Hierarchical Aggregation Patterns of Forest Gardens in Montane Landscapes in Sri Lanka

by

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This effort is dedicated to
the memory of Upali Senanayake,
and to
Kamy, Jerry, Ranil, Swami, and all who share in NSRC.

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CHAPTER 1

Aggregation and Hierarchy in Landscape Dynamics

As we become increasingly concerned about global environmental problems, we find that the crises are being fueled by the many actions of individual consumers everywhere, whether they are driving a car on a Los Angeles freeway, or a clearing a forest patch in Papua New Guinea. Even as national and international level policy makers become aware of the problems and attempt to address them (e.g. Tropical Forestry Action Plan (FA0, 1985), and the United Nations Conference on Environment and Development of 1992 (UNCED), they find that they are far removed in human organizational terms from the ground and relatively powerless to affect the processes occurring there (Romm, 1993 in press).

At least part of the problem is that there are no shared principles of understanding around which to organize environmentally focused responses that can link individuals through local, regional, national and international aggregates of human communication. If we are to build a new language of common understanding and management of human environmental interaction, part of the process is to focus specifically on understanding levels of aggregation or thresholds of scale in human impacts and how to create consciously structured social processes to manage these effects.

Landscapes are one such threshold level of scale. Landscapes are defined as heterogeneous land areas composed of repetitive patterns of interacting ecosystems. In scale, landscapes extend for at least several square kilometers and are usually bounded by geomorphic discontinuities[1] (Forman and Godron, 1986). Each landscape belongs to a larger region at which scale such characteristic features as the landscape's climate are determined.

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[1] By definition, ecology, including landscape ecology is concerned with functional relationships (e.g. Naveh and Lieberman, 1984:5)

Landscapes are an important scale when considering human impacts, because the effects of individual actions aggregate in them[2]. In an agricultural landscape, for example, people, organized into settlements of hamlets, villages or towns with characteristic land use patterns, are one force influencing landscape dynamics from within, through actions that modify vegetation patterns, water flows and nutrient levels. At the landscape level, some of the results of their actions become apparent as aggregated impacts. Individuals may or may not be aware of the change in the landscape as it occurs, and individuals acting alone are powerless to reverse the process. A purposeful change in the aggregate impact requires an aggregate human response in which all or most individuals see it in their best interest to cooperate in or comply with a common regime.

In a case study from Sri Lanka, this thesis presents an approach to analyzing a range of forces which determine land use and the resulting aggregated impacts on landscapes. For the specific landscape of interest, it analyses changing spatial patterns of local land use and infers resulting ecological implications for the larger landscape. It identifies some of the forces which generate these patterns. In conclusion, I draw implications for landscape scale approaches to mitigating human impacts.

1.1 Land Use Change in Highland Sri Lanka

The study focuses on an agricultural landscape in highland Sri Lanka. Sri Lanka is a 65,000 km2 island nation lying off the southern tip of the Indian subcontinent. Agriculture, for production of export crops and for locally consumed food, is the major source of income for the majority of the population, and water is the most limiting resource input for agriculture. The headwaters of all major rivers on the island emerge from the Central Highlands, making these mountains Sri Lanka's primary watershed catchment. Over the past two decades, the country has invested heavily in irrigation projects in the

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[2]It is conceivable, in places where individual landownerships are very large, that one landowner (perhaps a government) would be responsible for highly coordinated human impacts in a landscape. the case of a rural landscape with scattered private holdings is more common and provides the basis for discussion here.

lowland Dry Zone and the future return from these investments depends upon continued reliable and ample flows of clear water out of the mountains.

For many centuries the mountains were largely uninhabited and cloaked in forest. In 1881, forest cover was estimated to be 84% and by 1900 around 70% remained (NARESA, 1991:198). Records from the first comprehensive forest survey in Sri Lanka in 1956 showed 44% of the island under forest , and the most recent estimates suggest that 24% of the land is forested (Ibid). In the Central Highlands, natural forests now cover at best 9% of the land (GSL, 1990). Today, the highlands are densely populated and the number of people there continues to grow. The population in the District of Badulla in which the primary research area for this study is located, has increased by 20%, from 188 persons per km2 in 1963 to 244 per km2 in 1988 (NARESA, 1991:27).

Land use patterns continue to change. Large tea estates have replaced much of the forest, and where tea has failed, grassland called *patana*, is the dominant vegetation. In addition, there are growing numbers of small farmers, a highly disaggregated group, not all of whose management practices are well documented. For example, along with rice and vegetable fields, most rural households in the highlands have a forest garden of densely planted trees of many species around their homes. These agroforestry systems average just under an acre (ca. 1/3 ha) in size. The gardens are similar in some key ecological aspects of structure and function to natural forests (Senanayake, 1987; Everett, 1987) and they are estimated to make up 10-15% of land use in the highlands.

As perennial vegetation, forest gardens are likely to be key ecosystems contributing to watershed protection and maintenance of remaining biodiversity in the highland region, yet the phenomenon of the small farmers' forest gardens is not well understood. How extensive are the gardens? What is their structure and composition? How do gardens vary in space across the highlands and are they changing over time? What is the aggregated effect of forest gardens in the highland landscape? What factors determine farmers' management of garden structure and composition? What are the implications for policies

which seek to protect the watershed catchment, to maintain biodiversity or, in general, to enhance the quality of life of the highland people? The gardens provide an interesting and little studied ecosystem to choose as a focus land use for this study.

This study addresses the problem of conceptualizing the impacts of land use change across scale in space and time. I analyze this problem within a framework that integrates three models, one for ecological systems function, one for human behavior and organization, and one for spatial pattern. Hierarchy theory provides a framework for synthesis of the three.

1.2 Hierarchy Theory

In this approach the natural world is viewed as a multi-layered system, hierarchical in space and time (Allen and Starr, 1982; Salthe, 1985; Mueller, 1992). As Salthe points out (1984:9), the appeal of hierarchy lies in its presentation of entities and processes in the world as having characteristic patterns, which are the basis for structures in which functional components operating at different scales can be related to one another (Urban et al, 1987).

Hierarchies are nested structures in which lower level units provide materials or services for upper levels and upper levels constrain and control actions of lower levels. Each entity in the structure has the dual nature of being at once a whole and a part - what Koestler called a Janus faced holon, after the Greek guardian god of portals, Janus, who had two faces (Koestler, 1967). Hierarchies are dynamic systems, having horizontal information flow among components within levels and vertical flow between levels in both directions. In order to explain a phenomenon, "one needs to look up a step in the time/space hierarchy to understand the constraints under which it occurs, and descend a step to determine causality." (DiCastri and Hadley, 1988: 6; Koestler, 1967).

When elements are ordered into hierarchical structure, clear analytical criteria to distinguish levels are important. Salthe notes that no single criterion would be adequate,

and proposes that five principles be applied when placing components or identifying levels in an existing hierarchy (summarized from Salthe, 1985:170-173):

* Individuality - Entities at each level must be distinguishable as individuals. In other words, the boundaries of all systems belonging to each level of scale in the hierarchy must be clearly defined. In ecology, boundaries defining ecosystems vary with scale and are determined according to the purpose of analysis. For one investigation an ecosystem could be confined by the surface tension of water around a tiny raindrop, and for another, by the edge of an extensive rainforest.
* Composition or Nesting - Entities in the next lowest level must be contained within those of the contiguous upper level. In dynamic terms, events at higher levels generally occur more slowly than lower level events, but may hold more influence over the focal level.
* Incommensurability - Entities at different levels must not correspond in size, amount or degree.
* Constraint Capability - Interactions between entities at contiguous levels must be capable of initiating conditions upward or imposing boundary conditions downward. Phenomena emerging at the 'focal level' are generated by creative processes at the lower, initiating level which has a knowable structure and rules. These processes tend to occur at a comparatively high frequency and small scale (Urban et al, 1987; Allen and Starr, 1982). The higher level environment or 'boundary conditions' depending on the degree of organization, can contextualize, regulate, coordinate or control the focal level processes and possibilities. The environment itself, viewed from the focal level as a highly unpredictable dispenser of random events, can be factored into further levels from above or outside its outer threshold or boundary.
* Robustness - The ordered relationship between components in the hierarchy must have some meaning or basis in a believable reality.

It is the position of the observer, the focal level, which creates the frame of reference for the analysis as these principles are applied (Salthe, 1985:163). The levels are intransitive. From any particular point in time and space, the lower level initiating conditions are compositions of small scale events. The 'boundary conditions' of the level above are the result of relatively unchanging conditions with respect to the referent. The scale transformations between levels reduce the strength of signals passing between levels and account for our difficulty in conceptualizing the defining characteristics, such as individuality, on more than a few levels at once, or at levels very far removed from our vantage point.

In this study, for example, this difficulty in perceiving processes occurring at several levels removed in space and/or time from the vantage point of the individual may be applied to the perception of the individual farmer in a large agricultural landscape and the degree to which he or she is likely to know what the cumulative impacts of the individual actions of surrounding land users are over time.

The creation of a theoretical structure of phenomena conceivably could take on other, not necessarily hierarchical forms. However, hierarchical structure has characteristics particularly applicable to analysis of pattern. It allows causal relationships and relationships of control to be interpreted. It generates complexity by linking the interaction of differently scaled processes. It generates stable entities with boundaries in our interaction with them (Salthe, 1985:9).

This once largely theoretical approach emerging from general systems theory (e.g. Bertalanffy, 1968; Pattee, 1973) may now be applied to large scale phenomena using the recent developments in technology which make spatial analysis at large scales possible, even extending to global dimensions. Hierarchy theory in particular, provides a very useful approach to the study of ecological systems (Allen and Starr, 1982; Salthe, 1985).

In this dissertation, I apply a triadic approach (Salthe, 1985) to study the interactions between contiguous hierarchical levels, so as to encompass the system (a

landscape in highland Sri Lanka), its structural components (ecosystems including the forest gardens) and its environment (the surrounding region) simultaneously.
I address the following questions:

1) How can the aggregated landscape level role of a given ecosystem or land use be assessed?

2) How can the possible landscape factors (boundary conditions) that create initial conditions for the ecosystem be isolated?

The first question is addressed through spatial analysis of landscape structure and composition from which certain landscape ecological functions can be inferred (e.g. Turner, 1990). The second question is approached with a state factor systems model. In conclusion, I combine both methods in an application of the results drawn from the analysis of the first two questions. All three approaches are informed by landscape ecology.

1.3 Landscape Ecology

Landscape ecology has been a focus of academic inquiry in Europe from the early part of the century and, especially in Central Europe, has become well integrated into regional planning processes (Naveh and Lieberman, 1984) . In the United States, landscape ecology is a newly emerging field which has its antecedents largely in the work of early American vegetation ecologists. Among others, Clements emphasized temporal process as he studied progressions of change (successions) in plant communities (Clements, 1916). Gleason argued from a more localized spatial focus that the pattern of distribution of plants in a community was based upon the particular mix of environmental circumstances faced by each individual plant (1926). Watt, focusing on the pattern of change in spatial distribution and successional process in a shrub community finally

brought together the link between pattern and process in time and space which are the core of vegetation ecological inquiry (1947).

Systems theory emerged strongly in a range of scientific fields during the 1950's and 1960's (Bertalanffy, 1968; Koestler, 1967) and systems ecology gained many adherents (Odum, 1969). In the mid 1970's, once the concepts and tools of systems thinking had been well integrated into ecological thought, interest grew in systems dynamics, for example, in predicting patterns of natural disturbance regimes (White, 1979; Borman and Likens, 1979; Mooney and Godron, 1983; Pickett and White, 1985). As the next decade began, technology and research methods such as carbon dating, fire history and pollen analysis, remote sensing, large fast computers and geographic information systems software, became increasingly available[3]. These enabled researchers to enlarge the temporal and spatial scales of their analyses. At the same time, there was increased effort at theoretically addressing the ambiguities of defining boundaries on ecosystems and problems of comparing systems across changes in spatial and temporal scale in a flurry of work on hierarchy (Pattee, 1973; Allen and Starr, 1982; O'Neill, 1986; Salthe, 1985).

With the systems theoretical views and international efforts such as the UNESCO sponsored Man and the Biosphere studies beginning in the 1960's and 1970's (e.g. UNESCO, 1977), stronger links to the European tradition were forged, especially in viewing people as part of rather than separate from natural processes (Vester, 1980; Naveh and Lieberman, 1984). These perspectives reinforced the perspectives developing in Human Ecology beginning in the 1950's (Hawley, 1950), and expanding with a wide range of studies by cultural anthropologists in the 1960's (e.g., Vayda, 1969; Rappaport, 1967) and on into the 1970's and 1980's (e.g., Rambo and Sajise, 1984; Marten, 1986). Finally, from the mid 1980's on, landscape ecology emerged as an international field which would build on and continue in the footsteps of the earlier community and ecosystem

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[3]One particularly interesting application of several of these methods in landscape ecology is by Allen for the Sta Jiminez Mountains, New Mexico (1989).

ecologists and use the new theoretical and technological tools to apply the inquiry into pattern and process across supra-ecosystem, landscape level scales in space and time (Burgess and Sharpe, 1981; Naveh and Lieberman, 1984; Forman and Godron, 1986; Turner, M.G., 1991; Hansen and di Castri, 1992). Studies which focused in particular on implications of human interactions with forests and natural resource management include, for example, from the Pacific Northwest of America, those by Franklin and Forman on the impact of timber harvest systems on disturbance rates (1987); by Ripple et al on measuring landscape patterns influenced by timber harvest in the Cascade range (1991); and by Grant (1990) on implications of forest management for hydrologic regimes.

1.3.1 Landscape Structure

Hierarchical principles can be usefully applied to landscape analysis. In a watershed, a typical landscape unit, for example, a variety of ecosystems coexist and relate to one another with respect to the larger topographically defined hydrological regime common to all. Other factors demonstrating such constraint capability or boundary conditions (*sensu* Salthe) affecting all ecosystems in a landscape are climate, parent material and human impacts.

