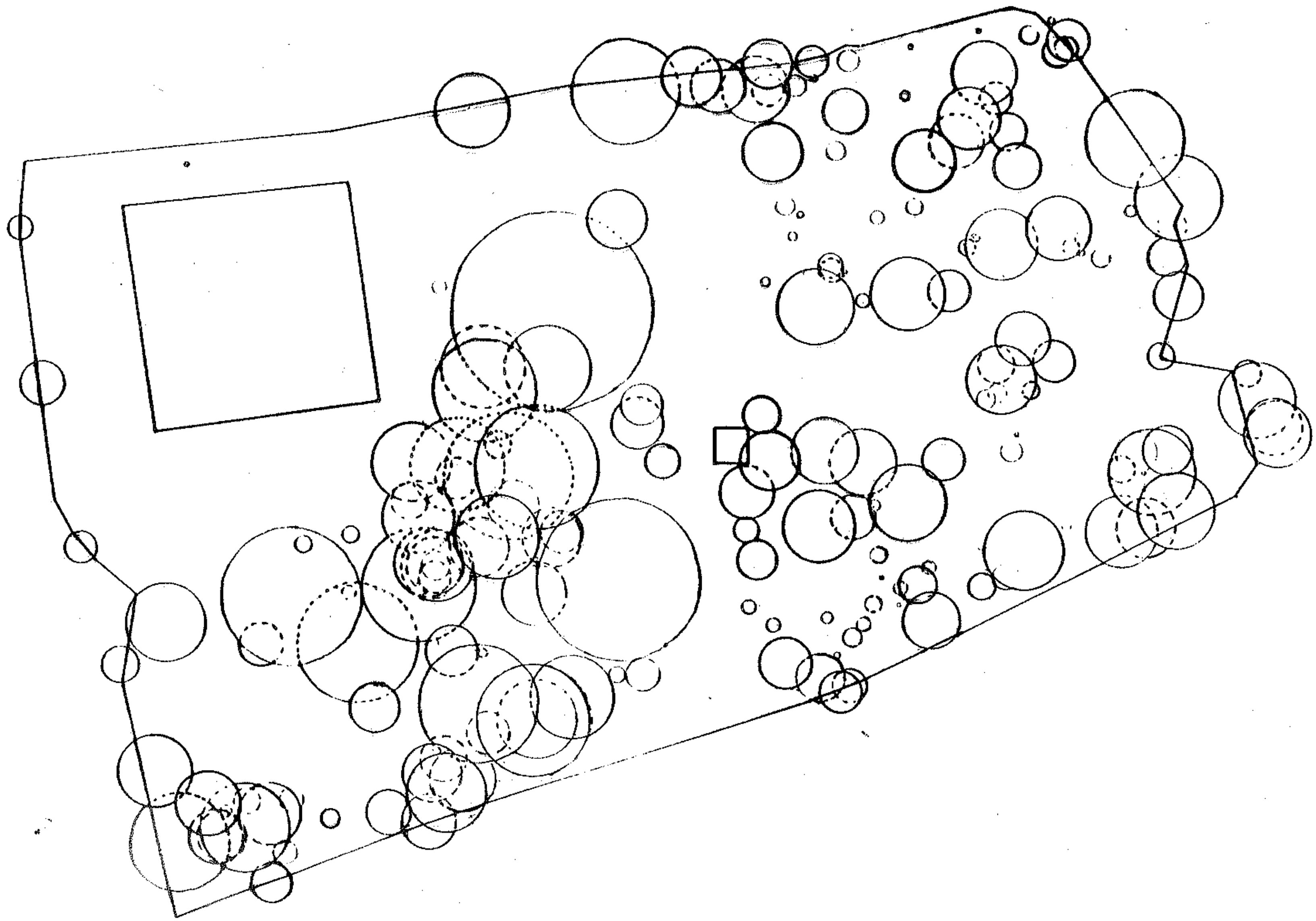
In interviews, the species of trees planted were distinguished from "volunteers" or self-sown species. Volunteers are usually left to grow and may eventually be used for fuel. The proportion of such volunteers to planted species (many of which also are actually volunteers from planted species within the garden or from surrounding gardens) will give a conservative estimate of natural regeneration occurring in the gardens. Information on planting practices was also elicited.

Succession

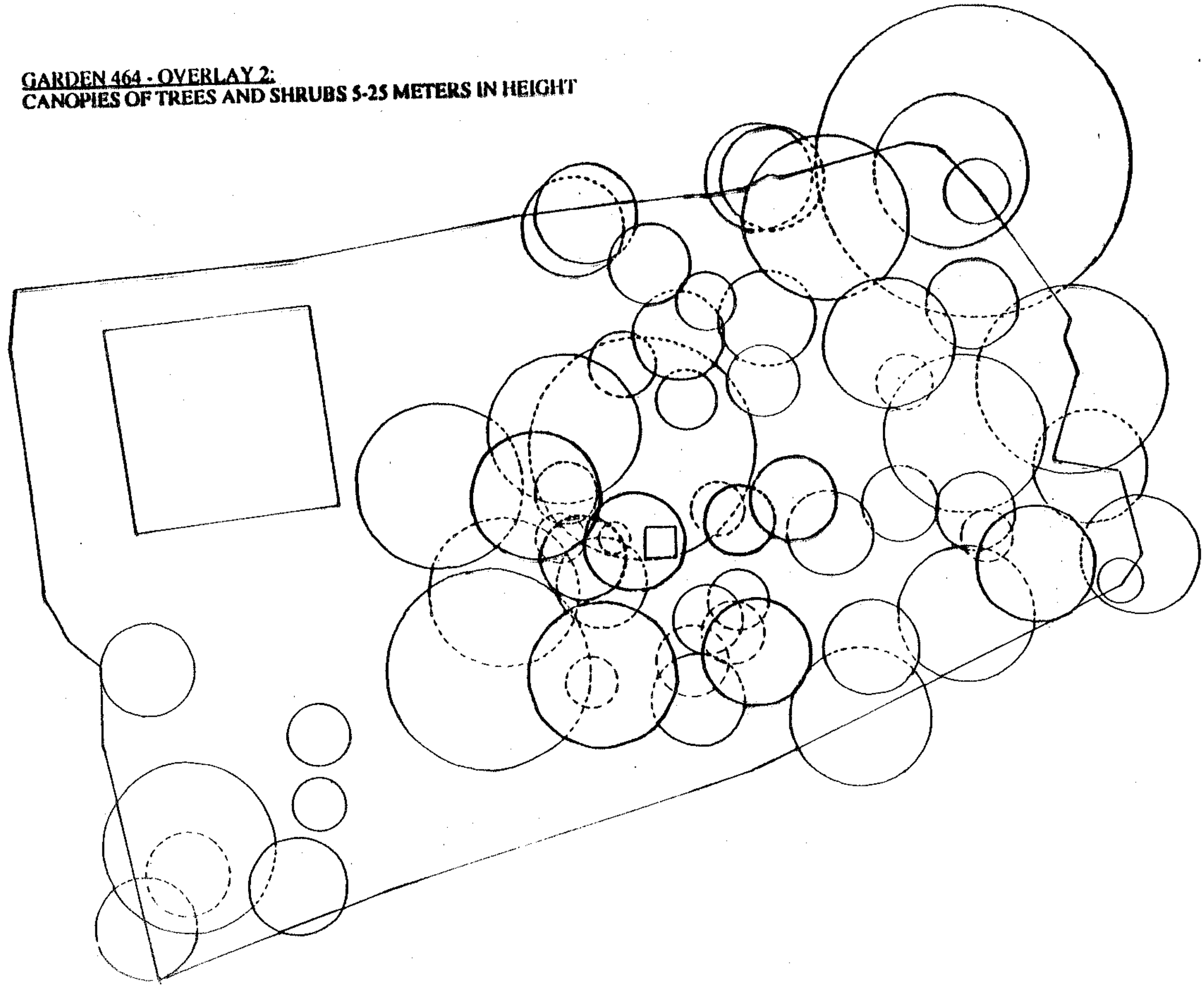
Although the concept of succession is rarely discussed in connection with systems designed and planted by people, it is appropriate in a case in which the biomass production on a site changes from grassland scrub to forestlike garden, with, if people and sometimes livestock may be considered to be part of the system, no outside energy inputs added.