In the landscape, individual ecosystems are defined as patches, often patches of vegetation, which differ in their composition or structure from their surroundings and therefore can be distinguished by their appearance (Forman and Godron, 1986:83). Vegetation patches occur at a variety of spatial scales and across a range of temporal scales through gradients of intensity and duration (Lugo, 1988; Clements, 1916; Gleason, 1926; Watt, 1947). Variation in a landscape's vegetation creates distinctive and ever changing patterns with important implications for ecological processes in the landscape (Dunn et al, 1990; Gardener et al, 1987; O'Neill et al, 1988; Forman and Godron, 1986). Further, such information has many possible applications. Hydrological or biodiversity focused efforts, for example, might seek to manipulate vegetation to maintain or balance flows of clear water supplies (Kattelman, 1987), hold fertile topsoil in place while growing crops

(Zijlstra, 1989), or sustain habitat for native flora and fauna (Burel, 1992). Having both theoretical and applied value, vegetation patterns describe landscape structure and are appropriate for use as a primary indicator of landscape function. Metrics for spatial pattern analysis have been developed which use analysis of the distribution patterns of vegetation patches to study landscape level processes (Turner, 1991). Several metrics are applied in this study and are discussed in greater detail in Chapter 3.

1.3.2. Landscape Function

Ecosystems are usually individually defined or bounded by their structure and composition, or by their function (Odum, 1959; 1975). A major emphasis in landscape ecology is understanding the principles of relation between ecosystems in a landscape. The focus here is largely on fluxes and flows of gasses, minerals, nutrients and organisms between ecosystems. A type of landscape budget may be conceptualized in which each ecosystem plays a role as a storage sink, a consumer and/or a transmitter of energy and matter.

The principle of nesting applies in that landscape level change can be seen as the result of aggregations of changes occurring in and between its component ecosystems. While each ecosystem sub-component may maintain different rates of flux and flow, the landscape as a whole is an open system and will have a net inflow or outflow of matter of different types. The landscape in turn is one of several or many landscapes in a larger geographical region, serving as a sink or source of nutrients and other element fluxes. The ecosystem is a component of the local landscape, and the local landscape of a regional landscape, and so on to a global scale in a hierarchically integrated ecologically functioning system.

The focus of this inquiry has been defined as a hierarchically nested triad of ecosystem, local landscape and regional landscape, using vegetation pattern as an indicator of ecosystem level fluxes. A wide variety of fluxes and flows beyond the scope of a single inquiry of this kind occur in landscapes. Therefore, this study emphasizes the very general

characteristics of two nested landscape and ecosystem flows. First is landscape hydrology, and especially the degree to which local land use ecosystems may have aggregated effects on the quality and quantity of water flows within both the localized and the extended landscape, including a large regional watershed. Second, the concern is with biodiversity, in particular, with dynamics of change and the relative capacity of the localized landscape to sustain the organisms (including people) living in it.

A key area of influence pertaining to these issues are mechanisms which create or modify patches in the landscape mosaic, ranging from variation in environmental baseline conditions to anthropogenic or non-anthropogenic disturbance regimes. A series of principles for relative stability, resilience and persistence have been developed and applied to ecosystems (Holling, 1973; Odum, 1975) and agroecology (Conway, 1986; Altieri, 1987). Stability refers to the ability of an ecosystem to maintain relatively balanced levels of fluxes and flows over time. Persistence refers to an ecosystem's ability to maintain itself over time. Resilience refers to the ability of an ecosystem to return (or the rate of return) to a previous level of relative stability after a disturbance. These principles might be applied at the landscape level as well.

A relatively stable landscape in terms of maintaining biodiversity or capturing water, for example, may be conceptualized as having a high degree of resilience such that changes occurring in flows of water or numbers and species of organisms in and between some of its ecosystems remain balanced by a capacity in other ecosystems for absorbing surpluses, at least for some length of time. If resources drain or move rapidly from one ecosystem to another, both ecosystems will change (perhaps very abruptly, violently) which may lead to an aggregated (and cumulative)[4] effect, changing the landscape as a whole. For the case of water flows, a sudden change from vegetation cover to bare soil in one ecosystem may lead to both rapid water run-off and erosion of soil to neighboring

[4]I use the terms 'aggregated' and 'cumulative' interchangeably to indicate summations (plus emergent properties) in both space and time simultaneously.

ecosystems, such as streams with further effects triggered on water flows and organisms there.

The rate and scale of changes occurring will determine the degree to which a given landscape can support the existing diversity of life. Applications of island biogeography theory indicate, for example, that it may be beyond the capacity of many species to adapt to a suddenly occurring, intense and repetitive disturbance regime such as annual agricultural cultivation or logging. The degree to which connecting less-disturbed areas remain may determine these species' survival (Harris, 1986; Franklin, 1988; Lovejoy et al, 1986).

A variety of systems models have been employed to elucidate such formative and functional landscape scaled processes in various parts of the world (Naveh and Lieberman, 1984: Ch 3). State factor systems analysis is one such approach which can be applied to landscapes as well as ecosystems[5] (Jenny, Arkley and Schultz 1969; Jenny, 1980).

1.3.3. State Factor Ecosystem Models

A state factor ecosystem model assumes that an ecosystem or any property of the ecosystem is characterized by initial conditions or state factors from outside the system, and that if specific magnitudes can be assigned to the state factors (independent variables), the value of a given property of interest in the ecosystem, the dependent variable, can be determined (Jenny, 1958:6). Dokuchaev was the first to publish a state factor equation for soils in 1898 (Jenny, 1961). Jenny subsequently modified the early model which had defined soil as a function of climate, organisms and geologic substrate, to include a more specifically defined set of factors (1941). For the ecosystem as a whole (l)[6] or for its various properties, such as soil (s), and later vegetation and animals (v, a), these state factors were climate (cl), topography (r = relief), parent material (p), organisms (o) and

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[5]The 1969 Mendocino Ecological Staircase study by Jenny et al, though called an ecosystem study, is actually a landscape study. Each terrace in the staircase is really a separate ecosystem, separated by a pronounced discontinuity (Arnold Schultz, pers. com.).

[6]Jenny proposed "l" for "larger system", a term he used before he became aware of Tansley's ecosystem (Arnold Schultz, pers. com.).

time (t), defining a model of initial conditions at a point in time (t_0) now conventionally known as 'clorpt'.

$$l, a, v, s = f(cl, o, r, p, t \ldots)$$

The added dots indicate spaces for locally determinate factors not subsumed under 'clorpt', such as salt spray or high winds.

It is important to distinguish the role of the biotic factor, 'organisms' outside the system as opposed to the variables 'vegetation' and 'animals' which are part of the ecosystem (Jenny, 1958). As a state factor, 'o' represents the potential organisms (or species pool) that could appear in the system. These include, for example, all of the potential propagules of plant species within dispersal distance of the ecosystem. Seeds, for example, might arrive in the system, but never germinate, or they could arrive, germinate and die for some reason and therefore not appear as organisms in the ecosystem at whatever point in time (t_1) an inventory is made. Plants that grow up in the system, on the other hand, are a dependent part of the system and are acted upon by the state factors.

State factor models are comprehensive but very general conceptual models which are never solvable if all factors are allowed to vary simultaneously (Phillips, 1989). However, they are particularly appropriate for applications in which one seeks to maintain the awareness of systems relationships while focusing particularly on the role of a single factor. In a procedure similar to gradient analysis, the factor of interest can be highlighted while the others are held constant, for example in a "climosequence" (Jenny, 1958):

$$a, v, s = f(cl)_{o, r, p, t}$$

The state factor model is flexible enough to allow hierarchical analysis of factors in which some factors are held constant at large scales in space and time, while others are analyzed in detail at smaller levels of scale. Further, state factor analysis has recently been

modified to include people (Amundson and Jenny, 1991), and has contributed to the total human ecosystem approach (THE) of landscape ecology described by Naveh and Lieberman (1984).

Hypotheses

I hypothesize that each state factor takes on a range of expression depending on the analytical scale of focus. A landscape scale rainfall pattern is a subset of a regional climate and may well differ in specific amount, timing and intensity from the average value at the larger scale. Further, I suggest that the relative significance of state factors is likely to vary with scale in space and time, and that the model can be applied to identify key variables for a given time and scale. Finally, I propose that the aggregated landscape level effects of a land use practised by many households operating under one set of state factors at time = t_0, may have a feedback effect powerful enough to modify the expression of those same state factors as initial conditions for household land use at a future time = t_1. The flows between ecosystems in the landscape and the aggregated effects of these flows on the state factors at various scales, which may feed back to influence the initial conditions for the ecosystem level, may be conceptualized as a simple cybernetic system (Fig 1.1).

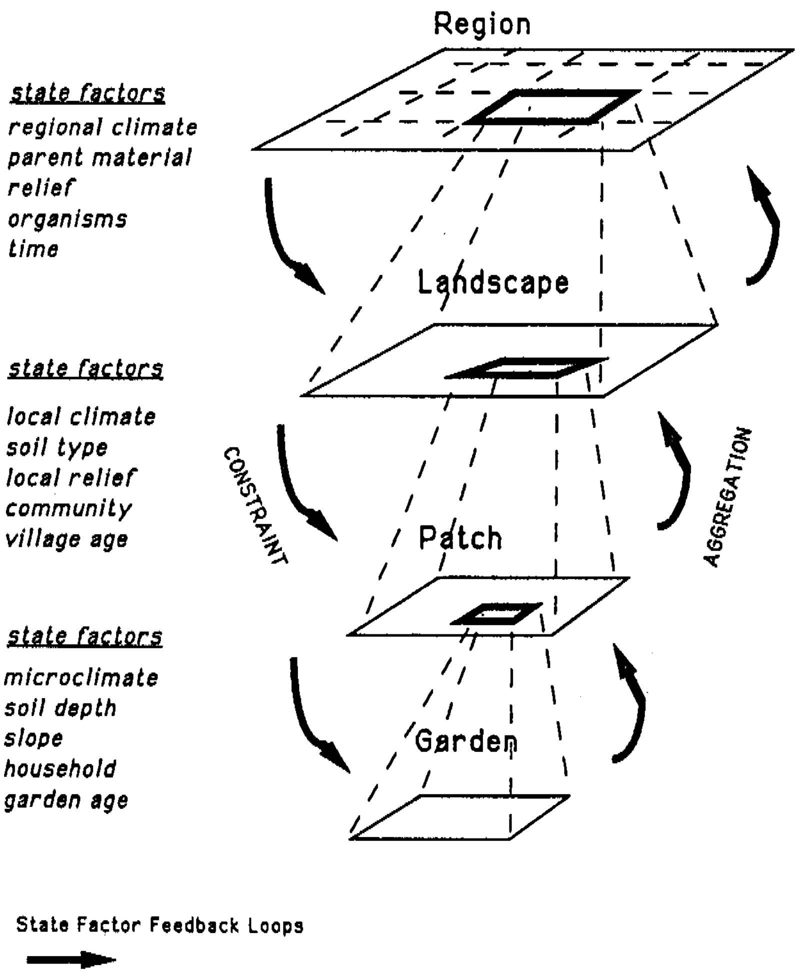
In the model, most state factors are defined following Jenny. However, the role of organisms, in particular of people, is reinterpreted.

The Role of 'Organisms' as a State Factor and as Dependent Variables

First, it is necessary to distinguish between people in the role of the state factor 'organisms' and people who as dependent variables are part of the landscape system[7]. In their discussion of humans in state factor theory, Amundson and Jenny (1991) distinguished ecosystem independent human genotype (o_h) and initial culture (c_i) as state factors. These state factors differ from the dependent variables human phenotype (h) and

[7]Vegetation is the key dependent variable here, and will be discussed below. Animals and livestock are certainly system components but are not central to this inquiry and will be excluded from discussion.

Fig.1.1 A Hierarchy of State Factors in the Landscape



evolving cultural attributes (c) inside the landscape system. Similar to the distinction made for the biotic factor, the genotype and initial culture represent human potential at time zero (t_0), while the phenotype represents the actualization in the form of human culture and behavior in the landscape developing under the influence of all state factors from t_0. The new state factor equation reads:

$$h, c, a, v, s = f\,(o_h, c_i, cl, o, r, p, t \ldots)$$

For the purpose of my study, the definition of the human role must be further clarified. To understand and predict human impacts, it becomes important to learn why people in a given place over time do what they do to shape the landscape. Environmental variables (climate, parent material, and topography) necessarily shape the landscape but much of their influence develops in time and spatial scales generally beyond the focal level of human experience and is not likely to be controllable by people. People can and do manipulate localized soil fertility within an ecosystem or a landscape but have little or no direct effect on large scale weathering processes. Human impacts can be global in scale - we influence global climate patterns with the aggregated impacts of pollution and deforestation - but we are certainly not able to purposefully manipulate our impact at this scale or even control it at this point[8]. In effect, once accounted for, these environmental state factors operating at broad scales become relatively non variable constraints.

The human factor is more complicated. Amundson and Jenny distinguished human genotype and culture as state factors. For the purpose of the models developed here, I employ a definition of culture as integrated political, economic and social processes which have potential to influence the people in a landscape from all levels of social organization.

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[8] I use the term manipulate here to include both the ability to control and to achieve a purpose. While people have an influence on the environment, we are not (yet) as a species able to agree and organize well enough to actually have control over our impacts, much less manage our actions purposefully on a global scale.

At some levels of social organization, such as family and village communities, people operate as dependent variables within the landscape, subject to the influences of state factors on the conditions for their land use practices. At other levels, such as regional governments, and the global economic system, aggregations of people operate at larger scales. In these, people, organized into groups, are state factors (i.e. beyond the borders of immediate local control), which potentially shape land users' actions in the landscape, for example by determining market prices for agricultural crops or land tenure systems[9].