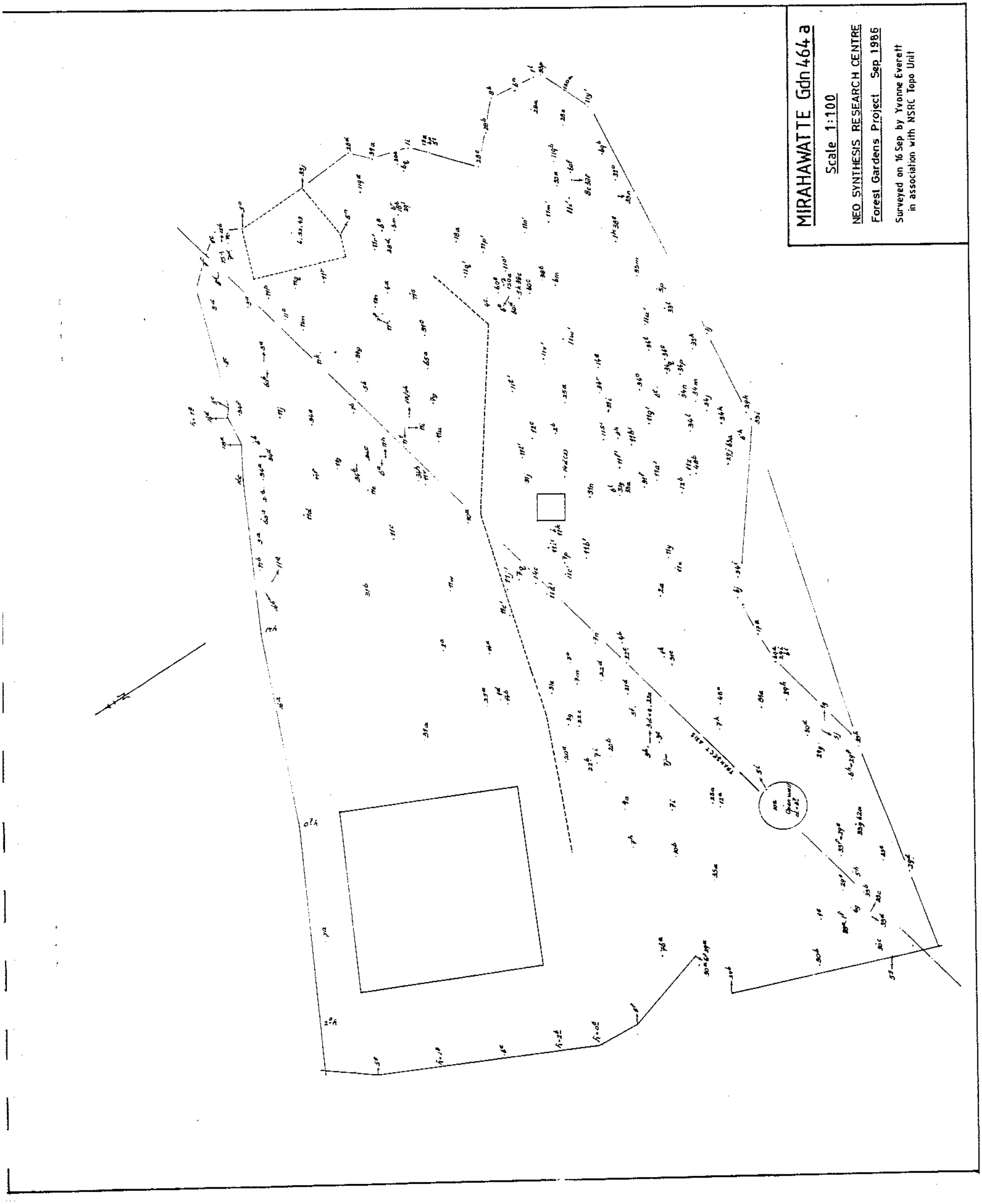
Since succession was first described by Clements in 1916, the concept has been much debated. Clements described succession as the directional change of vegetation, proceeding through stages in which each stage prepared the site for the next, a process which eventually would lead to a stable, self perpetuating climax state (Clements, 1916). While the underlying dynamic of succession is accepted by most ecologists, many aspects of Clements' theory have been subject to modification (Miles, 1979:13). For example, some authors

GARDEN 464 - OVERLAY 1:
CANOPIES OF TREES AND SHRUBS 0-5 METERS IN HEIGHT



GARDEN 464 - OVERLAY 2:
CANOPIES OF TREES AND SHRUBS 5-25 METERS IN HEIGHT




MIRAHAWATTE Gdn 464 a
Scale 1:100
NEO SYNTHESIS RESEARCH CENTRE
Forest Gardens Project Sep 1986
Surveyed on 16 Sep by Yvonne Everett
in association with NSRC Topo Unit

emphasize the continuous nature of change subject to many influences in which delineated stages of succession are necessarily arbitrary. Whittaker has stated:

> "Causes of successional changes are to varying degrees external to the community or internal to the community; many successions involve both kinds of causes and reciprocal influences. In any case, a gradient of changing species populations and community characteristics parallel one another. A succession is an ecocline in time." (1975:171)

Another aspect of the original model which is subject to debate is the notion of climax.. Ecologists have rebelled against a seemingly deterministic vision of a uniform, static state. Again, Whittaker has presented an expanded definition:

> "The climax community is to be conceived as an open system in steady state through which individual organisms, energy, nutrients and organic matter flow, while the community remains relatively constant over time. The climax community is self maintaining: adapted to essentially permanent steady-state function in relation to its environment, potentially immortal if not disturbed." (Ibid:180).

Maximum biomass is seen as a good measure of climax in terrestrial systems, based upon near equity of total organic synthesis and breakdown. A mature forest would be an example.

While the concept thus stated is clear, succession proceeds slowly on a given site and is difficult to measure. One common way of analysing the process is to delineate stages of change for a particular vegetation type based upon the species

composition evident on similar sites under similar conditions. If the growth requirements of component species are known, the species of a given plot of vegetation can thus be categorized as belonging to one or another stage in succession for that vegetation type. This process can be applied to natural vegetation as well as to human managed systems.

The site quality of the gardens and the surrounding unmanaged vegetation was very similar for such major factors as initial soils and climate. An understanding of succession in the gardens was approached by studying the known growth habits of volunteer species from the surrounding forests and grasslands. The unknown process of within garden and between garden change could thus be compared with succession outside the garden. While only remnants of natural forests remain in the Uva Basin, Gaussen et al have described the naturally occuring forest species at this elevation in Sri Lanka (1965). Species from earlier stages of succession are found in grasslands and scrub brush patches. Several of these species occur in the gardens. Their growth requirements, growth rates and longevity are known, and they can be assigned to relative categories representing different stages of succession.

The planted species in the gardens were divided into groups paralleling those of the forest species along a continuum based upon growth requirements, growth rates and longevity. In order to analyse within garden patterns of change, the

distribution patterns of these species in the gardens were noted in particular for the fifteen gardens with mapped or sketched species locations. Farmers were interviewed to learn which species were planted together and where. Between garden patterns were compared using variables of garden age, and size, as well as a family's total landownership which had been noted in the household interviews. In the following chapter the analysis of the data gathered and the results of the analysis will be presented.

CHAPTER 4

DATA ANALYSIS AND RESULTS

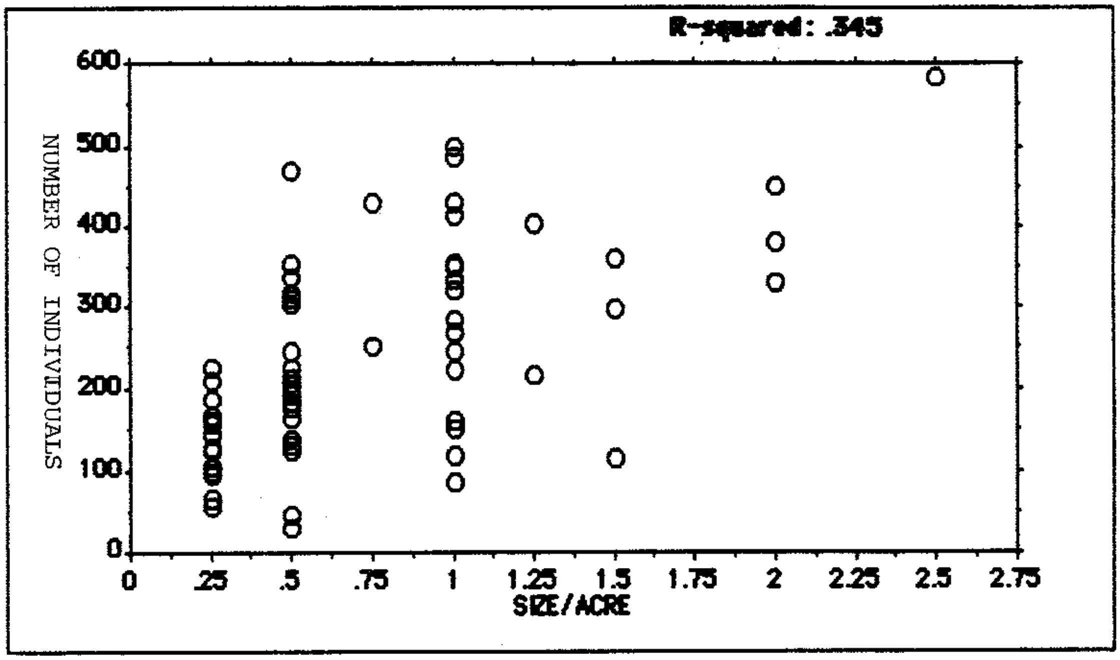
Data gathered in the Mirahawatte gardens were organized in seven categories to provide a basis for comparison with data for the seven indicators of sustainability in the forest model. *Density, Cover, Tiered Structure and Species Diversity* are four indicator categories for which the discrete data gathered were suited to quantitative analysis. *Dominance,* as well as the indicators of process, *Regeneration* and *Succession,* are categories for which a qualitative analysis was more useful. In the following pages the results of the data analysis for each indicator will be presented and compared with relevant data on forest systems from the literature. The degree to which each indicator from the forest model is applicable to the gardens will be discussed. Based upon these results for the individual indicators, the applicability or usefulness of the model as a whole, will be discussed in Chapter 4.

DENSITY

Forests produce and store large amounts of biomass. *Density,* defined in Chapter 1 as the number of woody perennials per unit area, is one descriptive indicator of above and below ground biomass. Figure 6 presents a correlation of garden size and the number of individuals per garden found in the 61 household survey. The average number of individuals found per unit area depended upon

garden size, with greater numbers of individuals per unit area found in smaller gardens. The gardens ranged in size from 1/4 acre with an average number of 137 individuals (n=14;); to 1/2 acre with an

FIGURE 6: CORRELATION BETWEEN GARDEN SIZE AND NUMBER OF INDIVIDUALS



average of 253 individuals (n=20;); to 1 acre with 314 individuals on average (n=15;). The largest garden in the survey was 2 1/2 acres in size with 584 individuals (average numbers of individuals were not calculated for size classes of 3/4 acre and greater than 1 acre due to the small sample sizes of 2-3 each.)

Smaller gardens are more dense and more intensively managed. It is possible that owners of small gardens are less likely to own other land and are thus more dependent on their gardens for subsistence. The average density of 314 individuals per acre can be

used in comparing garden density to average density values for various forest types in the literature. Density values for various forest types are tabulated below (Table 1) from Holdridge's Life Zone Classification (1971). They were selected because they represent a range of tropical forest types found in similar climatic and site conditions in Sri Lanka. The premontane wet and lower montane wet types correspond best with the natural forest types found near Mirahawatte. Holdridge inventoried all trees above 2.5 cm in diameter, a narrower categorization than the garden survey which included all seedlings and saplings noticed which could be positively identified. Yet the proportion of individuals of <25cm diameter measured in the gardens was less than 25% so that at least 235 trees per acre remain for comparison.

TABLE 1:

DATA FROM FIVE TROPICAL FORESTS IN COSTA RICA[1]

TROPICAL FOREST TYPE	STAND DENSITY (NO. TREES/ACRE)
DRY	235
MOIST	238
PREMONTANE WET	241
LOWER MONTANE WET	212
MONTANE RAIN	247

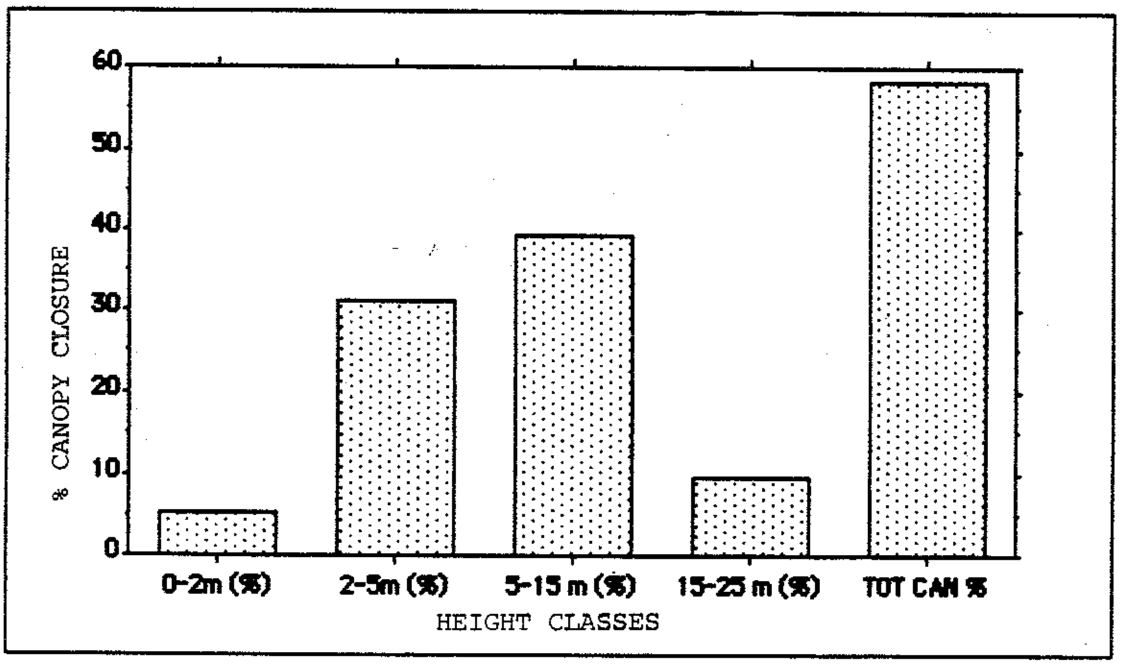
A comparison of the data suggests that the Mirahawatte gardens are of a similar density as several natural forest systems and that they fit the forest model in this regard.

[1]Data taken from Holdridge, 1971 (Dry, 1A/p.74; Moist, 3/P.178; Premontane Wet, 4/p.219; Lower Montane Wet, 10/p.479; Montane Rain, 6/p.527)

COVER AND CANOPY LAYERS

Cover was chosen as an indicator of forest structure under the supposition that a high degree of vegetation cover leads to a relative stabilization of microclimate in an ecosystem to the benefit of nutrient cycling, and to greater protection of soil as the canopy and leaf litter shield the ground from the impact of precipitation. In addition the degree to which the canopy is structured in identifiable levels may give insight into stand age structure and successional processes, and their influence upon energy capture and processing. Cover was measured as a proportion of the garden area and for each of four height classes in the five mapped gardens. Figure 7 is a bar chart presenting the mean canopy closure for each height class and for the total.

FIGURE 7: MEAN CANOPY CLOSURE IN FOUR HEIGHT CLASSES AND TOTAL



The average crown closure for these gardens was 58% (min 47%; max 72.4%). The cover provided by perennial vegetation in each of the four height classes varied considerably. Perennial cover at the ground to 2 meter level was low at 5% (min .8;% max 19.7%). There was 31% cover at 2-5 meters (min 21.6%; max 45%). The maximum proportion of crown closure was found at the 5-15 meter level with 39% (min 19.6%; max 55.9%), dropping to a sparse 10% at above 15 meters (min2.6%; max 18.1%).

The most significant closed canopy layer is not of the tallest trees, often *Eucalyptus sp*, but of the 5-15 meter layer of large fruit, firewood and timber producing species. The garden canopies are patchy with very dense closure and tall trees in clumps away from the house and in live fencing around the property, with some more open spaces left close to houses for small vegetable and flower beds.

Cover is defined as the vertical projection of the crown or shoot area of a species to the ground surface expressed as a fraction or percent of a reference area (Mueller-Dombois and Ellenberg, 1974:80). The Braun-Blanquet scale is often used to quantify cover abundance in studies of vegetation ecology. Dansereau and Kuecheler have added useful descriptive terms to a slightly altered scale. Five magnitudes of cover can thus be distinguished: Level 1) < 5% or *sporadic cover*; 2) 5-25% or *rare cover*; 3) 25-50% or *parklike/patchy cover*; 4) 50-75% or *interrupted cover*; and 5) 75-100% or *continuous cover* (cover classes from Braun Blanquet;

terminology from Dansereau and Kuechler who add an "almost absent" class at <1% cover). Mueller-Dombois and Ellenberg in presenting these methods, give examples of cover classes of Beech forest on limestone soil as 90% cover in tree layers; and for Oak-hornbeam forest on moist soil with 60% cover in the upper tree layer; 32% in a lower tree layer; and 40% in a shrub layer (Mueller-Dombois and Ellenberg, 1974:147-48). Two examples are a very limited pool for data comparison but nevertheless provide some insight.

The garden canopies are not as closed as the Beech forest is reported to be. The Oak-hornbeam forest falls in the *interrupted* category with the gardens (average closure 58%). However, the upper canopy levels of the oak forest with 60% cover are considerably more dense. This may indicate:

(1) *The gardens are at an earlier stage in succession at which their upper canopies have not filled in.* However the gardens do include high proportions of mature late successional species, which suggests that the gardens as a whole should not be classed as belonging to early successional stages (this argument will be continued in the discussion of succession in the gardens below).

(2)*The 15-25 meter height class for the gardens in fact represents emergents rather than the upper level of canopy closure.* This may be a valid consideration as most of the

highest level trees in the gardens were *Eucalyptus spp.*, exotics with a taller growth habit than the average natural forest upper canopy trees at this elevation in this climate. As indicated above, the 5-15 meter height class had the most dense canopy. In this case the 5-15 and the 15-25 meter height classes might be summed, which would lead to an average combined canopy closure at this level of approximately 49%, a measure closer to the Oak-hornbeam upper canopy and at the high end of the *parklike/patchy* cover class.

A possible explanation for the lack of applicability of the model in this case is that as the gardens are managed to include components of annual and shade intolerant plants, one would not expect more complete upper canopy closure (one would not expect 100% canopy closure over an appreciable area in any forest as tree falls would cause some degree of canopy opening).