In science, we can never determine exact causality, but it may be possible to distinguish the expressions of the human state factor which influence people's choices from outside, and behaviors which are determined from within the landscape by the interplay of all state factors together. Some such behaviors may be found to be correlated with changes in vegetation management patterns. These practices would be candidates for conscious conservation oriented action. People operate as individuals and also as members of social groups, such as family, villagers and political parties. The direct impact in land use is by individuals (Govil, 1991), but the driving motivation for influencing landscape patterns in one way or another may or may not be so localized. In the model it will therefore be useful to distinguish between human influences which are part of the landscape system and influences from outside that are part of the human culture state factor. The influences are expected to include local history and cultural development which shape individuals' household level and community level actions, including customary settlement and land use patterns.

From inside the landscape system people will be guided by their own knowledge and experience, by the resources available to them and by customary patterns of behavior, all subject to the influence of the system state factors. From outside, peoples' land use

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[9]Individuals may belong to a variety of organizations which give them different roles in the model at different points in time or scale. The farmer hoping for rain and subject to the conditions of the state factor climate is also the individual who belongs to a National political system and whose vote may topple a leader and bring about land reform which affects the farmer's ability to get more land in time *t1*.

motivations will be influenced by prevailing social, economic and political systems at the regional and national levels including, for example, the degree and nature of centralized planning and control over access to land, markets and information, and various policies affecting land use which can include development projects, and subsidies, research and extension in agriculture. The human culture state factor can even operate from the international level to influence remote small farmers' land use, such as when the cost of petroleum increases and fertilizers become more expensive. Operating from outside the landscape, the state factor 'human culture' is largely independent of the other state factors and functions without being constrained by them.

Developing a state factor model includes a series of steps (Jenny, 1961; Dunn et al, 1990:175). First, the landscape of interest is defined. Its component ecosystems are described. Then a base period (to) is determined, against which future changes or impacts will be assessed, and the historical development from the base period is described, including the direction of changes and rates of change and their context[10][11]. Thus, the state factor 'time' is built into the model from the outset. Historical developments shed light on the other state factors which are formative for the landscape; in general, they will parallel Jenny's ecosystem 'clorpt' model.

In this study I use historical research and spatial analysis to describe changes in vegetation patterns in the Central Highland region of Sri Lanka from a time period t_0 to t_1

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[10] Several factors need to be taken into account in attempting to study vegetation change. Ecologists have long studied vegetation changes over time, beginning formally in the U.S. with Clements and Cowles. One of the greatest difficulties they encounter is that rotation ages for vegetation and trees in particular are often very long, longer than a human working lifetime. This fact speaks to the limits on human perception in time and space. It is thus difficult to simply monitor change as it occurs unless a very well organized and well endowed project has been set up to transcend changes in staffing. Often researchers with an understanding of a vegetation community's development process can see vegetation at various stages of development around them and can surmise how the plant composition on a given site is likely to change in the course of the following decades. This approach is called 'substituting space for time'. If one seeks to understand vegetation development over a longer time horizon, historical research methods ranging from perusing historical records, photographs, inscriptions and other archaeological remains can provide sources. Paleobotanical methods such as analysis of fossilized pollen and carbon dating can give researchers insight to the most distant pre-history.

[11]

(pre-historical to post independence) and for one landscape in the Uva Basin from time t_1 to t_2 (1956 - 1988). Then a state factor systems model is applied to define key variables which influence the patterns of one land use, forest gardens, at a range of landscape ecological, human organizational and temporal hierarchies of scale. I consider the case of forest gardens to be particularly relevant as a long evolving, knowledge intensive pattern of land use, which maintains important ecological functions at the individual household, aggregate community and landscape scales, and which is now being modified quite rapidly.

In the following chapters, I address the questions raised in this chapter in a sequence suggested by the state factor model approach. In Chapter 2, the Sri Lankan context and relevant state factors for this study are introduced in a sketch of the biogeophysical, historical and socio-cultural background of the highland landscape. The land use and vegetation types in the region are described and the regional and village study areas are briefly discussed. The research methods, modeling and analytical approaches applied in this study are presented in Chapter 3.

In Chapter 4, the baseline foundation for applying the state factor ecosystem model is laid. Using Geographic Information Systems (GIS) coverages developed from aerial photographs, the recent history of land use change in the focus landscape in the Uva Basin is quantitatively described using spatial metrics. In particular, patterns of aggregation in forest gardens from the household to the landscape level and changes in these patterns are analyzed in detail. In Chapter 5, a state factor model of vegetation change, focused on initial conditions influencing these forest garden agroforestry systems is developed. In conclusion in Chapter 6, the theoretical and site specific implications of the findings in Chapters 4 and 5 are discussed. As a demonstration of alternative approaches to managing vegetation while integrating ecological considerations in the study landscape, a GIS coverage of a modified land use pattern for the landscape, based on expanding tree planting in areas subject to severe disturbance is presented.

CHAPTER 2

Highland Land Use in the Context of Sri Lanka: The Biophysical, Historical and Socio-economic Background, Present Land Use Patterns and Villages Studied.

The purpose of this chapter is to provide an introduction to Sri Lanka, and in particular, to the Central Highlands and the land use patterns prevalent there. The brief sketches of biophysical, social and political circumstances on the island and the presentation of the historical development of land use patterns in the chapter's first two sections provide the context for Sri Lanka's present land use and vegetation patterns. A more detailed discussion of land use in the highlands then follows and includes an introduction to the study sites and to the general variability in settlement and land use pattern which they represent. Finally questions to be addressed in this dissertation which arise concerning links between past, present and future land uses in the region are raised.

2.1 Biophysical Background

The island of Sri Lanka lies across the Palk Straits off the Southeast coast of the Indian subcontinent. At its longest point, the island extends for 434 km, between 5 54' and 9 52' degrees North of the equator, and at its widest for 225 km, between 79 and 82 degrees East longitude. Sri Lanka's area is 65,610 km2 and is thus comparable in size to West Virginia or Costa Rica.

2.1.1. Geology

The island is ancient, as nine tenths of Sri Lanka was formed as part of the Indian shield in the Precambrian, over 570 million years ago. (Cooray, 1967:77-79). Its hill and coastal regions are physiographically similar to the rugged Nilgiri and Palni Hills and the coastal plain near Madras on the neighboring South Indian continent (Ibid: 63). Uplifting and erosion have produced the island's present geomorphological division into three peneplains: a flat coastal plain rising inland to around 100m above sea level; a second peneplain which suddenly projects in elevation from the coastal plain and ranges between 300-800 m; and a third interior plain rising steeply for another 1,000 meters to an average

level of 1,500-2,000 m with mountains peaking above 2,500 m (Ibid:49). These latter two peneplains form the Central Highlands (Fig.2.1).

Geologically, the Central Highlands are part of the Highland Series made up of metamorphosed sediments and chernockitic gneisses. The mountains along the southern wall of the high country form two open semi-circles which are joined in the shape of an anchor by a series of mountains and high plains leading up to Mt. Pidurutalagala, at just over 2,500m, the tallest mountain in Sri Lanka (Cooray, 1967 and Fig 2.1). The axis of this anchor is the climatic divide between the Wet Zone and the Intermediate Zone. The western branch of the anchor cradles the high rainfall region of the Hatton Plateau including the Kotmale area discussed below. This region is the primary source of water for the Mahaweli river system (Karunatilake, 1988; Zijlstra, 1989; ODA, 1990a). The eastern branch of the mountain range forms the rim of the Uva Basin, an area of intermediate climate drained by several rivers which flow into the Uma Oya and then join the Mahaweli below the Randenigala Reservoir. This area, the focus of this study, is less represented in the scientific literature, though there has been landscape ecological work on tea in the highland landscape (Marby, 1971); on agrarian change (Weitzel, 1971); and a landscape architecture based study of the provincial capital, Badulla (Dicke, 1991).

2.1.2. Climate

The Central Highland massif strongly influences the island's climate and produces a wide range of microclimatic variation (Fig. 2.1). From May through September, the southwest monsoon blows across Sri Lanka, encounters the mountainous barrier and drops most of the moisture it carries on the southwestern corner of the island. From December through February, the wind blows from the opposite direction across the more gradual northeastern flank of the mountains bringing precipitation to the whole island. Thus, the southwestern quarter of Sri Lanka has two rainy seasons and is called the Wet Zone; the remaining land, which has one rainy season, is the Dry Zone. Part of the highlands, on the border between wet and dry falls in the Intermediate Zone. The driest parts of the island,

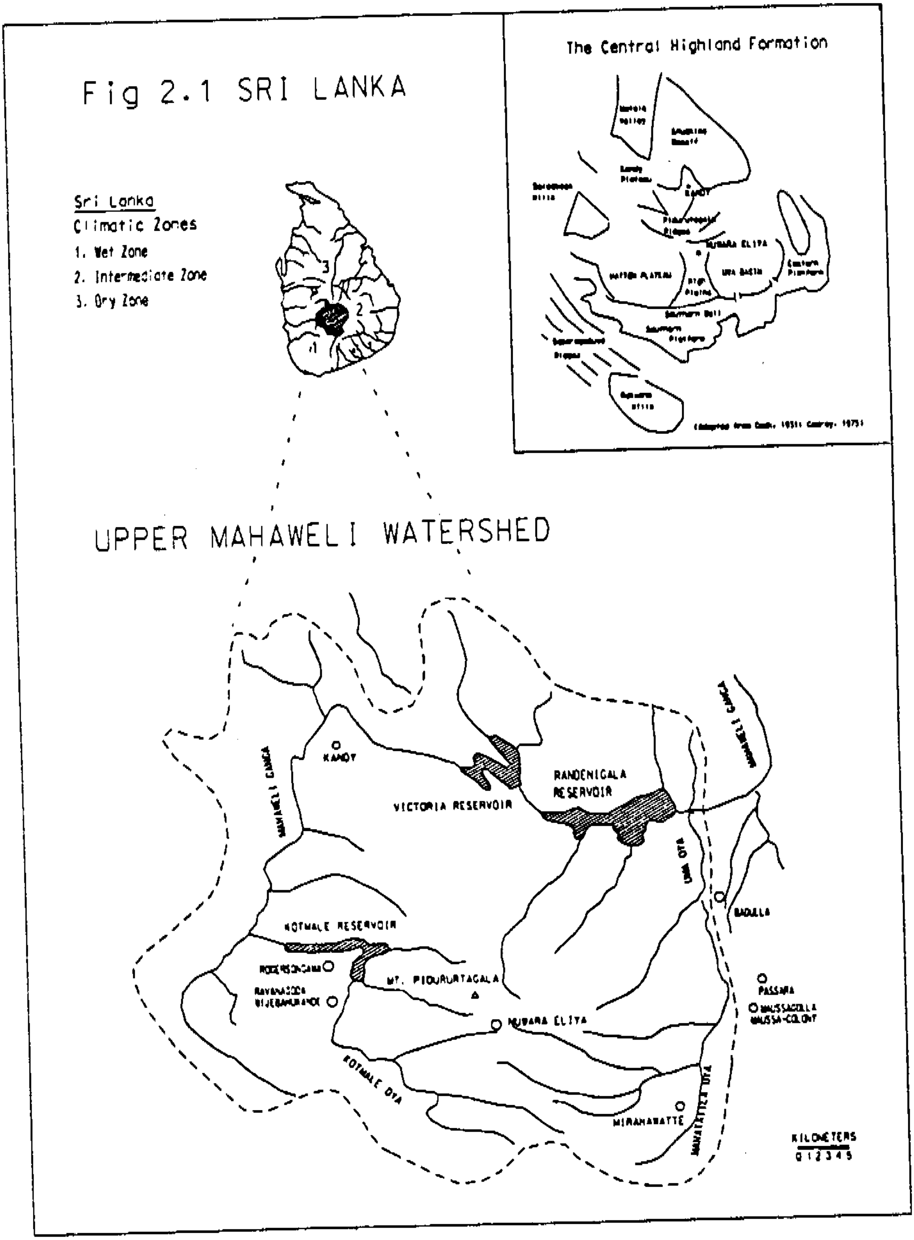

Fig 2.1 SRI LANKA

the northern tip around Jaffna, and the southeastern coast, receive between 950-975 mm of rainfall per year, all in one season; and the wettest areas near and just north of Ratnapura and below Nuwara Eliya receive between 4,000 and 5,450 mm of nearly daily rain with some monsoon peak downpours. The average relative humidity ranges from highs in Ratnapura and at Galle on the South Coast of 85% and 84% to a low of 77% at Trincomalee on the East Coast. The average annual temperature in the lowlands ranges from 26.5 C in Galle to 28 C in Trincomalee. With increasing elevation temperatures cool in the highlands with an average of 24.4 C in Kandy, and a cool 15.4 C in Nuwara Eliya. (Climate data summarized from Domros, 1976: 72-94).

2.1.3. Soils

Climate has been the major factor determining soil formation all over Sri Lanka (Moorman and Panabokke, 1961). Most of the Central Highlands have the same Red-Yellow Podzolic soils found throughout the Wet Zone[1]. The soil provides a clear indication of past predominance of forest vegetation. Red-Yellow Pozolics are usually moist soils which develop on old land surfaces under forests in warm to tropical climates. They are fairly well weathered, with clay horizons and low base saturation, and are agricultural soils of good quality (Brady, 1974: 331).

2.1.4. Biodiversity

Sri Lanka has greater biodiversity per unit area than any other country in Asia and has been recognized by the US National Academy of Sciences as one of eleven tropical sites demanding special attention because of its high levels of endemism and vulnerability to habitat destruction (NARESA, 1991:222). This high degree of diversity is the result of the island's geological history and varied topography and climate. The island has been separated from the Indian Subcontinent for 12 million years, and while still holding many species in common with it, ample time has passed for speciation processes to occur (GSL,

[1]There is a great deal of local variability, but it was beyond the scope of this study to go into greater detail.

1988). For example, all 45 species of the Dipterocarpaceae (a very important genus of plants in the Asian tropical forests) found on Sri Lanka are endemic (Werner, 1984:169). Given the often very destructive tendencies of large human populations, it is surprising that the great biodiversity found in Sri Lanka persists after many centuries of high population density.

2.2. Historical Development of Human Impacts on the Highland Landscape, with Particular Emphasis on Perennial Vegetation[2]

From a very early period, people living in Sri Lanka transformed the landscape with their land use practices. An understanding of the historical evolution of human influences on vegetation pattern can provide useful information for an effort to understand present patterns more fully. The history of habitation on the island can be divided into several periods according to major events affecting the population, settlement and consequently their transformation of vegetation patterns.

2.2.1 Pre-colonial Period: The Ancient Cities Rise and Fall, and the Population's Move into the Wet Zone and Mountains

Before people arrived on the island, most of Sri Lanka was probably covered with forest vegetation varying from thorny scrub to rainforest and some savanna land, depending upon local elevation and rainfall characteristics (Domros, 1976:116). It remains unclear when humans first lived on the island. Implements from Stone Age cultures, estimated to date from around 10,000 B.C and termed the Balangoda cultures, have been found by archaeologists; but little is known about these early inhabitants (DeSilva, 1981:6-7). It is believed that immigrants from northern India first began to arrive on the island around 500 B.C. and that Buddhism was introduced and embraced by their king between 250-210 B.C (Ibid: 9). Written evidence dates from this time when monks began to record events. The primary source for early information is the 'Mahavamsa' or 'Great Chronicle

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[2]During the Colonial Period the island was known as Ceylon. The name was changed to Sri Lanka after independence. Here 'Ceylon' is used to described the island when referring to events of the Colonial Period.

of Ceylon' compiled from historical data by Buddhist monks in the 6th century B.P. Beside stone inscriptions, this is the only written record of this early period in the island's history (Anon, 1986 ed).

The ancient civilizations of Sri Lanka, which began to develop from the 3rd century on, were centered in the North Central Dry Zone and flourished between the 5th and 12th centuries. The archaeological remains of Anuradhapura (with the city's zenith in the 6th century) and Polonnaruwa (lasting from the 6th into the 12th century) reveal evidence of complex city states with large monastic populations, universities, libraries, and extensive pleasure gardens as first indications of horticultural management.

Located on forested, semi-arid plains with concentrated seasonal rainfall and long droughts, very sophisticated systems for irrigation of rice paddies formed the basis of these hydraulic societies. The systems consisted of often huge earthen reservoirs, called 'tanks'[3] which were linked via extensive canal systems. The canals brought water from the perennial streams and rivers emerging from the highlands and flowing across the lowland plains. Brohier (1935) provides a detailed description of the ancient irrigation civilizations, including the myriad of small scale, rain-fed village tanks in the areas surrounding the major population centers. His and other historical work (Anon, 1986; DeSilva, 1981) along with the archaeological ruins themselves indicate that in this period people transformed the Dry Zone landscape. They cleared the forests, harnessed the water emerging from the mountains in their irrigation systems, grew rice and gardened to feed the cities (Perera, 1979:306). The literature suggests that during this time the rest of the island was sparsely if at all inhabited (Ibid; DeSilva, 1981; Codrington, 1929).

Beside indicating peoples' clearing of forest trees to make way for development and cultivation, it is interesting to note the early beginnings of purposeful tree management and

[3]The reservoirs are called 'tanks' from the Portugese 'tanque' meaning reservoir (Goldsmith and Hildyard, 1984). The engineering skills employed in their construction were highly developed. In his discussion of Ceylon's hydraulic society, Leach described one canal of the 55 mile Kalawewa tank canal system which, for the first nearly flat 17 miles of its length, has a steady fall of six inches per mile, enough to maintain the water flow by gravity (1959:9).

use dating from this period. In his discussion of horticulture in ancient Sri Lanka, Dikshit (1986) distinguishes two types of gardens existing in early Ceylon, as royal gardens and private gardens (including gardens belonging to monasteries). He notes that as the chroniclers were most interested in the activities of the royalty, the private gardens are not often mentioned, though they existed throughout the early period and were probably far more numerous than the fewer, more splendid royal parks (Ibid:263). One indication of the importance of trees and private gardens is that from the 6th century onward, gardens were taxed to provide kings with a share of garden fruits. In addition, early inscriptions include regulations prohibiting cutting of certain tree species (Ibid:315).

A unique occupational caste of gardeners, the *malakara*, emerged to work in royal and temple gardens (Ibid:314). Playing a cultural and religious role, temple gardens and trees were a particularly important subgroup of gardens. The Mahabodhi tree (Ficus religiosa), situated in the Mahameghavana gardens near Anuradhapura, dates from this period and is said to have been a scion of the Bo tree at Bodhigaya under which the Buddha gained enlightenment. It is the oldest planted tree known and was and still is greatly revered by pilgrims, including present day political leaders. The importance of trees and plants in general to the culture of Sri Lanka's inhabitants is highlighted throughout the early literature by writers in the colonial period. Tennent for one, called it a simple, "vegetable economy" in which all household implements and nutrition are derived from plants (1859:161).

Among the species from the ancient gardens, some of which were exotic trees imported for the royal parks, there are many which are found in highland forest gardens today. These include: Artocarpus incisa (breadfruit); Artocarpus heterophylla (jak); Areca catechu (areca); Bambusa spp. (bamboo); Citrus sinensis (orange); Cocos nucifera (coconut); Eugenia javanica (rose apple); Ficus benghalensis; Jasminum grandiflorum (jasmin); Mangifera indica (mango); Michelia champaca (sapu); Musa spp (banana); Phyllanthus emblica (nelli); Piper betel (betel); Piper nigrum (pepper); Tamarindus indica (tamarind); and Tectona grandis (teak) (Anon, 1986). Clearly, gardens with trees were

important from early in the island's historical age. However, the ancient cities with their gardens situated amidst rice fields claimed from the forest were not destined to survive.

In the 10th century Cola invaders from South India, after first gaining control over the Jaffna peninsula, forced the Sinhalese kingdom South from Anuradhapura to Polonnaruwa. Then in the 13th century the Polonnaruwa kingdom also collapsed (DeSilva, 1977:42). Historians are unsure as to why the civilization collapsed when it did, and they hypothesize a variety of contributing factors including further invasions; a failure of agricultural production as the organization behind the irrigation system broke down; outbreaks of malaria and other fevers; and a population exodus toward the South and Southwest (Ibid:43). After the fall of Polonnaruwa, with few people left in scattered villages, a secondary growth of semi-deciduous dry forest reclaimed much of the Dry Zone, and there was little human disturbance again until the 20th century (Perera,1979:306).

The displaced Polonnaruwa population settled in the previously sparsely inhabited Wet Zone lowlands and mountains of the Central Highlands. In the lowlands, for the next three centuries, successive Sinhalese kingdoms fought for predominance until they were taken over by the Portugese in the 16th and 17th centuries. Meanwhile, in the highlands, the Kandyan Kingdom emerged in 'Malayarata', the highly defensible, and previously hardly settled mountain region (DeSilva, 1977: 46-50; DeSilva, 1981:82). The heart of the Kandyan Kingdom lay in the town of Kandy on the western side of the mountains.

Dicke suggests that many of the migrants who fled from Polonnaruwa to Malayarata chose to settle in the Uva Basin, a 700 km2 region of rolling hills surrounded by high mountains at the edge of Kandyan territory. The basin's intermediate climate would have been attractive because, when compared with the rest of the Wet Zone, it was more like that of the lowland Dry Zone from which people had immigrated (1987:79-80). It may have been familiar for other reasons as well. The region lay on the old path from the Dry Zone to Adam's Peak, one of the most sacred places of pilgrimage for Buddhists on

the island[4]. In addition, the region had mythological standing. According to legends, the Uva Basin was part of the garden of Ravanna, the warlord king of Lanka who stole Sita in the great Indian epic, the Ramayana. Many legends of origin for villages in the Uva such as Sita Eliya, Welimada, Uva Paranagama and Ella, refer to Sita.

Judging from the scale of their works, what must have been a large population settled in the Upper Uva and Kotmale areas central to this dissertation. The people cleared the forest and developed dry and wet rice cultivation techniques for the steep hillsides with stream irrigation, terracing, and extensive canals including long tunnels (Brohier, 1935 III:33-34). By the late 17th century, Badulla, the capital of the Province of 'Ouvah' as it was then known, was the second most important town in the Kandyan Kingdom (Knox, 1681:7).

Clearly a population large enough to construct irrigation works of the extent described by Baker (1855) and Brohier (1935) will have affected vegetation patterns in the Uva landscape with their agriculture. There are several types of *patana* grassland in the highlands distinguished by microclimatic and edaphic characteristics, of which the 'summer-dry patana' of the Uva Basin is one (Mueller-Dombois and Perera, 1971:8). The either 'natural' or anthropogenic origins of the various *patanas* and their successional status have been the subject of some debate (clearly summarized by Domros, 1976:116-117 and Werner, 1984: 138-141). The ecological description of De Rosaryo (1945, 1946 a,b,c) and research by Holmes (1951) are most credited today (Werner, 1984:141). Holmes convincingly argued on the basis of detailed edaphic (see also CH 2.1.3 Soils), ecologically and historically based logic, and controlled experiments, that the *patana* in the upper Uva is of anthropogenic origin and that at one time, the area was densely forested with tropical moist evergreen and sub-tropical evergreen montane forest.

[4]At Ambagamuwa there is an inscription on a stone pillar of an edict of King Vijayabahu I (1055-1110 AD - Polonnaruwa) about building rest houses for pilgrims travelling to Adam's Peak through Uva province with granting of villages to provide for the travellers (Seneviratne, 1988)

As the highlands are believed to have been uninhabited throughout the ancient historic period, two alternatives present themselves as periods of forest conversion to *patana*. Either the prehistoric Stone Age cultures or the post Polonnaruwa settlers must have cleared the forest. Even if the prehistoric peoples had achieved the scale of clearing to create the extensive patana, the maintenance of the grassland subclimax through cultivation, grazing and/or fire during the centuries of the Anuradhapura and Polonnaruwa periods would have required a noticeable population density. The highlands would hardly have been described as uninhabited. Thus, it is most likely that the *patanas* in the Uva are an anthropogenic vegetation type dating from the 13th century onward. By the time that foreign chroniclers began to describe the Uva, the transformation was well underway. Knox described the rice rich "Province of Ouvah" as:

> " a country well watered, the land not smooth, neither the hills very high, wood very scarce, but what they plant about their houses." (1681:7).

The settlement and land use pattern which emerged and which still characterizes most highland villages today was a modification of Dry Zone settlements based upon rice cultivation in the irrigable valley areas. *Gangoda* or homestead land of individual houses, surrounded by forest gardens of trees called *gewatte* , were located on higher ground above and around the paddy fields (*kumburu*). Managed forest patches called *watte* emerged in the wet Kotmale and possibly other areas. *Chena*, a shifting cultivation system involving annual burning of fields, was carried out on the upper slopes above villages, especially in the drier areas such as the upper Uva. Forests between administrative districts of the Kandyan kingdom were kept as reserves and protected from felling (Knox, 1681:3).

While the people who settled in the mountainous 'Malayarata' Kandyan kingdom with its 'Province of Ouvah' prospered in relative isolation, the Polonnaruwa migrants to the lowland areas in the South and Southwest took advantage of their coastal location to participate in trade. Cinnamon, gathered wild from the mid- and upland forests, was

highly prized in the courts of far away lands. Beginning in the earliest times, the island had been an important link in the trade routes of South Asia, at first for the Arab and Chinese ships and later extending into the Mediterranean (DeSilva, 1977:3). After his two year visit from 1292-1294, the explorer and wealthy trader Marco Polo referred glowingly to the wonders of the island of 'Serendib' (Domros, 1976:197). Predominantly Muslim traders had settled in small communities along the coast and with the increased interest in cinnamon began to penetrate inland. Tamil traders from the kingdom of Jaffna on the North coast of the island bought and sold a variety of goods. Sri Lanka imported rice, dried fish, salt, silk, muslin, butter, sugar and vegetable oil from Bengal, Coromandel and the West Coast of India in exchange for Ceylonese elephants, areca nut, spices, coir, ropes, cowry shells and pearls (DeSilva, 1981:174-176).

In 1498, Vasco Da Gama 'rediscovered' the island. The Portugese, who were interested in gaining a monopoly on cinnamon exports, came back in 1506. They were successful in their efforts to win both trade and territory, and by the end of the century controlled both the existing cinnamon trade and influenced much of the rest of the island excepting the Kandyan Kingdom in the Central Highlands (DeSilva, 1973).

From this period onward, tree crops, whether taken from the forest or from intensively managed plantations or gardens, became central to the island's economic development. The course of Sri Lanka's history is largely dominated by various governments' desire to exploit the profit potential of the island's trees. Today the initial prize, cinnamon, has been superceded by tea, rubber and coconut. These perennial crops have transformed the island's landscapes and remain the mainstay of the export economy.

2.2.2 Colonial Period - The Influence of the Development of the Plantation Economy on Land Use Patterns (1506 - 1948)

By 1594 there were seven kingdoms in Ceylon: Kotte, Sitawaka, Jaffna, Seven Korales, Kandy, Chilaw and Uva. At this point, resentment against the Portugese, who controlled the southwest coast and its profitable trade, led Sitawaka, Seven Korales, Kandy

and Uva to unite under the King of Kandy. In the next three decades, while the Kandyans wrangled with the Portugese, the Dutch became a powerful presence in Asia. In exchange for the monopoly on cinnamon harvested from their kingdom, the Kandyans signed a treaty with the Dutch in 1638 to help overthrow the Portugese, who subsequently lost their hold on Ceylon in 1658 (Ibid, 1973).