DOMINANCE AND ABUNDANCE

The concept of *dominance* is commonly used to describe the superior biomass or competitive influence of one or another species in a plant community, and, in ecology, is measured in terms of foliage cover (Shimwell, 1971:112-113). It may not always be possible to identify a single dominant species (or even a dominant group of three or four species) for a given community. Under some conditions, such as those of the humid tropics, single species dominance may depend upon unfavorable soil characteristics, while

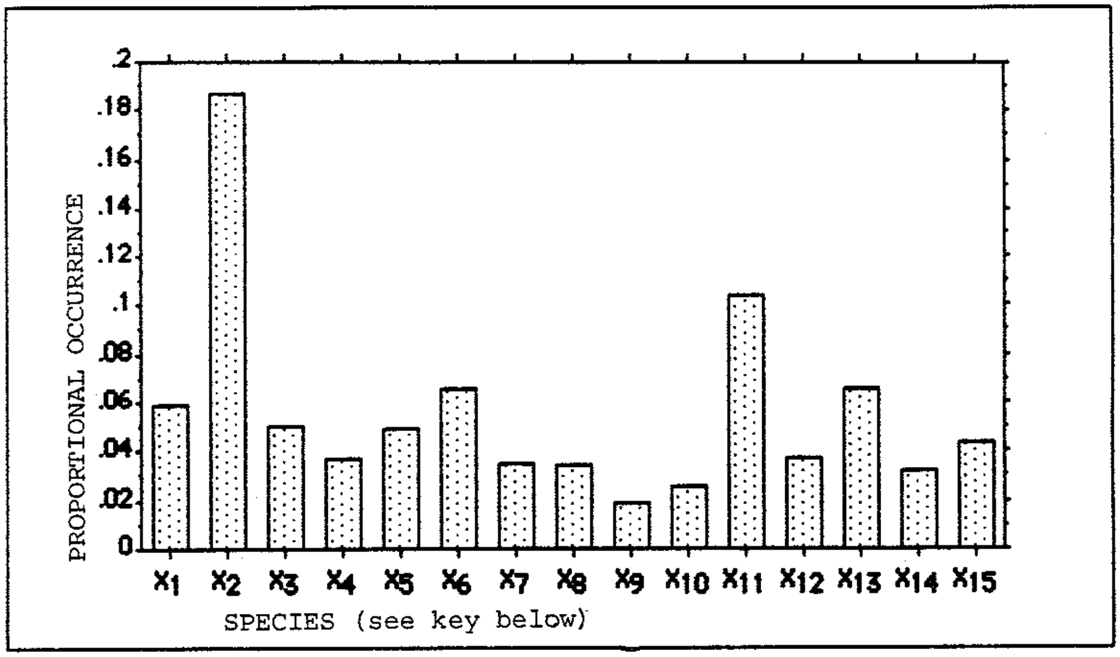
mixed species communities are more prevalent (Richards, 1952:243). Under these circumstances the relative dominance of one or another species, or even of a genus, may not be very significant. In the Mirahawatte gardens, for example, the banana (Musa sapientum) is the second most common perennial species, occurring in 60 out of 61 gardens, and the most prevalent. Yet on average bananas make up no more than 19% of all individuals in the gardens.

Figure 8 shows a ranking of the fifteen most commonly occurring species in the gardens with their proportional abundances.

Abundance and occurrence are correlated but not synonymous. *Artocarpus integrifolia* (Jackfruit), for example, which was found in all 61 gardens visited, is the most commonly occurring species, yet the mean abundance (number of individuals of one species) of *Musa sapientum* per garden is higher. In these cases notation of the prevailing life forms may be more descriptive of overall vegetation structure. I have therefore chosen to limit the definition of *dominance* here to *life-form dominance* .

Trees are the dominant life form in the gardens, as is evident from the data which describe density and cover. As shown above, the values for both characteristics are at mid range for density and moderate for cover in the gardens, indicating a forest to parklike structure and the dominance of trees

FIGURE 8: THE 15 MOST COMMON SPECIES AND THEIR ABUNDANCE



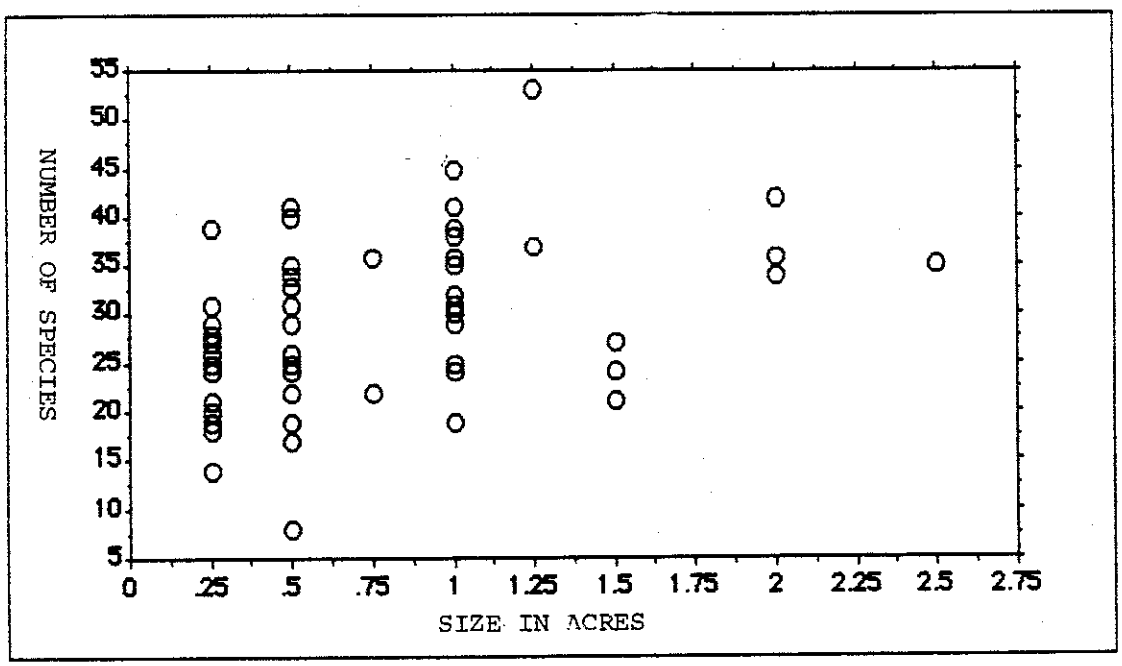
.x1 = Artocarpus integrifolia (jack); x2 = Musa sapientum (banana); x3 = Persea americana (avocado); x4 = Psidium guajava (guava); x5 = Litsea ovalifolia; x6 =Neolitsea involucrata; x7 = Anona cherimolia (custard apple); x8 =Michelia champaca; x9 = Carica papaya (papaya); x10 = Mangifera indica (mango); x11 = Eucalyptus grandis; E. tereticornins; E. camaldulensis; x12 = Grevillea robusta (silver oak); x13 = Gliricidia sepium; x14 = Erythrina lithosperma; x15 = Caryota urens (fishtail palm) (uses are included in the species list in Appendix 2).

SPECIES DIVERSITY

Simply stated, *diversity* refers to the number of species found in a given area, its *species richness* (Whittaker, 1975:94). It was chosen for the model of sustainable forest structure as an indicator of the system's ability to fully exploit its site for biomass production by taking advantage of individual species' growth habits to gain access to nutrients, energy, and space not equally available to all species. The importance of diversity in reducing the risks of large scale pest and disease outbreaks to which species are differentially susceptible was also considered.

On average there were 29 species per garden in the 61 garden survey (min=8; max=53) or 38 species per acre. A correlation of garden size and species richness (r=.158) in Figure 9 shows proportionally greater species diversity in smaller gardens.

FIGURE 9: A CORRELATION OF NUMBER OF SPECIES AND GARDEN SIZE



Species areas curves from the low to midland Singharaja tropical forest in Sri Lanka (Table 2) show the following data (Gunatilleke and Gunatilleke, 1981:317)

TABLE 2:

SIZE	NUMBER OF SPECIES IN SINGHARAJA
.25 ha	30-50
.405 ha	*38 species in the Mirahawatte gardens*
.5 ha	40-60
.75 ha.	47-75
1.0 ha	55-80

Data on species richness in tropical forests range from highs of 550 species per .5 acre in the La Carbonera Fogforest (Vareschi, 1986:132) and a more moderate 127 species per acre in a Costa Rica premontane wet forest (Holdridge, 1971: 219) to lows of 35 species per acre in a Sarawak mixed Dipterocarp forest and 37 species per acre in a mixed rainforest in Nigeria (Richards, 1952:230). These few examples of tropical forest species richness from the literature demonstrate that the forest gardens, while not nearly as species rich as many tropical forests, do fit within the lower bounds of the range of diversity, most importantly fitting well within the species richness noted for Singharaja forest in Sri Lanka.

The *evenness* of species distribution is an additional measure of diversity which describes the degree to which the number of individuals of one species may proportionally dominate in a community, thus making the community functionally less diverse. Whittaker notes that "equitability is correlated with diversity, and dominance concentration is inversely correlated with both."

(Whittaker, 1975:96). The relative evenness of species distribution in the gardens has already been indicated in Figure 8 (15 most common species) above. A system in which the most prevalent species by far, in this case *Musa sapientum*, on average makes up 19% of the species composition (with the next two species on the list at 11% and 7% respectively) is fairly even in distribution. In summary, the gardens are as diverse as several forest systems in similar environments and therefore fit the model with respect to this indicator.

REGENERATION

Regeneration is an indicator of change in a system which can be related to changes in forest structure by monitoring the age and species composition of a stand. Regeneration indicates the ability of the system to reproduce itself into the future. Plant propagation through selective planting by people is not ordinarily included, yet it is a major contribution to the perpetuation of the gardens.

In Chapter 3, two types of "regeneration" were distinguished: 1) "regeneration" by planting; and 2) natural regeneration. Data regarding regeneration by planting in the gardens were not measured quantitatively. Farmers generally obtain seeds and/or seedlings from a) the garden; b) the gardens of family and friends; c) from fruit obtained in the market; and d) from a now defunct government nursery in the village or from other extension facilities in the area. Valuable fruit tree seedlings such as coffee or citrus, are

carefully cared for initially, and later left to grow with little additional maintenance. Few farmers prune their fruit trees. Grasses and herbacious weeds are cut back once or twice every year, but most volunteering woody perennials are allowed to grow. A valuable volunteer seedling such as a mango may be transplanted to a preferred site, while locally native species which provide firewood and timber are left and then periodically cut back for fuel or harvested at maturity for timber.

The proportion of individuals from these specifically local volunteer species in the gardens was noted as an indicator of natural regeneration occurring in the gardens. The species *Achronychia laurifolia, Calophyllum inophyllum, Eleaocarpus glandifuler, Ficus fergusonii, Ficus hispida, Garcinia echinocarpa, Litsea ovalifolia, Neolitsea involucrata,* and *Psidium guajava* (naturalized) were found to make up on average 17% (min 2%; maximum48%) of all perennials in the gardens. The true number of volunteers would be expected to be much higher as non natives such as mangoes and fishtail palms planted in the garden will contribute to regeneration as well. The data gathered were not sufficient to pursue this question.

Another measure of continued regeneration for gardens could be the degree to which they are still planted. This would be an indication both of their biological, and of their socioeconomic sustainability. Observations in the village suggest that a forest

garden is planted immediately upon completion of building construction on all permanent homestead sites.

In sum these qualitative evaluations suggest that the forest gardens fit the model for natural regeneration in part, at a minimum for the 17% of volunteers; and if the definition of regeneration is modified to include human manipulation of the gardens, the model fits well.

SUCCESSION

Evidence of succession was chosen as an indicator of the forest system's ability to withstand short term perturbations as well as long term trends of change in the climatic, physiographic and biotic factors which influence the forest system, and to maintain itself into the future. The degree to which succession as an indicator from the forest model may be validly applied to a garden system managed by people deserves some discussion.

In the following pages I take the stance that people are one biotic factor affecting succession on a particular site, although different in degree and effect than a roaming herd of elephants, for example. Under human management, a garden begun on fire climax grassland of very poor site quality will support vegetation dominated by trees within a few years' time. The process might not occur without human intervention protecting a site from fire, on the other hand, if there were no people in the area, there might be

considerably fewer burns as people often use fire as a tool to influence vegetation composition, and a natural succession might take over. In the Uva, people are present and for the puposes of this discussion will be treated as part of the ecosystem. The degree to which the process of garden development from the grassland to the forest like stage is comparable to natural forest succession is of interest here. Vegetation changes in "stages of succession", or "phases of regeneration" have often been defined through their species composition (Whittaker, 1975; Watt, 1947).

Gaussen described the occurrence of native species of secondary mid-elevation montane forests in Sri Lanka (1965). Several of the predominant species, such as *Neolitsea involucrata, Litsea spp., Garcinia echinocarpa, Achronychia pedunculata* and *Cinnamomum sp.* are common in forest gardens as well. Other species belonging to climax stages of lower elevation forests, such as *Artocarpus integrofolia, Mangifera indica* and *Caryota urens,* are among the most prevalent garden species.

Species of different stages along the continuum of succession are identifiable in the natural forests. They are distinguished by life form, growth habit and growth requirements. These categories can similarly be applied to the species composition of the gardens. A table comparing the process and species composition of succession in the mid elevation natural forest of the Uva region and that of the forest gardens of Mirahawatte is presented below (Table 3).

TABLE 3: FOREST AND GARDEN SUCCESSION

STAGE	FOREST SUCCESSION	SPECIES	GARDEN SUCCESSION	SPECIES
I	shade intolerant grasses, annual herbs, beginning perennial herbs	Imperata cyl. Cymbopogon Themeda tre. Lantana acul. Osbekia asp. Micriglasia	annual vegetables, flowers some herbs	Brassica sp. Capsicum s. Coriandrum Cucurma s. Ruta grav. Tagetes sp.
II	shade tolerant grasses and herbs, shrubs and small, quick growing trees beginning to dominate	Phyllanthus Wendlandia Psidium gua. Ficus hispida	perennial herbs, some shade tolerant annual ornamental shrubs, short lived trees and beginning seedlings of small fruit trees	Ananas sa. Musa sap. Manihot e. Saccarum Jasmine sp. Psidium gu.
III	small trees and saplings dominant with shrubs and herbaceous ground cover below	Calophyllum Cinnamomum Ligustrum w. Neolitsea in. Litsea ovalif.	fruit trees, small woody shrubs and trees; vines; saplings of later succession species	Citrus sin. Coffea arab. Anona ch. Persea am. Erythrina
IV	mature trees with a closed canopy dominate; small tolerant trees and shrubs in understory, herbs and leaf litter cover the ground	Garcnina ech Garciniea mo. Eleocarpus Mangifera z. Aleurites tr.	mature fruit and timber trees dominate with shrub and small tree understory herbs and leaf litter on the ground; vines common	Artocarpus Caryota ur. Cedrella to. Mangifera i. Michelia ch.

Four groups or "stages" are distinguished which fit phases in the development process described. The boundary lines of such "successional stages" are drawn arbitrarily with borderline species fitting well in the upper and lower ranges of neighboring stages.

The next step in applying the concept of succession to the forest gardens, was to find out whether the stages of succession from the table were identifiable in patterns of species composition in the

forest gardens, or whether on the other hand, species distribution within the gardens was random with respect to succession.

In addition to the five gardens which had been mapped in detail, ten gardens from the original 61 garden survey were selected. They were chosen to complement the five gardens so that a full range of age and most size classes of gardens were represented. The species placement in the ten gardens was sketched. Patches of species belonging to the different stages were found to be clearly distinguishable Figure 10 is a sketch and overlay of one garden delineating such patches of vegetation.

Two approaches were used to learn more about the vegetation patches and their possible organisation. The first involved interviewing the farmers of the fifteen gardens sketched in order to elicit information about garden management which might lead to such patterns. Were there common management patterns based upon ecological knowledge and or socio-economic need which could be identified? The second was to study the relative proportions of each stage found in the gardens. If a process of succession occurs in the gardens, then one would expect the proportion of later successional stages to increase with garden age.

GARDEN # 293
3/4 ACRE

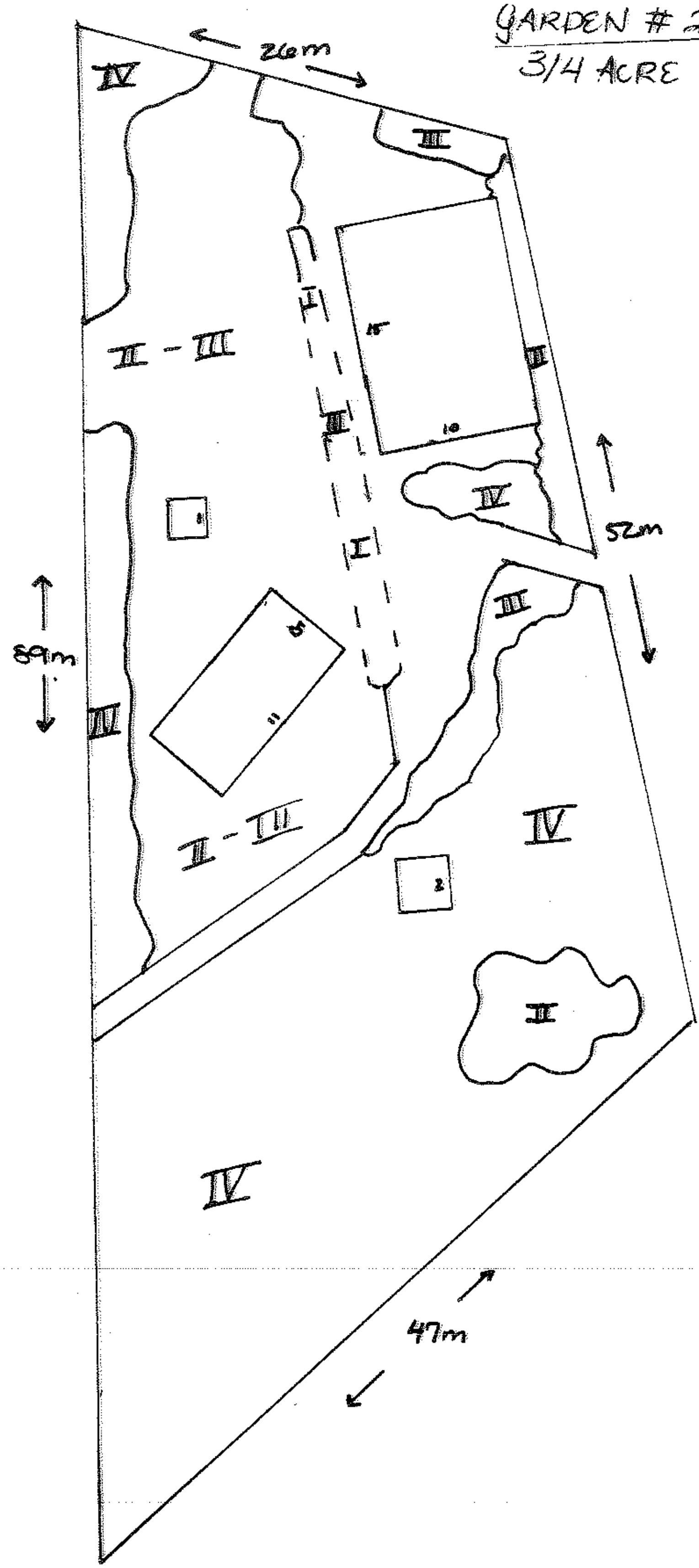


FIGURE 10: PATCHES IN GARDEN VEGETATION

Results of the Garden Management Interviews

Two approaches were undertaken in the interviews conducted. On the one hand, farmers were interviewed as to the compatibility of the fifteen most frequently occurring species in the gardens. Compatibility was defined as "not affecting flowering, fruiting and growth in a negative way". These questions were asked in order to better understand management practices and to test the idea for the proposed successional stages for species found in the gardens.