The Dutch exploitation of cinnamon began to significantly alter the patterns of indigenous land use. The Vereenigde Oost Indische Campagnie (VOC), the Dutch trading corporation, held the monopoly of cinnamon for the Far and the Near East. Ceylon cinnamon was of superior quality and demand in Europe always exceeded supply (DeSilva, 1981:161-162). The Dutch enforced their monopoly rights severely, with capital punishment likely for someone destroying a cinnamon plant, peeling plants without authorization, or privately trading in, or transporting cinnamon. The VOC curtailed other land use such as *chena* dry land shifting cultivation near cinnamon forests as it might cause harm to cinnamon trees. The VOC focus on its monopoly, in response to a doubling in price of cinnamon in Europe, included confiscating all potential cinnamon land and forcing resettlement of old villages. This interference with local land use patterns led to considerable tensions. The people in the South and Southwestern parts of the island began to rebel against the Dutch and support the Kandyan kingdom (DeSilva, 1973). Kandy was still under obligation to the Dutch for the cinnamon monopoly but otherwise remained a sovereign kingdom. The treaty arrangements for extracting wild cinnamon from the midland forests controlled by the Kandyans became increasingly cumbersome to the Dutch (Codrington, 1929:146).

In 1669 the VOC began experimenting with cinnamon plantations (as opposed to gathering cinnamon wild from the forest). Soon other crops, including coffee, sugar, cotton, indigo and tobacco followed (DeSilva, 1977:58). The cinnamon plantations were very successful and as a result, Dutch policies toward the Sri Lankan people living in the lowlands changed. Land previously taken was given out to settlers under the arrangement

that one third of each plot given would be planted to cinnamon, pepper and cardamom. DeSilva notes that this provided a share in the profits for the local people and a beginning of monetization of the local economy (Ibid: 166). Gardens, modified from the indigenous homestead gardens, now also produced cash crops of mixed spices including cinnamon, pepper and cardamom. The gardens still provide nearly all of the cinnamon and pepper exported from Sri Lanka today (Ceylon Chamber of Commerce, 1984).

Despite the successes occurring in the lowlands, the Dutch and the Kandyans argued more and more over the treaty terms and the Kandyans sought aid from other European powers. They contacted the British and eventually, influenced by larger concerns in the global empires, the British took over the Dutch controlled territories of Ceylon in 1796 (DeSilva, 1981). There followed a period of nearly a quarter century of often violent Kandyan resistance to British rule.

The unrest peaked with the Uva rebellion of 1817-18 (Ibid.). Faced with a guerilla war against the Kandyans who instigated a simultaneous revolt across their mountain kingdom, the British pursued a policy of terrorizing the population. Villages were burned, harvests, livestock and fruit trees destroyed. According to one estimate, over 10,000 people lost their lives (Tennent, 1859:91-92). Another noted that none of the members of the leading families in the kingdom survived. They were either killed in battle or by smallpox and other hardships which followed (Davy, 1821).

This is an explanation for the abandonment of the many irrigation works and the establishment of extensive *patana* grasslands on what were once agricultural fields discovered by Baker twenty five years later (Baker, 1855) and rediscovered by Brohier in the 1930's (Brohier, 1935). After gaining control over Kandy and finally putting down the Uva Rebellion in 1817, the British became the first single power to rule throughout the island since the height of the Polonnaruwa period.

The new British leaders tried to expand cinnamon marketing further but were thwarted by trade restrictions at home which allowed Javanese and Chinese Cassia to gain a

foothold in the European market (Codrington, 1929:178). As the demand for Ceylonese cinnamon fell, the British colonials sought alternative sources of profit. Experiments began to show promise by the 1830's, particularly for coffee which had a rapidly expanding market in Europe at the time . Coconut, tea and chincona (quinine) plantations followed in the 1860's but initially coffee was the major crop. As coffee grew particularly well at mid to high elevations, these developments fundamentally transformed the highland landscape.

With strong support from the colonial government, the private plantation economy expanded rapidly. The government financed road and railroad construction for improved communications and transport. It also passed legislation which paved the way for land sales. The legislation demonstrated that the British were either unfamiliar with or oblivious to the indigenous land use pattern. While focused primarily on rice cultivation and homestead garden production, extraction of products from the forests, and particularly *chena* cultivation with long fallow periods, were part of the land use system. Yet, the Crown Lands Encroachment Ordinance of 1840 stipulated that all land for which people could not produce evidence of title belonged to the crown. Nearly 90% of all land on the island became crown land which particularly affected forest lands and customary *chena* land (Government of Sri Lanka, 1990).

There is some debate about the effects of the ordinance on the people at the time. Roberts concludes that the ordinance did not affect many villagers directly (1973:160). Others, as an indication of the severity of its impact, allude to the sudden appearance of landlessness and the expansion of shared forms of tenure used to avoid fragmentation of landholdings (Government of Sri Lanka, 1990).

Clearly, the ordinance had lasting historical effects on land use patterns. Some of the aquired land was sold to coffee and tea planters and remains under extensive state owned plantations to this day. Villages, which had previously expanded out to new settlement nuclei with passing generations' population growth, were constrained in their access to land and ability to grow. This may have led to the fragmentation of landholding

sizes and pressures on the organization of economic activities in a village over time (Roberts,1973:160). Furthermore, as a result of amendments to the ordinance in 1843, 1931, 1947 and 1954, even today 150 years later, over 80% of the island remains under government control (GSL, 1990).

The ordinance's immediate effect on forests was drastic. Tennent describes the extent of the often indiscriminate forest clearing (1859: 230, 250, 252):

> "The mountain ranges on all sides of Kandy became rapidly covered with plantations; the great valleys of Doombera, Ambogammoa, Kotmalie, and Pusilawa were occupied by emulous speculators; they settled in the steep passes ascending to Neuera-ellia; they penetrated to Badulla and Oovah, and coffee trees quickly bloomed on solitary hills around the very base of Adam's Peak (1859:230)".

The coffee boom is likened to a gold rush, attracting European speculators who bought tens of thousands of acres every year (Ibid.). By 1857, 80,950 acres were producing coffee. By 1878 when its production peaked, coffee extended to 273,000 acres. The vast forests between mountain provinces which had been reserved under the kings of Kandy soon disappeared. Finally, in 1875, the Secretary of State for Colonies prohibited further sale of lands for coffee plantations above an elevation of 5,000 ft (Karunaratne, 1987:60).

The plantation economy brought other significant changes. A large volume of seasonal labor was required and the planters found the people of the surrounding villages, mostly small farmers working their own or customary lands, unwilling to work as wage labor. Migrants from southern India were brought in to meet the demand (Moldrich, 1990).

In the late 1860's a leaf disease, Hemileia vastratrix began to affect coffee plants and within 15 years had completely destroyed the industry (DeSilva, 1977:67). Within surprisingly few years during which many planters went bankrupt, tea, on which trials had begun decades earlier, emerged as the new crop. By 1890, tea exports accounted for 53.7 million British pounds of the island's total revenue of 90.8 million (De Silva, 1981:289). Tea proved to be more resistant to diseases but also required a year round labor force. The

migrant laborers became permanent workers. Plantations emerged as self-contained settlements with an Indian Tamil labor force[5] that had little interaction with surrounding Sinhalese villagers. The plantations' cash economy and the villages' subsistence economy were largely segregated. In the highland landscape of the Uva basin, extensive tea estates of often a thousand or more acres each emerged and were interspersed by native villages of a few hundred acres of paddy fields, forest gardens and chena land. Tea planting was dominated by Europeans who could afford the capital costs required to build and maintain the tea processing factories (De Silva, 1981:282). The most marginal lands, failing coffee or tea production, reverted to patana grassland. Small patches of forests were limited to inaccessible ravines.

The population of the Central Province and Uva increased rapidly from 851,940 in 1824 to 4,106,300 in 1911. Some of the sudden increase was due to the influx of estate laborers from South India (DeSilva, 1981:297).

DeSilva notes that the plantation economy was disproportionately larger than the food producing 'traditional' sector of the economy when compared to other colonies. Plantations took unquestioned precedence over paddy production (rice was imported) until the mid 20th century. During the first half of the 20th century, the plantation economy experienced a boom during World War I, particularly in demand for rubber, and was carried on through World War II (Ibid).

2.2.3. The Post Independence Period - Land Reform and the Mahaweli Project

Sri Lanka gained independence from the British in 1948. Two major political parties emerged and have dominated political development including major land use policies

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[5]There is a major distinction drawn by Sri Lankans in general between these estate workers, known as 'Indian Tamils' and the 'Sri Lanka Tamils', who settled first many centuries ago on the North coast of the island around Jaffna and are now a very influential and often affluent minority in all realms of Sri Lankan society. The current Civil War is based on a dispute between a segment of the Sri Lanka Tamils and the Sri Lanka Government, led by a Sinhalese majority.

until today. The United National Party (UNP) pursued liberal economic policies. The Sri Lanka Freedom Party (SLFP) was more social democratic and Sinhalese nationalist in its orientation. Several smaller parties ranging from nationalistic to Marxist in their political ideology also participated in the political process. The UNP was elected to form the first government of Sri Lanka (GSL). At the time, Sri Lanka had a free market economy with over 90% of the island's foreign exchange earnings coming from agricultural exports, primarily tea, rubber and coconut, and the majority of the island's labor worked in agriculture (Karunatilake, 1988:25). During the next decade, the global terms of trade for agricultural products declined, and the SLFP came to power. In the 1960's after a new election, the GSL, led again by the UNP began to intervene more strongly in the economy. Imports and exports were regulated and the state sector took on a greater role in developing manufacturing and transportation.

By the mid 1960's the need for long range planning in the development of water resources became apparent. The population was dependent upon imports of staples, especially rice, to meet its basic needs. Furthermore, population growth rates of 2.3% or more meant increased competition for available resources all over the island but particularly in the very crowded Wet Zone. It was hoped that restoration of the Dry Zone agricultural potential through irrigation and enhancement of hydro-power generation could disperse the population pressure and alleviate many of the nation's development problems (Ibid: 26-27).

Over 16,000 reservoirs (tanks) remain in Sri Lanka as the legacy of the ancient irrigation civilizations of Anuradhapura and Polonnaruwa in the 5th through the 12th centuries. Many of these are small village reservoirs actively managed by farmers today. At the turn of the century, the irrigation department had been founded and ancient irrigation works began to be repaired. This effort was carried on by the first governments after independence. Now, in the 1960's, the GSL began plans for a major project. The United Nations Development Programme (UNDP) and the Food and Agriculture Organization

(FAO) were called upon for the assessment and planning phase. The planners focused on the Mahaweli River Basin (Ibid).

The 206 mile Mahaweli Ganga (great sand river) is the largest river in Sri Lanka, draining 10,450 km2, amounting to 16% of the island (Karunatilake, 1988: 10: NARESA, 1991:147). It carries over 7,650 million cubic meters of water per year which amounts to 20% of all river run-off. Like all major rivers in Sri Lanka, the Mahaweli's headwaters lie in the Central Highlands (Fig. 2.1). Here Mahaweli confluences from the Wet Zone western side (Kotmale Oya, Kurundu Oya, Kalu Ganga, Ma Oya) emerge from areas of year round heavy rainfall and rivers on the drier East side (Uma Oya, Badulu Oya and Loggal Oya) capture the North East monsoon and inter-monsoonal downpours (Ibid: 11). By 1967, UNDP and FAO had proposed a 30 year Master Plan for development of the Mahaweli. It would create holding reservoirs in the foothills, assure water supplies to areas already under cultivation and deliver water to new areas for expanded development.

In 1970, the SLFP came to power. Under its leadership government control on the economy was tightened with strict import substitution and generous social welfare policies. Work on the Mahaweli project slowed down. In 1971, land reform was carried out. Under the Land Reform Ordinance of 1971, large, private estates were broken up and foreign owned estates were nationalized. Some of the land which fell to government as a result of land reform was redistributed to landless and small farmers, but 82% of the land is still in public hands (GSL, 1990).

In 1977 the SLFP lost the national elections to the UNP leaving behind a combined legacy of a very weak economy and a very high rating on social welfare. The new UNP government changed the economy's course toward export oriented growth with fewer subsidies and social welfare expenditures, less regulation of the economy, particularly of imports, encouragement of private enterprise and foreign investment and major investments in infrastructure. The combination of still high social welfare ratings and very liberal economic policy served to attract the attention of the international donor community to help

fund the government's goal of once again taking up the Mahaweli Development Scheme (Karunatilake, 1988).

The USA, Canada, Australia, UK, Federal Republic of Germany, Sweden, the EEC, the Netherlands, Belgium, Kuwait, Saudi Arabia, Japan and several international funding agencies including the World Bank all supported the project with loans or grants (Karunatilaka, 1988:50). The funds were granted under several conditions, including that the Sri Lanka rupee be devalued, all controls and restrictions on the economy be dismantled and welfare spending be reduced. Further, the project's completion time was shortened from an original 30 year implementation schedule to seven years.

Thus, the Accelerated Mahaweli Development Programme (MDP) began in 1978. Five of the original 15 major reservoir projects were selected for construction. They were largely completed by the early 1990's. The project has been a major investment. A 1988 estimate of the total cost of the project by its scheduled completion in 1992 was 50 billion rupees (Karunatillake, 1988:154). The average annual expenditure of government capital on this project alone was 30% of GNP (Ibid:155).

Now that it is completed, it is hoped that the MDP will be able to meet the targets of food and energy self-sufficiency. A key component in the project's success will be systems maintenance. Provisions for maintenance have been made for the dams and irrigation channel systems. Provisions for the protection of the Mahaweli watershed, the source of the system's water, are also important. Much has changed in Sri Lanka since the days of the early Dry Zone irrigation-based civilizations and many new variables will influence the success of the project over time. One of these is land use change in the watershed catchment areas upon which the system depends for its water supply. Various authors have emphasized this relationship. Brohier, for example, noted

> "...the whole system of water storage and carriage which in ancient times helped in irrigating the low-country is centered on the natural reservoirs up in the mountains" (Brohier, 1935, p.65)

He goes on to discuss the function of forest vegetation in capturing water which filters into the soil to form the sub-surface springs that maintain perennial river flows (Ibid). Vegetation cover and human land use are significantly different today than it was 700 years ago. At that time, the highlands were densely forested with few if any inhabitants. Today the land use patterns are very complex and determined by a large number of disaggregated groups of people whose actions are not easy to predict or direct. Large tea plantations, now being privatized, and extents of grasslands where coffee and tea plantations failed, have largely replaced the forest. There is a dense population of small farmers growing rice, vegetables and trees in villages situated between the larger tea estates.

Scientists have noted land use related changes in the runoff patterns including an overall increase in runoff and increased runoff/rainfall ratios with higher peak flows and reduced dry season runs for several river basins (Madduma-Bandara, 1985; Madduma-Bandara and Kuruppuarachchi, 1988, see NARESA, 148; Madduma-Bandara personal communication)). Time series data on sediment loads are not available, however in theory, the changes in runoff/rainfall with high rainy season flows would indicate increased erosion and sediment transport. Sediment transport is noticeable in high rates of siltation of reservoirs and tanks (NARESA, 1991: 148).

On the whole, the historical trend of land use in the highlands operates against national hopes for sustained year round high quality water yields to the lowlands. If the trend is to be countered, careful analysis of highland land use patterns and their causation will be needed before policies to change present practices will be successful. Factors which influence settlement and land use today include population pressure, land tenure and government administration and policies.

2.3 The Present Demographic, Administrative and Socio-Economic Context of the Highlands

2.3.1 Population and Demographics

In 1981, the time of the last census, Sri Lanka's population was 14.9 million. According to the most recent estimates, population had grown to 17.9 million people by 1991 and was expected to increase to 19.3 million by 1996 (FRG, 1988:17). With an average of 257 people per km2, the island is one of the most densely populated countries in the world[6]. Among less industrialized nations in Asia, Sri Lanka is second only to Bangladesh in the number of persons per square kilometer (NARESA, 1991:25). The uneven distribution of settlements further exacerbates the density. Fifty five percent of the population live in 24% of the area, the Wet Zone (Ibid.). Still, Sri Lanka is a largely rural agrarian society. The non-urban population was estimated to be 78% in 1981 (NARESA, 1991:28). With the exception of the sprawling metropolis of Colombo, in the Western Province, villages dominate the landscape (Dicke, 1987:41-44) At the same time, the majority of Sri Lankans live within 50 km of a town of 20,000 people which provides most of the services of a city (Ibid: 40).

Despite its comparatively low growth rate when contrasted with other nations of similar levels of industrialization, Sri Lanka's population continues to expand rapidly. Population has, for example, grown steadily in Badulla district (Table 2.1, Fig. 2.2). Population density has increased here by 24% from 188 persons per km2 in 1963 to 234 persons per km2 in 1986 (GSL, 1986). Since population growth accrues both from births in a region and from inmigration from other areas, this will have implications for land use practices in cases where new immigrants bring alternative approaches to management with them (Perera, 1985:65,66). On the basis of my own data, comparisons of birthplaces for three generations in 173 households in the study areas indicate an overall inmigration of 13% of the population from a distance of greater than 25 kilometers. Sixty percent of all

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[6]To use an alternative measure 1/d, this leaves each Sri Lankan with only 3,891 square meters (.96 acres) of land (A. Schultz, pers. com.)

Table 2.1

Population and Population Density by District 1871 - 1986

	All Island		Badulla*		Nuwara Eliya	
Year	Population	per km2	Population	per km2	Population	per km2
1871	2,400,400	37	129,000	15	58,200	48
1901	3,566,000	55	186,700	22	153,000	126
1911	4,106,400	na	216,700	na	155,500	na
1931	na	82	na	36	na	194
1946	6,657,300	103	325,200	45	268,100	221
1953	8,097,900	125	372,200	56	397,700	268
1963	10,582,000	165	521,800	188	521,800	328
1971	12,689,897	196	615,405	218	450,278	377
1981	14,846,750	232	640,952	241	603,577	391
1986**	16,117,000	249	668,000	234	514,000[7]	295

*note: Until 1963, Badulla included what is now Moneragala District.

** The 1986 figures are estimates based on the latest census in 1981.

(Source: GSL, 1986:22-37)

[7] I do not know why this drop in population estimate occurred.

respondents had been born in their present village of residence. There is a significant difference in the migration pattern for men and women; sixty-six percent of all men live in their village of birth, whereas only 52% of women do. The pattern is most pronounced for men in older villages where fully 86% were born in their present village of residence. This can be explained by the customary pattern of a woman marrying and moving into her husband's family, often in a different village from her own, known as *diga* (Wijesekera, 1987:86). Still, even among women, inmigration is not normally from beyond the region, with 33% of women marrying into a village came from less than 25 kilometers away[8]. Thus, most of the population growth for the villages in this study is internal to each region. The average number of children for the 173 households surveyed in all three regions was 1.75, with a slightly higher rate of 2 children per household in the Welimada villages.

2.3.2 Ethnicity and Religious Affiliations

Sri Lankans are a diverse ethnic mix. The dominant majority are Sinhalese who make up 75% of the population and live predominantly in the Southern and Central regions of the island. Tamils are the next largest group comprising 18%. The Tamils are nearly evenly divided into Sri Lanka Tamils living in the North and East (descendent in part from the Cola invaders of earlier centuries), centered for many centuries in the city of Jaffna; and Indian Tamils, who were brought in as a labor force under British colonial rule and largely live and work on tea and rubber estates in the southern and central regions of the island. Moors, many of whom trace their ancestry back to Sri Lanka's pre-colonial heyday in international sea trade, and others who more recently arrived from India comprise 7% of the people. Remaining ethnic groups include Burghers, descendent from the Dutch colonials, Europeans, Chinese and people of Malayan origin, all of whom live predominantly in Colombo and along the South Coast (DeSilva, 1977:277).

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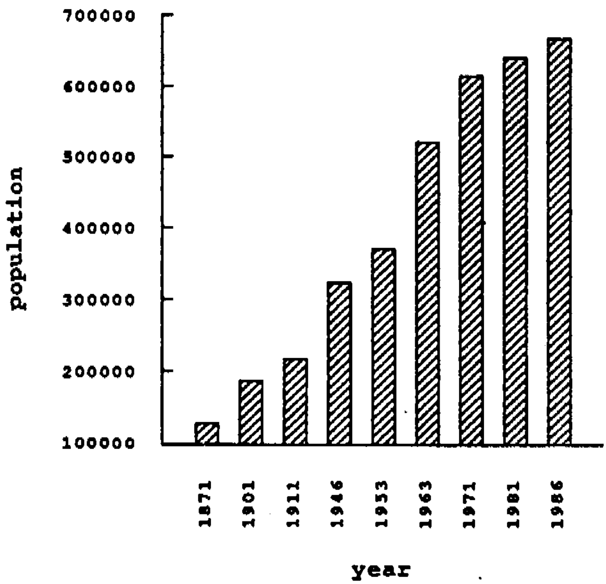
[8]There is some degree of temporary migration to the Middle East, particularly among women who find employment as household labor; as well as migration by both men and women to Colombo. This phenomenon, though encountered in a few cases, was not quantified here.

Fig. 2.2 POPULATION GROWTH IN BADULLA DISTRICT



Religious affiliations follow but do not duplicate the ethnic breakdown. The majority of the Sinhalese, 70% of the population, are Theravada Buddhist. Most of the Tamils, 15% of the population, are Hindu, but many converted to Christianity during the Colonial period. Today, with most of the Europeans and some Sinhalese, Christians are 7% of the population. The remaining 7% of people are of Muslim faith. Sinhala, a Pali and Sanskrit derived language, is spoken by the majority. In addition, Tamil and English are official languages, with English often spoken by the educated classes of Sri Lankans especially in Colombo, Kandy, and areas frequented by tourists.

In the Central Highlands, the vast majority of villagers are Sinhalese Buddhists. In the hundreds of villages which dot the landscape, 90% or more of the people are Sinhalese. Small pockets of Moors and Tamils live in some villages and in rural towns such as Matale and Bandarawela, where most are involved in trade. In addition, a large number of Indian Tamils live and work on the government-owned tea estates[9] which cover many thousands of hectares in the mountains. Around the towns near the estates, such as Nuwara Eliya, Welimada and Keppetipola, Tamil and Moor vegetable farmers are very successful. Table 2.1 and Fig 2.2 illustrate, for the areas of interest to this thesis, some of the differences in population density and population growth over the last century.

2.3.3. Administration and Public Lands Policy

Sri Lanka has nine provinces, each of which has several districts that are further subdivided into divisions[10]. Each province has an appointed Governor, each district a Government Agent (GA) and each division an Assistant Government Agent (AGA). One division includes numerous villages, so called Grama Sevaka Niladhari (GS) units, with each appointed GS taking on the combined traditional roles of Headman, Cultivation

[9] In 1991 the Government of Sri Lanka (GSL) decided to privatize the large tea estates which had been under the management of two large government corporations. This process is now underway and is expected to bring some change to the estates. However, it is too soon to begin to assess the results of this policy change and it is beyond the scope of my study to attempt to follow it. Here all such estates will be referred to as owned and managed by the GSL.

[10] Western, Central, Southern, Northern, Eastern, North Central, North Western, Sabaragamuwa, and Uva.

Officer and Special Services Officer for a village or sub-village unit of 200-400 households. Today, government land in the highlands is administered by the Government Tea Corporations, the Forest Department and the Government Agents.

There is an extensive body of legislation on land use and environmental protection in force today. The severe erosion and landslides caused by rapid clearing of forest lands for coffee planting in the 1800's for example, led to the British Forest Protection Ordinance of 1875 to protect forests above 5,000', and the 1885 Ordinance on Forests and Wastelands which restricted felling and transport of timber (Karunaratne, 1987). At the turn of the century the Forest Department was established. The Fauna and Flora Protection Act was passed in 1937. The Kotmale landslides of 1947 led to the passing of the Soil Conservation act of 1951. More recently the Agrarian Services Act and the Mahaweli Authorization Act have had an influence on land use.

2.3.4. Land Tenure and the General Model of Settlement Pattern

Perhaps the largest body of land law (and certainly the most complicated) deals with land tenure issues. The land tenure system in highland Sri Lanka is a complex mixture of the indigenous Kandyan laws, Roman Dutch law and British colonial rules.

Prior to the Colonial period all land belonged to the king. He gave land grants to temples and to his subjects in exchange for services and some proportion of produce. Forest land was kept in protective reserves under the king's jurisdiction. During the 17th century Dutch colonial period, Roman Dutch Law was introduced in the lowlands. When the British gained control, they recognized the Roman system (GSL, 1990:158). Meanwhile the Kandyan customary system still operated in the mountains. In 1840 the British passed the Crown Lands Encroachment Ordinance (CLEO). All land for which owners could not show title or continuous cultivation fell to the colonial power. Homesteads, paddy fields and some other lands with clearly defined rights remained with the people. However, all forest lands, and most *chena* lands (which under Kandyan and customary law had had customary access rights attached to them) went to the British. The

system which has evolved since is still predominantly based on Roman law with private property the rule. However Kandyan customary law still applies to the Kandyan Sinhalese, especially when it pertains to conserving landed property in the family (Ibid:159). Roman law applies where the customary law falls short. The CLEO is still the primary land law upon which most other legislation pertaining to land is based (GSL, 1990:152).

During the years leading up to independence and for several decades afterwards, a number of very large private land holdings emerged, while on the other end of the scale, landlessness became very common. In 1935 the Land Development Ordinance (LDO) was passed as a mechanism for land alienation to the rural poor. In 1972 under the SLFP government land reform was carried out (Land Reform Law of 1972 No1; and No39 in 1975). Many large estates, especially tea estates which had belonged to foreigners, were nationalized[1]. Under the new rules no individual is allowed to own more than 25 acres of paddy land and 50 acres of other cropland (GSL, 1990:181). Still, island wide, 27% of households are landless; 42% have less than .5 ha. Small holdings are either held by off-farm owners of the business or professional classes or of descendents of the wealthy minority of the rural people; or they are peasant owners (Peiris, 1977:217). As a result of the land reform (and despite some degree of redistribution of lands to the poor), the government again increased the amount of land under its control. Today the Government owns 82% of all land (GSL, 1990).

Much has been written about the complex customary tenure systems in rural Sri Lanka (Leach, 1961; Obeyesekere, 1967; Moore, M.P., 1978) which largely concern paddy lands. Homestead gardens are usually privately owned with title, or *de facto* control based on long term occupation of government owned land. With the high population density in the villages and relatively sparse use of the large areas of surrounding

[1]The GSL ran the large tea estates through two government corporations. In 1992 a new policy of privatizing the large tea estates was announced and it is now being implemented.

government owned land, illegal encroachments are very common. Sometimes people who have lived on a site for a long period of time are granted property rights, but such unplanned expansion is, from an ecological standpoint, arguably less desirable than more planned population expansion in government subsidized village settlement programs. In addition to such access for settlement, villagers commonly graze livestock on government land. Felling trees on government land is illegal, and enforced wherever possible[2].

For the case of Badulla district (282,200ha) for example, the Government owns 82% of the land in the district. This land is held under several categories, including forestland, tea estates, urban land roads and land for village expansion. Under the LDO and other programs for 1990, access to 68,064 ha of government land (29%) in Badulla district had been granted in programs ranging from outright titles through inheritable land granted to landless people which may not be sold, and lands which are not inheritable or transferable but for which renewable short term cultivation permits are issued (AGA's Passara and Welimada, 1991). The remaining 18% of land in the district was privately owned village and urban land.