It would be expected, that species in the same or similar successional stages would be more compatible and more likely to be planted together than species of differing stages; and the further apart the stages, the less compatible and less likely to be grown together. Farmer classification of compatibility resulting in similarly identifiable groupings would suggest ecological knowledge grounded in an understanding of species life form, growth habits and growth requirements. In addition to questions directed specifically at these questions of compatibility, questions concerning general garden planting, management and yields were posed. The results which will be discussed in detail elsewhere (Everett, forthcoming), are sumarized below.

A pairwise comparison of the fifteen species was used to elicit information on species compatibility (A data sheet is presented in Appendix 4). Respondents were asked whether the species in a given pair were compatible if planted in close proximity. Again,

compatibility was defined as "not affecting flowering, fruiting and growth in a negative way". Each pair was given a '+' for compatibility or a '-' for incompatibility. The responses for each pair (9-15 each) were summed and the proportion of positive or negative responses was noted. If the majority of responses was positive, the pair was called 'compatible', if the majority was negative, the pair was called incompatible. If equal numbers of positive and negative responses were given, the pair was labeled neutral ('0'). Thus 120 pairs with 9-15 responses each were tabulated.

As a test of the successional stage delineations, each pair was then assigned to two stages, one for each of its two species based upon the delineations from Table 1 Five stages and mid stages (II; II/III; III; III/IV; and IV) were identified for this purpose. Thus for example *Musa sapientum* (banana), was classed in stage II as a shortlived early successional species, while *Artocarpus integrifolia* (jak) was listed as III/IV because it occurs in both late in stage III and in stage IV. As a pair they were listed as II:III/IV. All pairs were then compiled in sets, based upon their successional stages (e.g. all II:III pairs were one set). There were fifteen possible sets. The number of compatible and incompatible pairs in each set was noted.

A two tailed Wicoxon matched pairs signed rank test for small samples was applied to the compatible and incompatible pairs in the 15 groups (Table 4). This non-parametric procedure is a common statistic used to investigate differences among a set of n matched

pairs of observations The null hypothesis states that no difference exists between members of a pair. (Chiang, Selvin and Langhauser, 1984-85:14.6). At S=24.5, (n=15) the difference between seral stages was found to be significant at the level of.05.

TABLE 4:

WILCOXON SIGNED RANK TEST OF SUCCESSIONAL STAGE COMPATIBILITY

Pair Stages	# +	#-	dif	rank	-rank
1 II-II	3	0	3	8	
2II-II/III	2	0	2	5.5	
3 II-III	6	3	3	8	
4II-III/IV	0	12	-12	-14	-14
5 II-IV	0	2	-2	-5.5	-5.5
6II/III-II/III	1	0	1	2.5	
7II/III-III	5	0	5	10.5	
8II/III-III/IV	4	1	3	8	
9II/III-IV	0	1	-1	-2.5	-2.5
10III-III	13	2	11	13	
11III-III/IV	18	9	9	12	
12III-IV	2	3	-1	-2.5	-2.5
13III/IV-III/IV	21	1	20	15	
14III/IV-IV	5	0	5	10.5	
15IV-IV	1	0	1	2.5	

TOT-24.5 =S

P(S+) OR (S-) < 25 = .05 for n=15

Thus, significant successional patterns can be identified in the forest gardens and are recognized by farmers on the basis of species compatibility.

Proportions of Successional Stages and Garden Age

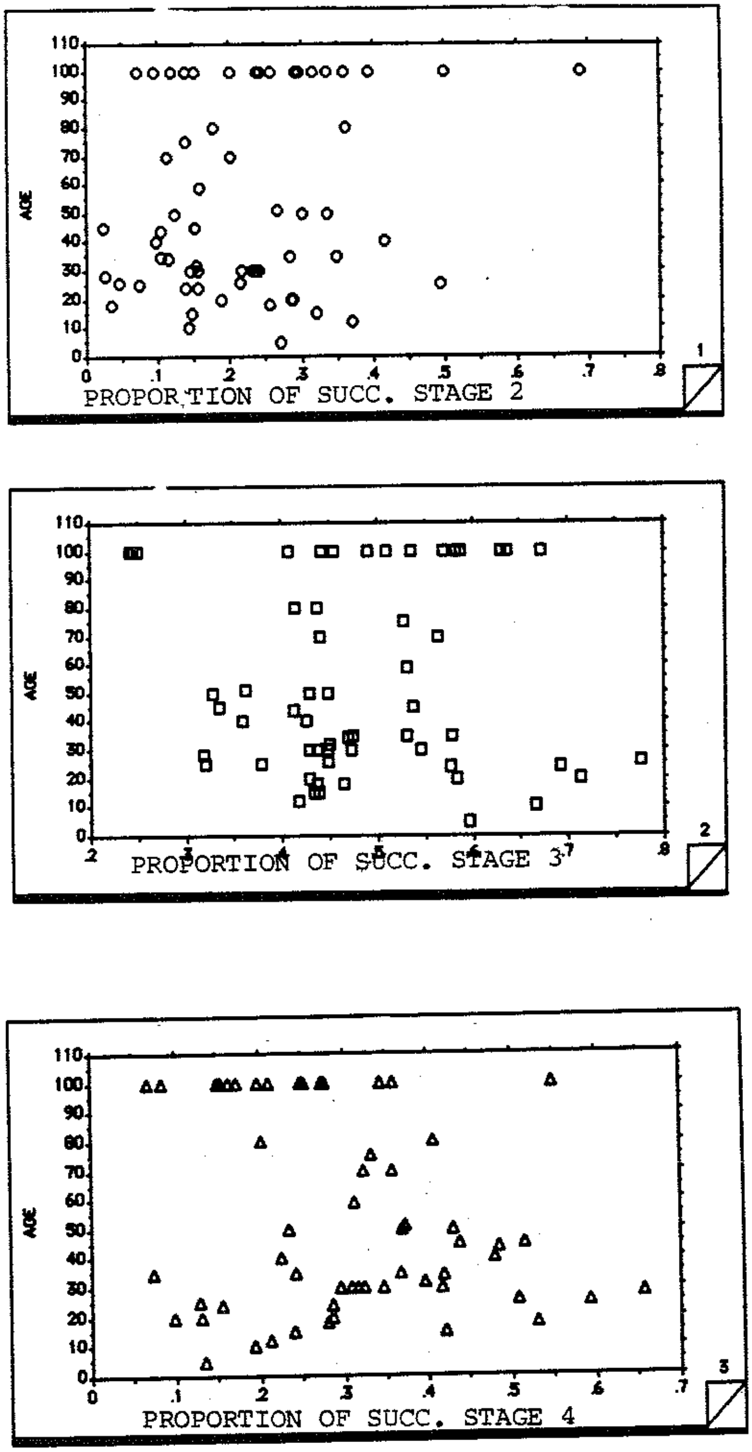
A comparison of between garden patterns of succession for woody perennials was made by relating the proportion of individuals

in stages II, III and IV to individual garden *age*. A correlation between high garden age and a high proportion of late successional stage in the garden was expected. The older the gardens the larger the proportion of 'older' or late stage succession plants one would expect; the younger the garden, the higher the proportion of early successional, shade intolerant and short lived plants one would expect. (Figure 11).

The trend toward a correlation of the proportion of late successional stage vegetation with garden age was not significant at the .05 level. While there is no linear relationship between succession and garden age, some correlation seems to be present which might be visible with an alternative form of analysis and a larger data set. As analysed here, the data indicate that the process of change in the gardens, though in some ways resembling natural succession does not proceed as assumed for a natural forest system here, and therefore does not fit the model for this indicator.

The results of this chapter suggest, that values for four of seven indicators comprising the model of sustainable forest structure, *density, dominance, layered canopy* and *species diversity,* are similar to values found for forest gardens. However, the values for *canopy closure* fall below values measured for natural forests. The process of change in the forest system, indicated by *regeneration* and *succession* does not follow the same pattern in the forest

FIGURE 11: A CORRELATION OF GARDEN AGE AND PROPORTION OF SUCCESSIONAL STAGE



gardens, and while there is some similarity to the forest systems, the gardens can not be said to fit the model for these indicators.