In 1989 in Badulla District there were 69,813 agricultural operators[3] including 8,515 women. Thirteen percent were landless but leasing land, and 32% cultivated homegardens only. In the district, the average holding size is .69 ha as opposed to the figure for Sri Lanka as a whole which is .78 ha. Ten percent of the area is in holdings of less than .4 ha (38% of all holdings) and 53% of all holdings are .4-1.62 ha in size.[4]

I found a range of tenure categories in my survey of 173 households. There were only two cases in which the garden and house were rented by the people living in it (both

[2]Limited staffing limits the government's capacity to enforce the laws for small scale theft of timber or fuelwood gathering. Gathering of 'dead and down' wood is allowed.

[3]The term 'agricultural operator' was taken from the government statistics for the district. I was not able to get an exact definition of it use but gathered from the context that it refers to people with officially documented control over agricultural land for some specified period of time (i.e. including short term leases).

[4]Landed people may also lease land, but this is not reflected in the available data. Temple lands are not included in this category of private land.

cases were of relatives of the landowner). In some areas people live on what is officially still government land (i.e. with no formal title). In a few cases in each village several families share an undivided lot. This may be an underestimate due to false responses, but in general for these villages, most people at least own or have *de facto* control of the land they live on. In parallel with the district wide information, there are many cases in which the house and garden are the only land owned. In these villages only about half of the households visited own any paddy land, even fewer own tea. Many of the households holding paddy lands rent out portions to other villagers, and those holding tea may employ laborers on their land. This situation, though descriptive of the villages surveyed, may not be representative of the highland region as a whole. Landlessness is a major problem throughout the highlands, but it may be less visible in older, well established villages. For example, the laborers who work in the fields in Wijebahukande and Ravanagoda largely come from nearby settlements and new colonies on marginal lands in which there may be a larger proportion of landless families. Landownership compared by region is presented in Table 2.2.

Table 2.2 Land Ownership per Household in Villages Surveyed Compared by Region

	All Villages	Welimada	Kotmale**	Passara
(n)	173	92	50	31
All Land*	**1.01**	**.60**	**2.12**	**.47**
Garden	**.51**	**.33**	**1.02**	**.21**
(n)	82	49	23	10
Paddy	**.47**	**.29**	**.88**	**.38**
(n)	67	42	21	4
Tea	**.62**	**.22**	**1.34**	**1.02**
Gard Age	52 yrs	40.4 yrs	70.7 yrs	58.2 yrs

* land in hectares; note that many households do not own any paddy or tea land.
** In Kotmale two very large land owners significantly skew the average holding size.

In the villages, nearly all land is held by private individuals. Paddy fields and homestead land including forest gardens, small holder tea and houses are privately owned. The skew between small and large landowners is high in the Kotmale villages, where the survey happened to include two very large landowners (with around 15ha each). While the surveys in the Maussagolla and Mirahawatte areas did not include large landowners, it is common in older villages for one or two families to have larger holdings (though limited to the ceilings imposed by the 1971 land reform). There is no extensive village commons land today, though people customarily graze livestock on government owned land.

As population grows, the government sets aside areas for village expansion in which new colonies from older villages are established. These settlements include provisions for household plots (often very small) and some basic infrastructure such as roads and water taps. They normally do not include agricultural land. In rural areas, small household plots may not satisfy all peoples' needs, including basic necessities such as fuelwood. It is possible that some of the encroachment into government owned grassland and forests is not only by landless. This type of haphazard extension of settlement on the marginal fringes of an already densely settled area may exacerbate erosion, destroy native species' habitat or cause other ecological disturbances. At the same time it is difficult to control without alternative, enforceable land use planning (Zijlstra, 1989 Table 6.1).

2.4. Present Land Use and Agriculture

Agriculture accounts for 25% of GDP, almost 50% of total employment and export earnings, and 40% of all government revenues (for example, through the large government owned tea estates). According to one study, 90% of the rural population depends directly or indirectly on agriculture (NARESA, 1991:6-7). Translated into area values, paddy rice production covered 758,000 ha in 1984, while tea, rubber and coconut plantations for export covered 786,000 ha. "Other crops" accounted for 218, 000 ha. (Ibid, 1991: 98). In the highlands where only one paddy crop is commonly grown per year, these "other crops" are a very significant land use.

2.4.1. Perennial Cash Crops

The island economy depends heavily on exports of perennial crops. Tea, rubber and coconuts are predominantly large estate crops. Tea holdings of less than eight ha in size (the GSL definition of 'small holder') make up less than 17% of the area under tea. Only a third of the rubber crop comes from small holders. Coconuts are more mixed with 64% coming from holdings of less than 20 acres (Pieris, 1977:215).

In addition, there are a number of so called "minor export crops" (MEC's) raised on over 50,000 ha island wide[5]. These crops in 1974 made up 8.9% of Sri Lanka's exports. In 1981 they were 11%. The latest figures, from 1988, in which MEC's accounted for only 5% of all exports, reflect the political troubles of the late 1980's which made crop transports extremely difficult. The MEC exports for the early 1990's can be expected to be higher again.

These crops are grown in a variety of circumstances. Cardamom usually comes from large units, often planted illegally in reserve forest understory. Pepper is mostly a mixed crop from large estates, though efforts to extend pepper to small holders are very visible in the highlands. Half of the cacao, citronella and cinnamon grown comes from large estates, and half from small holders. Sri Lanka supplies 33% of the world cinnamon market and is its single largest exporter (all other nations have less than half of 1% of the world market (IFAD and SIDA, 1990).[6] Cloves, nutmeg and coffee largely come from mixed small holder plantations and homegardens.

Government strategy since the 1960's has been crop diversification with subsidies for planting and inputs to producers, and tax incentives to exporters (Pieris, 1977:232). The Department of Export Agriculture (formerly the Department of Minor Export Crops) promotes cocoa, coffee, cardamom, pepper, cloves, nutmeg, mace, cashew, cinnamon,

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[5]Ministry of Plan Implementation, Department of Census and Statistics: Highland Crops and Livestock Statistics, Nuwara Eliya District, 1980: Table 8a.

[6]Note that much of what is sold under the trade name of cinnamon on the world market is actually cassia coming from China, Malaysia and Indonesia.

ginger, citronella, papaya and sesame crops. The department emphasizes distribution of seed and seedlings, development of small nurseries and it provides information on inputs, pruning, maintenance and planting subsidies. The emphasis on these (largely) perennial crops has been problematic for the Upper Uva region where few of them grow well (Domros, 1976). Instead, in the Nuwara Eliya, Welimada and Bandarwela areas, the emphasis in agricultural extension has been on annual vegetable cropping.

2.5 Vegetation and Land Use Types in the Highlands with Emphasis on the Uva Basin

Vegetation types vary in composition and extent with changes in elevation and rainfall patterns across the highlands but most of the basic categories of land use are the same, for example, for the three administrative divisions in which this study was carried out (Table 2.3). Note in particular the differences in climate in the three areas and the importance of tea and forests in rainy Kotmale while "other annual crops" and grassland are more significant in extent in the drier areas.

The major land uses are discussed here in a landscape ecological context. Drawing on available literature, flows of nutrients, water, flora and fauna which are likely to occur between a patch of a given vegetation type or ecosystem and its neighboring patches are discussed. The ecosystems are defined as either unmanaged 'wildlands' or managed land use types. As defined in this case, wildlands may be influenced by people and may even, as is the case for some *patana* , have anthropogenic origins, but they are not specifically managed to yield a crop or other output.

2.5.1. Wildlands

The major wildland ecosystems of the highlands are forests, wet and dry grassland formations and riparian areas. The forest and grassland vegetation types have been extensively studied by botanists and ecologists from early on (Trimen, 1893-1900; Pearson, 1899; de Rosayro, 1942, de Rosayro, 1950; Holmes, 1951; Koelmeyer, 1957;

Abeywickrama, 1959; Gaussen et al, 1968; Mueller-Dombois and Perera, 1971; Dassanayake, 1980; Werner, 1984). Riparian zones in the mountains have been less

Table 2.3
Land Use in the Central Highlands
(Passara, Welimada and Kotmale Divisions)

type of land use	Passara* ha	%	Welimada ha	%	Kotmale ha	%
'wildlands'						
grassland/scrub	3,800	14.1	1,420	7.5	870	4.0
dense forest	870	3.2	1,900	10.5	3,450	17.0
open forest	2,640	9.8	290	1.6	300	1.5
barren land	20	0		0		0
'managed land'						
forest plantations	1,080	4.0	2,500	4.0	550	2.7
homesteads	2,350	8.7	4,210	23.3	2,470	12.1
tea	7,630	28.3	2,320	12.9	10,670	52.6
mixed tree/peren.	20	0	0	0	270	1.3
paddy land	1,020	3.8	1,870	10.3	990	4.9
other annual crop (vegetables, sugar)	7,530	27.7	3,400	8.7	280	1.4
water	0	0	110	.6	400	2.0
urban land	10	0	20	0	40	0
total	26,970		18,040		20,290	

* annual rainfall averages 3,608 in Kotmale, 2,382 mm in Passara and 1,610 in Welimada. (Source: pers. comm with Assistant Government Agents, Passara, Welimada and Kotmale Divisions, Sri Lanka, 1991).

studied as ecosystems, however there is considerable literature on various sub-components. Starmuhlner noted that the rivers drain areas of crystalline rock and have steep gradients, especially toward the headwaters where 50-100% drops and waterfalls are very common (Starmuhlner, 1984). Stream hydrochemistry has been studied (Weninger, 1972), and there is extensive information on freshwater fauna, both vertebrate and invertebrate (e.g. Fernando, 1984; Senanayake, 1978).

Natural Forest

Natural forest once dominated Sri Lanka's vegetation. Today aerial photograph and satellite image interpretation indicate that less than 25% of the island and only 10% of the Upper Mahaweli Catchment remains under forest cover (ODA,1990b).

The forests of Sri Lanka have been classified into several types along elevation and climatic gradients. The first major distinction lies between Dry Zone, largely deciduous forests which make up 84% of all Sri Lanka's forests, and the remaining 16% of Wet/Intermediate Zone and montane forests (NARESA, 1991:199). The second is the differentiation of forests in the Wet/Intermediate Zone along the elevation gradient of the Central Highlands (Trimen, 1893-1900; Gaussen, 1968; Perera, 1979). Some of these latter forest types are found in the study areas[7].

The tropical submontane rainforest (Perera, 1979) extended from 600/900 to 1,500 meters. At least four forest communities once predominated within this range including two types prevalent in the Peak Wilderness at the southern rim of the highlands, one dominated by Doona gardenerii; and one by Palaquium rubiginosum. Communities with associations marked by Myristica dactyloides Gaertn.; and Garcinea echinocarpa are more prevalent in the the Knuckles range North of the Mahaweli River. (Werner, 1984:129-131).

Forests above 1,500 m are classified as tropical montane rain forest (Perera, 1979) and in some areas as cloud forest (Werner, 1984). They are characterized by Syzygium spp., Elaeocarpus glandifuler., Michelia nilagarica., Calophyllum walkerii; and Semecarpus spp. Cloud Forest thicket predominates on the often windy, perennially misty, and soil impoverished slopes at the highest elevations with species including

[7]The perhaps best studied forest type, the tropical lowland rainforest (e.g. Perera, 1979), is not found in the highland areas studied here. Today, there are 47,370 ha in the Sinharaja complex, the largest remaining example of lowland rainforest in Sri Lanka, which once extended from sea level to a gradual transition zone of 600-900 meters (Gunatilleke, 1990; deSoysa and Raheem, 1990).

Syzygium spp., Eugenia spp., Cinnamomum litsaefolium. Litsea spp. and Rhododendron arboreum (Gaussen et al., 1968:48-53)

Today, five forest reserves managed by the Forest Department still cover 26,890 ha in the highlands (Werner, 1984). The remaining forests outside the reserves are small fragments rarely more than 10 ha in size. These are often forest patches in secondary stages of succession with evidence of human encroachment. They are usually in steep and inaccessible drainages, or along streams inside large tea estates.

Despite the encroachment, the biodiversity even in the last patches of secondary natural forest in the study areas is still quite high[8]. For trees alone, Meyer identified 62 species from 30 families in a survey of six forest fragments in Welimada and Bandarawela Divisions in the Uva Basin in the Intermediate Zone (Meyer, 1989), and Everett et al [9] identified 78 tree species from 31 families in three forest fragments on the wetter side of the mountain range in Rogersongama, Kotmale division (unpubl. data). A brief bird survey around Rogersongama by skilled field naturalists included sightings of 39 bird species over a three day period in July, 1990 (Sujeewa Jaasinghe pers. comm.).

Beside providing habitat for native flora and fauna, forests hold the greatest volume of living biomass of all vegetation types. They are storage sinks for nutrients ranging from the most common, relatively immobile elements such as carbon, calcium and magnesium on through more highly mobile ions important for plant growth such as nitrogen, potassium, sodium, and sulphur. Studies indicate that the rapid breakdown and uptake of nutrients in the complex interactions between the tropical forest and soil ecosystems ensure that most of even the relatively mobile nutrients remain in place (Puri et al. 1980; Jordan, 1985). These would soon be leached out of soils in ecosystems of lesser biomass on the steep slopes in mountain areas with high rainfall. There, the forests' myriad of shallow

[8]These are areas in which no larger natural forests are left.

[9]Field research by Yvonne Everett with Ajit Lokuge, Sujeewa Jaasinghe, Shastri Mallawarachchi, Kaman Kumara Ranatungaarachchci.

and deep root systems also physically hold topsoil in place, resulting for the case of highland Sri Lanka, in the lowest erosion rates of any vegetation type (Zijlstra, 1989).