CHAPTER 5

CONCLUSION: DISCUSSION OF RESULTS

It is evident from the results of the data analysis in Chapter 3, that the model of sustainable forest structure and function is *not* a model of sustainable forest garden structure and function. Comparable values for the key structural indicators of sustainable systems, *density, dominance, layered canopy* and *species diversity* were found for forests and forest gardens, indicating their analogous structure with respect to these four indicators from the model. However, the analysis of data for the remaining three indicators, *canopy closure, regeneration* and *succession,* served to point out features which distinguish forest systems from the human managed garden systems.

The first four indicators along with *canopy closure* are really indicators of forest structure at a given point in time. As pointed out above, majority of these indicators suggest that the sustainable forest garden system has a structure analogous to that of a natural forest, a structure which allows the vegetation to capture and process energy and to recycle nutrients. Garden *canopy closure* was the only structural indicator for which the gardens diverged from values measured in natural forests. Several explanations for the divergence are possible. First, garden canopy closure was compared with canopy closure data from only two forest systems, the only similarly presented data which I could find. So, one could argue that the data are too weak from which to draw conclusions. Second, in the analysis

applied here, the amount of land in the gardens taken up by houses and the clearings immediately around the houses was included in the "open area" in the garden. Simply eliminating this amount of area lacking any vegetation could considerably increase the gardens' canopy closure rating. Thus this may also be a case of weak analysis rather than a weak indicator. Third, the somewhat lower rating for canopy closure in gardens may indicate that forest gardens, while structually very similar to forests have a more patchy arrangement of vegetation which results from management of the systems to fit human needs. Such a hypothesis could be tested, for example, with application of the Braun-Blanquet scale at a larger level of resolution, using photos of the mosaic of all gardens in the village from above. Here a different image might emerge.as larger contiguous areas of canopy along garden borders would reduce the impact of openings in parts of the gardens. Alternatively, cluster analysis or another form of analysis which would illustrate the pattern of vegetation placement might provide greater insight into garden structure. Thus, the comparison of data from the forest gardens and the literature on forest structure suggest that four indicators of sustainable structure are present in sustainable forest and forest like systems as hypothesized, while a fifth does not fit as analysed but might if the present analysis were improved or expanded upon.

To this point it would be fair to say that the model of sustainable forest structure and function does represent key processes of ecological sustainability and that for the indicators

presented here, the forest gardens are structural and functional analogues of natural forests.

The selected indicators of process or change in the system, *regeneration* and *succession* are difficult to apply to the forest gardens. This is due to the narrow scope of the model as initially defined which does not allow for analysis of socio-economic sustainability. Thus, while a certain proportion of the regeneration in the gardens (17% volunteers) is comparable to natural forest regeneration, the majority of perennials in the gardens are planted with socio-economic criteria guiding the choice and survival of species, rather than the seed dispersal and chance establishment occurring in the forest. By the same token, certain plant associations within the gardens can be related to stages of complementary growth habit which may be equivalents of successional stages, yet, as the lack of correlation of these successional stage equivalents with garden age suggests, the proportion of plants of one or another stage is guided by socioeconomic decision making of garden owners, rather than solely by a combination of physiographic, climatic and biotic factors acting on the site and its vegetation over time. (Depending upon one's perspective, this period of human inhabitance of the site might just be a blip in time of human biotic dominance over vegetation which would recede if people were removed).

These results indicate that the model of ecologically sustainable forest structure is useful as an initial tool in analysing sustainable systems' ecological structure and function at one point in time, but that is too narrowly defined to incorporate the complex processes of

systems maintenance and change for systems managed by people. Research toward understanding these processes and their socio-economic as well as ecological implications will be important in our ability to approach principles of ecosystem sustainability.

AVENUES FOR FURTHER RESEARCH

Several avenues for further refining of the model as well as for understanding the forest garden systems or other agroforestry systems have emerged in the process of compiling this thesis.

1) At the individual garden level many questions have been raised concerning the ecological and socio-economic criteria used by the farmers in designing their gardens. A description of the Mirahawatte forest gardens and garden management based upon field work carried out in 1985-86 is in process and may lead to identification of appropriate indicators for an understanding of socio-economic sustainability in the forest gardens.

2) One of the most valuable tools used in interviews was the pairwise matrix employed to elicit farmers' knowledge of species compatibility. Beside the straight affirmative or negative answers regarding the compatibility of a species pair, theories about the specific causes of incompatibility and general rules regarding species compatibility and placement in the garden emerged. A discussion of this approach to eliciting information for ethnoscientific research is forthcoming.

3) The application of the sustainable forest structure and function model here has served to underline the complexity of

vegetation composition on a site over time and the degree to which ecological theories of vegetation change can or cannot be applied to systems managed by people. This question might be pursued as suggested above, both at the individual garden level of analysis - for example beginning with cluster analysis of species associations - and at the village landscape level at which one would examine the mosaic of forest gardens in relation to the other forms of village land use. This village scale perspective would lead to greater understanding of the ecological and socio-economic influence of agroforestry systems in the larger landscape - and the degree to which, on this larger scale, they may be considered forest analogs fulfilling the role of forests for such functions as watershed protection or wildlife habitat.

APPENDIX 1: SURVEY DATA COLLECTION FORM

Household Interview

______ name ______ dist. to road ______ car ______ date ______

member	age	birthpl.	rel.	lang.	ed.	occup.
hh						

in village since? ______ in this house? ______ elec. ______ stove ______

radio ______

which types of land and how many acres?

	garden	paddy	tea	total
own				
rent				
r. out				
cultiv				

	gew.	kall.	oth.
dare %			

	lin	pil.	pipes
water months			

animals?

which crops

Garden

who	what ndj	fm	am	jjaso

Paddy

who	what ndj	fm	am	jjaso

Tea

who	what ndj	fm	am	jjaso

marketing who	what	how much	price unit	when/per. seas.	buy.

Latin name	Sinhala	# ind	ht	dbh	age	uses	how much	from	sold	given	left
Albizzia falcata	ratamara										
Albizzia lebbek	mara										
Aleuritus triloba	tel-kakune										
Anona cherimolia	wali anoda										
A. muricata	kathu anoda										
Areca catechu	puwak										
Averrhoa carambola	kamaranga										
Artocarpus heterophyllus	kos										
A. incisus	del										
A. nobilis	wal-del										
Camelia sinensis	the										
Garcinia chinocarpa	kokatiya										
Carica papaya	papol										
Caryota urens	mira										
Cassia spectrabilis	mai										
Cedrela thuna	thona										
Citrus aurantifolia	dehi										
C. aurantium	ambul-dodan										
C. maxima	jambola										
C. nobilis	jamanara										
C. sinensis	dodan										
Cocos nucifera	pol										

Latin	Singhala	#ind	ht	dbh	age	uses	how much	$con	sold	given	left*
Coffea arabica	kopi										
Coffea robusta	kopi										
Cupressus	cypress										
Elaeocarpus glandulifer	weralu										
Eletaria cardamomum	carademongu										
Eriobotrya japonica	lokat										
Erythrina lithosperma	eramudu										
Eucalyptus camaldulensis	terpentine										
Ficus religiosa	bodhi										
Gliricidia sepium	kona										
Hibiscus sp.	shoe flower										
Litsea ovatofolia	beeriya										
Mangifera indica	amba										
Manihot esculenta	maioca										
Michelia champa	sapu										
Morus alba nigra	mulberry										
Muntinga calabura	jam ghedi										
Musa sp.	kessel ghedi										
Neolitsea involucrata	kudu-daule										
Passiflora											
Persea americana	alig. peera										
Pinus carribea	pinis										
Piper betel	bulathkole										

English	Sinhala	#ind	ht	dbh	age	uses	how much	$con	sold	given	left*
Piper nigrum	gamiris										
Plumeria alba rubra	aurelia										
Punica granatum	delum										

Garden Inventory

______ name ____________________ size __________ acres date __________

owner ______________ for ______ years garden age ________ slope ______

soil h m l

	h	m	l
o.m.			
rocks			

water nd fm sm i-o

	nd	fm	sm	i-o
sources reliab.				
inputs period.				

aspect ______

comments

	HT	DBH	AGE
①	< 2m	< 4"	Seedling
②	2-5m	4-10"	Juvenile
③	5-15m	10-25"	Mat-Juv.
④	15-25m	25-35"	Mature
⑤	> 25m	> 35"	Old

APPENDIX 2

GARDEN PERENNIALS OF MIRAHAWATTE

LATIN	ENGLISH	SINHALA	USE	ID #
Acacia sp.				112
Acronychia laurifolia		Ankenda	F,M	29
Aegli marmelos		Beli	Fr,M	101
Agave sisalana	Agave	Hanna gass	Fe,Fi	30
Albizzia lebbek		Mara	F	44
Albizzia odoratissima		Suriyamara	F	68
Aleurites triloba	Candlenut	Telkakune	F	69
Alstonia macrophylla		Avarinuge	F	80
Anacardium occidentale	Cashew	Kaju	F,Fr	91
Annanas Sativus	Pineapple	Anasi	Fr	127
Anona cherimolia	Cherimoya	Anoda	Fr	7
Anona muricata	Soursop	Kathuanoda	Fr	70
Archontophoenix Alex.		Dotulu	Or	75
Areca catechu	Areca nut	Puwak	N	41
Artocarpus incisa	Breadfruit	Del	Fr	71
Artocarpus integrifolia	Jak	Kos	Fr,Fo,	1
Averrhoa carambola		Kamaranga		66
Azadiracta indica	Neem	Kohombe		73
Bambusa sp.	Bamboo	Una	T	28
Bixa orellana	Annato	Rucon	P	119
Calophyllum inophyllum		Dambe		57
Camelia tea	Tea	The	B	34
Carica papaya	Papaya	Papol	Fr,M	9
Carica sp.			M	
Caryota urens	Fishtail palm	Kitul	S,B,T	15
Cassia auriculata		Averie	Sh	114
Cassia spectrabilis		Mai	Fe,Sh	19
Casuarina equisetifolia	Casuarina		T	108
Cedrela toona	Toona		T	18
Cestrum nocturnum	Queen of the night	Rakumarimal	Or	39
Citrus aurantifolia	Lime	Dehi	Fr	21
Citrus grandis	Grapefruit	Jambole	Fr	59
Citrus nobilis	Mandarine	Naran	Fr	31
Citrus sinensis	Orange	Dodan	Fr	14
Citrus sp.	Lemon	Lemon	Fr	107
Citrus vulgaris	Bitter orange	Marmalade	Or	65
Cocos nucifera	Coconut	Pol	Fr,C,F	35
Coffea arabica	Coffee	Kopi	B	22
Coffea robusta	Coffee	Kopi	B	25
Crotelaria sp.		Andenih.		115
Cupressus knightiana/				123
Cupressus macrocarpa	Cypress	Cypress	T	36
Cyphomandra betacea	Tree tomato	Gasstakkali	Fr	83
Datura fastuosa	Datura	Atana	M	67
Dendroclamus giganteus	Bamboo	Una	C	28
Dioscorea sp.		Velale	V	94
Diospyros discolor	Velvet apple	Mabulu	Fr	120
Duranta repens				
Elaeocarpus glandifuler	Ceylon olive	Weralu	Fr	106

Eriobotria japonica	Loquat	Lokat	Fr,Fe	15
Eriodendron anfract.	Kapok	Kottepulum	F	85
Erythrina lithsperma	Dadap	Eramudu	Sh,Mu	16
Eucalyptus spp.	Eucalyptus	(K)Terpentine	F,T	11
Eugenia jaranica		Jambu	Fr	58
Eugenia michelii	Brazil cherry	Pitanga	Fr	109
Ficus fergusonii		Nuge		54
Ficus hispida		Kotedimbule		99
Ficus religiosa	Bo tree	Bodhi	R	125
Muntinga calabura	Jam fruit		Fr	105
Flacourtia ramontchi		Ugurasse	Fr,M	60
Garcinia echinocarpa		Kokatiya	O	33
Gliricidia sepium		Nangi morunga	Fe,Sh,	13
Grevillea robusta	Silver oak	Sabuku	T,Sh	12
Heliconia brasiliensis?	Lobster claw		Or	122
Hibiscus sp.	Shoeflower	Sapatumal	Or	40
Jacaranda mimosaefolia	Jacaranda		Or	113
Jalapa mirabilis				117
Lawsonia alba	Henna	Morathondi	R	82
Leucaena leucocephala		Ipil-ipil	Sh,Mu	56
Ligustrum walkeri		Bora	F,Fe	32
Limonia acidissima	Woodapple	Divul	Fr	84
Litsea ovalifolia		Beeriya	F,Fe,T	5
Lucuma palmeri		Lawulu	Fr	20
Macademia ternifolia	Macadamia nut		N	95
Madhuca logifolia		Mi	O	86
Makaranda tomentosa		Kenda		52
Mangifera indica	Mango	Ambe	Fr	10
Manihot sp.		Rubber	Fe,F	26
Manihot ultissima	Manioc	Maioca	V	27
Melaleuca leucadendron	Cajeput	Lothsombul	O	88
Mesua ferra	Ironwood	Na	R	110
Michelia champac		Sapu	T,F	8
Momordica charantia	Carilla	Karawilla		98
Moringa pterygosperma	Horseradishtree	Morunga	S	102
Morus sp.	Mulberry		Fr	53
Murraya koenigii	Curry leaf	Karapincha	S	38
Musa sapientum	Banana	Kessel ghedi	Fr	2
Neolitsea involucrata		Kududawule	F	6
Nephelium longana		Mora		81
Opuntia dillenii	Prickly pear	Katupatuk	0	87
Passiflora edulis	Passion friut	Passiona	Fr	45
Pawatta indica		Pawatta	M	121
Persea americana	Avocado	Aligata peere	Fr	3
Phylanthus sp.		Dikirile		77
Phyllanthus emblica		Nelli		97
Pinus caribeae	Pine		T	76
Piper betel	Betel leaf	Bulathkolle	Fo	111
Pithecolobium saman	Rain tree	Paramara	O	64
Plumeria sp.	Temple flower	Arelia	O	50
Pongamia pinnata		Karanda		96
Prunus persica	Peach	Peaches	Fr,O	47
Psidium cattleianum	Strawberry guava	Jam peere	Fr	37
Psidium guajava	Guava	Peere	Fr	4

Psidium guajava	Guava	Peere	Fr	4
Punica granatum	Pomegranite	Delum	Fr,M23	
Pyrus communis	Pear	Pears	Fr,O	51
Pyrus malus	Apple		Fr,O	93
Ricinus communis	Castor	Endaru	M	48
Salacia reticulata		Himbut		102
Sambucus nigra	Elderberry		O,M	55
Santalum album	Sandalwood	Sudthuhandung	O,T	62
Sechium edule	Chayote	Cho-cho	V	42
Semecarpus coriacea		Badulla		74
Sesbania grandiflora		Kathurumor.		89
Solanum indicum	Wild eggplant	Tibatu		43
Spathodea campanulata	Flame of the for.	Jus mal	O	62
Syzygium fergusoni	False clove	Walkarabu		42
Taddalia aculeata		Kudumiris		74
Tamarindus indica	Tamarind	Siambala	S	89
Tecoma sp.				43
Tectona grandis	Teak		T	128
Tephrosia pupurea		Pila		78
Tithonia diversifolia	Mexican sunfl	Titamal	Fe	49
Vitex negundo		Nikke		92
Vitis vinifera	Grape		Fr,O	100
		Waral		
Wendlandia notoniana		Sawan widele	Fe,F	24

Use Categories: B=beverage; C=construction; F=fuel; Fe=fence; Fi=fibre; Fo=food; Fr=fruit; M=medicine; Mu=mulch; N=nut; O=oil; Or=ornamental; R=religious; S=spice; Sh=shade; T=timber; V=vegetable

APPENDIX 4: SPECIES COMPATIBILITY MATRIX

~~S [illegible]~~ Sept 23 '86
#499 ±
B Panchirana
(1)

	1. KOS	2. Kessel	3. Alipeere	4. Peere	5. Beeriya	6. Kudu-dawule	7. Anoda	8. Sapu	9. Papol	10. Ambe	11. Terpentine	12. Sabuku	13. Nangi-murunga	14. Dodan	15. Kitul
1. KOS	1 +	2 −	3 +	4 −	5 +	6 +	7 −	8 +	9 −	10 −	11 −	12 +	13 −	14 −	15 +
2. Kessel		16 −	17 +	18 +	19 +	20 −	21 +	22 −	23 +	24 −	25 −	26 −	27 −	28 +	29 −
3. Alipeere			30 +	31 +	32 −	33 −	34 +	35 −	36 +	37 +	38 −	39 −	40 −	41 −	42 −
4. Peere				43 +	44 +	45 +	46 +	47 +	48 +	49 +	50 −	51 +	52 −	53 +	54 +
5. Beeriya					55 +	56 +	57 +	58 +	59 −	60 +	61 +	62 +	63 −	64 −	65 +
6. Kudu-dawule						66 +	67 +	68 +	69 −	70 +	71 +	72 +	73 −	74 −	75 +
7. Anoda							76 +	77 +	78 +	79 +	80 −	81 +	82 −	83 +	84 −
8. Sapu								85 +	86 −	87 +	88 +	89 +	90 −	91 −	92 +
9. Papol									93 +	94 −	95 −	96 −	97 −	98 +	99 −
10. Ambe										100 +	101 −	102 −	103 −	104 −	105 +
11. Terpentine											106 +	107 +	108 −	109 −	110 +
12. Sabuku												111 +	112 −	113 −	114 +
13. Nangi-murunga													115 −	116 −	117 +/−
14. Dodan														118 −	119 −
15. Kitul															120 +

TREE PLANTING MATRIX: "+" compatible "−" incompatible

1 at least one foot apart	12
2 banana won't bear, roots interfere	13 fence mainly for glincidia good mulch won't plant next to kos otherwise
3 1 ft or more spacing	14 dodan won't bear well – needs more light
4 if volunteer ok, otherwise wouldn't plant so close – peere won't bear, too shady	15
5	16 need at least 4 ft spacing
6	17
7 won't bear much fruit for anoda	18
8	19 ok if beeriya gets pruned to allow banana light
9 papol won't bear or grow	20 not unless volunteer kududawule
10 both are large trees need spacing	21
11 Eucalyptus takes all nutrients from soil so won't plant with fruit trees	22 Sapu usually away from fruit trees takes space + shade

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APPENDIX 3: GARDEN 464 TRANSECT