Forest influences on water flows in the landscape are likely to be mixed. On the one hand, forests are known to stabilize soils, and like a sponge, forest vegetation intercepts large quantities of water which might run off of bare land and slowly filters it into the watertable, providing for year round recharge of clear water for mountain streams. Thus forests contribute to water quality by filtering and moderating potentially soil erosive runoff, and to water quantity by extending flows beyond seasonal rainfall events. At the same time, trees use water for transpiration, thus reducing the overall amount of water run-off which might be used for other purposes (Zijlstra, 1989). Therefore, for the purpose of maximizing clear flows of water, the pattern of distribution of forest vegetation in the landscape will be significant (Kattelmann, 1987).

Patana Grassland

There are two major types of *patana*, known as 'wet' and 'dry'. The 'wet' *patanas* are found on the poorly drained high plains and are thus of edaphic origin. The dry *patana* grasslands and scrub are a fire subclimax vegetation type very prevalent in the Intermediate Zone. Much of the *patana* in the Uva is believed to have resulted after farmers' fields and irrigation systems were destroyed or abandoned in the 18th and 19th century wars between the Kandyans and the colonial powers (Ch 2.2). Additional *patana* is probably the end result of conversion from forests to first coffee and then tea plantations during colonial times (Holmes, 1951). Once the many marginal plantations on the steeper slopes with thin soils were abandoned, grasses recolonized the areas. The present grassland subclimax vegetation regenerates to scrub and then forest if protected from fire over an extended period of time (Ibid.). If the *patana* is not protected, frequent fires and grazing pressures keep the forest from returning.

The *patana* is very species diverse. Though dominated by Cymbopogon spp. and Imperata cylindrica (Gaussen et al, 1968:50), a variety of other plants including shrubs and

trees coexists in this community. In one study, over 140 plant species were identified (Mueller-Dombois and Perera, 1971). Many fauna live in or use the patana as part of their habitat. These include wild boar, various wildcats, monkeys, barking deer, sambhar, and a wide range of birds and reptiles.

In the Uva Basin, the grasslands are usually on steep slopes and dry hilltops, places unattractive for agricultural use. They have less biomass and are lower in nutrient storage capacity than the forest ecosystem. Other than as grazing land for village livestock, they serve no economic purpose. Yet, as grassland, undisturbed *patana* probably protects the soil from erosion and at the same time traps and filters less water than forests do. Indications from research show that the runoff rates from *patana* are high, making this an ideal vegetation type from the perspective of maximizing immediate water flow (Maduma-Bandara, 1985; NARESA, 1991).

Chena , the traditional form of shifting cultivation, was practiced in the *patana* near villages. Today many areas which might have been *chena* lands in the past have been converted to permanent vegetable cultivation.

Rivers and Riparian Zones

The riparian zone is disproportionally important as the area of interface between terrestrial and aquatic ecosystems and a key zone of fluxes of nutrients into and out of the landscape (Gregory et al, 1991). Riparian vegetation filters nutrient flows, moderates water temperature and reduces the input of pollutants to streams and is fundamental to maintaining water purity. Access to the riparian zone is basic to the survival of most wildlife.

There are nine major rivers and 94 smaller rivers with a collective length of 4,560 km in Sri Lanka (NARESA, 1991:257). Ecosystem studies on lowland wetlands and flood plains have been undertaken (IUCN and WWF, 1989). However, I am not aware of any such study of mountain rivers. The environmental importance and sensitivity of these systems for water flows and as habitat for flora and fauna is recognized legally by the GSL

in the provision of riparian zone protection ordinances. These are, however, often not or only partially enforced, as is evident in the frequency with which cultivation occurs right down to the waters' edge. Human impact on the mountain streams includes damming, channeling and pumping water for irrigation, mining sand from the stream beds, grazing and watering livestock, fishing with dynamite caps and adding all manner of pollutants from laundry soap to agricultural chemicals and motor oil (pers. obs).

2.5.2. Managed Land Use Types

Human land use in the highlands includes tea estates, forest plantations, forest gardens and homesteads, small holder tea and vegetable or *chena* cultivation. The traditional village settlement pattern throughout the highlands has been focused around growing rice and tree crops for subsistence. Low lying lands which could be irrigated were formed into terraced paddy fields. Houses were located above the fields on higher ground in homesteads densely planted with a wide variety of utility tree and shrub species. On yet higher slopes above the homesteads people practiced chena, the indigenous form of shifting cultivation. Forest or grassland extended beyond the cultivated lands. From the colonial period on, tea cultivation expanded and now covers a large proportion of the total area in the highlands with the traditional villages scattered in lower valley areas in between the large estates which are often located on high plateaus. Since the colonial days, many villagers have converted their land to small plots of tea. The leaves can be sold to nearby large plantation factories for processing. Others plant vegetables as a cash crop.

Tea Cultivation

As indicated in Table 2.3, tea cultivation is the most extensive land use in the study region. Badulla district is the third largest tea growing area in Sri Lanka with 15.5% of the tea estates (defined as >8ha) and small holders (< 8 ha) Tea extends over 36,000 ha with 88% in holdings of >20 ha. Half of the holdings in the remaining 12% of the land are smaller than 2 ha. There are two major categories of tea planting, the large-scale

government estates, which extend for hundreds and sometimes thousands of hectares, and privately owned, usually smallholder tea found in villages surrounding larger government owned estates. As agroecosystems, tea plantations vary greatly in their planting configurations and management from dense, lush carpets of high yielding varieties of carefully pruned, fertilized and plucked bushes, to sparsely scattered clumps of older variety tea in neglected fields (Marby, 1971). The best lands on the large holdings tend to have the highest yields, while more extensive marginal lands produce less and are increasingly abandoned as they become unprofitable (Zjilstra, 1989). Shade trees are very common in plantations and range from exotic shade and light timber or fuelwood producing trees such as Grevillea robusta, and fast growing nitrogen fixing species such as Erythrina lithosperma and Gliricidia sepium, to more localized mixtures including native or naturalized timber and fruit tree species in smaller holdings.

The landscape level role of the tea, based on its extensive scale alone is significant. In most cases, particularly on intensively managed large holdings, this agroecosystem persists on a steady diet of agro-chemical imports to make up for the nutrient drain in exported tea leaves. The effects of the chemical use on surrounding ecosystems is unknown, though likely to be influential due to the large extent of this land use type. The potential for 'organic' tea cultivation without chemicals has been recognized, and at present one large private estate with a factory is producing and marketing 'bio-tea', while the government sector is testing the idea (R. Senanayake and L. Perera pers comm.). The tea's contribution to soil erosion varies with management (Zijlstra, 1989:10). Highly productive tea closes in a continuous canopy about one meter above the ground with shade trees two to five meters above. Extensive root networks protect the soil from erosion most of the time (tea is heavily pruned back every four years or so, leaving the soil more exposed for a few months). In poorly managed plots, weeding between scattered bushes may leave large patches of bare soil exposed to erosion. In the Uva area with its seasonally strong winds, many estates have extensive shelterbelts of trees, often Cupressus sp., along their borders.

On some large estates natural forest patches along water courses are protected which may provide additional protection against erosion, as well as filtering of chemicals before run-off reaches the water. These forests also provide valuable habitat for native flora and fauna. The large scale monoculture cultivation pattern of tea itself is not likely to be suited as habitat for most wildlife although a wide range of bird species are encountered in the scattered shade trees throughout the tea fields.

Forest Plantations

The Forest Department began efforts to afforest the highlands during the British period and there are many hectares of plantations in the mountains today. During the 1950's various germination trials, and growth and yield experiments were undertaken on native tree species by the forest department (Forest Department archives, Colombo). These trials were discontinued and the focus shifted toward hardy and quick growing exotics, mostly of Pinus spp. and Eucalyptus spp. There were 37,573 ha of Eucalyptus and 27, 646 ha of Pinus plantations in 1986 (GSL, 1986). Plantations are usually found on steep slopes and mountain tops on former grassland. The Eucalyptus plantations provide poles for light timber and fuelwood of low economic value. Some of the Pinus plantations are tapped for resin and within a limited distance away from the processing facility, provide some employment and economic yield. These plantations are very susceptible to fire during the dry season and a large proportion of them are lost through wildfires before much of their resin or wood can be harvested.

The plantations' ecological value is questionable. In the Uva Basin, the biodiversity supported by these plantations is lower than that of any other ecosystem. Few if any other plant species beyond the dominant monoculture of Eucalyptus or Pinus are evident in the plantations. Comparative studies of birds and soil fauna in four highland ecosystems (Pinus, Eucalyptus, Forest Garden and Natural Forest) in Welimada division show very few species represented in the forest plantations (Senanayake, 1987).

The plantations are often lauded as protecting the upland watersheds. Yet fires started in plantations by lightning strikes or arson regularly spread into the surrounding patana leaving bare soil exposed to the wet season rains. Surface soil erosion within the plantations can be estimated to be very high, particularly after a fire when the protective duff layer of leaves or pine needles has been burned away. There is rarely any ground level shrub vegetation which could buffer the rain. Furthermore, all trees use water in transpiration and the Eucalyptus microcorys, E. grandis and E. tereticornis most commonly planted here are known to be relatively thirsty species (R.P. Bisht et al, 1989; Dhyani et al, 1990: Shiva et al, 1986.). Thus, far from protecting the water flows, the yield of clear water from these plantations is likely to be less than from the (undisturbed) patana they are planted on.

Paddy fields

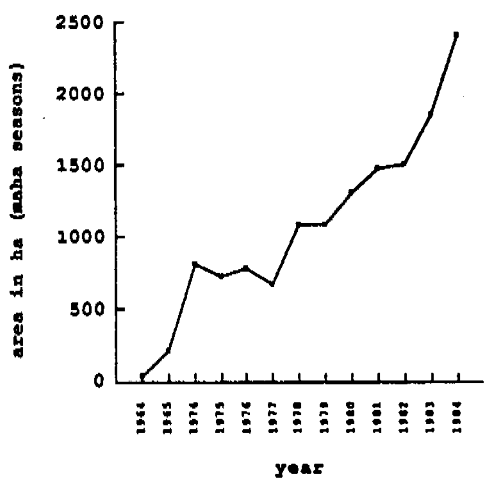
Rice is the staple food crop in Sri Lanka and virtually all land which can be irrigated is used to grow it. In the highlands, where extents of flat paddy land are limited, there is no surplus. Most rice is grown for subsistence and many farmers supplement their supplies for part of the year with lowland rice bought in the market.

One or two rice crops are grown per year depending upon the amount of water available. Each plot of a few square meters to .25 ha is enclosed by small dikes or bunds between terrace levels and various other small discontinuities in which many plant and animal species thrive (e.g. Senanayake, 1983; Fernando, 1984). The system is based on careful control of water flows, and soil erosion is minimal (Zjilstra, 1989). High Yield Varieties of seed, fertilizers and pesticides have been used in most villages for the last 20 years or more. The long term effects of these inputs on water quality, human health and wildlife have to my knowledge not been studied in Sri Lanka (e.g, Fernando, 1984; for the case of South Asia see P.K. Gupta, 1986). If experience from many other parts of the world is any indication, neglect of this issue will cause major problems in the future (e.g. Carson, 1962; IAEA and FAO, 1982; Marco et al, 1987).

Vegetable Cultivation

In the comparatively cool and dry upper Uva Basin, the second crop in the paddy fields is likely to be a temperate climate vegetable grown for cash (tomatoes, potatoes, cabbages and beans are common). Beside cropping in paddy fields, many vegetable crops are grown in what were once *chena* fields, on the grassland slopes above and around the villages. First introduced by the British and grown on a very small scale, commercial production of temperate climate vegetables for the urban Colombo and Kandy markets began to grow from the early 1960's. Extension efforts by the Government Department of Agriculture, with research stations based in the towns of Nuwara Eliya and Bandarawela, focused on crop development and provision of input subsidies for farmers. Potato cultivation for example, expanded rapidly in Badulla district (Fig. 2.3), with similar trends

Fig. 2.3 POTATO CROP EXPANSION IN AREA AND YIELD 1964 - 1985



in Nuwara Eliya. In the Uva Basin, the intensity of cropping increases along an elevation and temperature gradient from Bandarawela to Welimada to Nuwara Eliya.

In the vegetable cropping areas surrounding Nuwara Eliya there is little other vegetation left outside forest reserves and government tea estates (which often protect natural drainages with forest buffer strips). Despite the relative dryness of the region, the humidity levels and number and diversity of insect pests are still tropical. As a result, the crops are grown with heavy inputs of agrochemicals, especially fungicides and insecticides. The cost of mostly imported and fossil-fuel based inputs has increased and has severely cut into the profit potential for smaller farmers in the more marginal areas. There is growing concern over the effects of agricultural chemicals, for example, on water quality for the local population but little research has been done (Fernando, 1984). The flora and fauna within these systems, which are characterized by constantly disturbed soils and high levels of chemical inputs, are probably fewer in number than for other ecosystems in the landscape.

Soil erosion, often directly into mountain streams is a major side effect of this cultivation. Farmers need the relatively scarce supply of water for vegetable cultivation and thus will plant on even the steepest slopes along streams, clearing all native vegetation away. Interviews in the area of primary importance in this regard, the Matatila and Belipola hamlets, indicate that intensive vegetable cultivation is still a recent phenomenon (10-15 years). Few can or will afford the labor to build soil conserving terraces along contour lines. According to the farmers, incentives for soil protection, such as building walls or planting trees, are low unless they have title and security of tenure. During the period in which I carried out interviews here, land grants to one half acre plots were being given out. Farmers who had been cultivating 1-2 acres were passing up the rainy season and waiting until the next year to plant trees, when they would know for sure which half acre was really going to be theirs and thus be worth the effort.

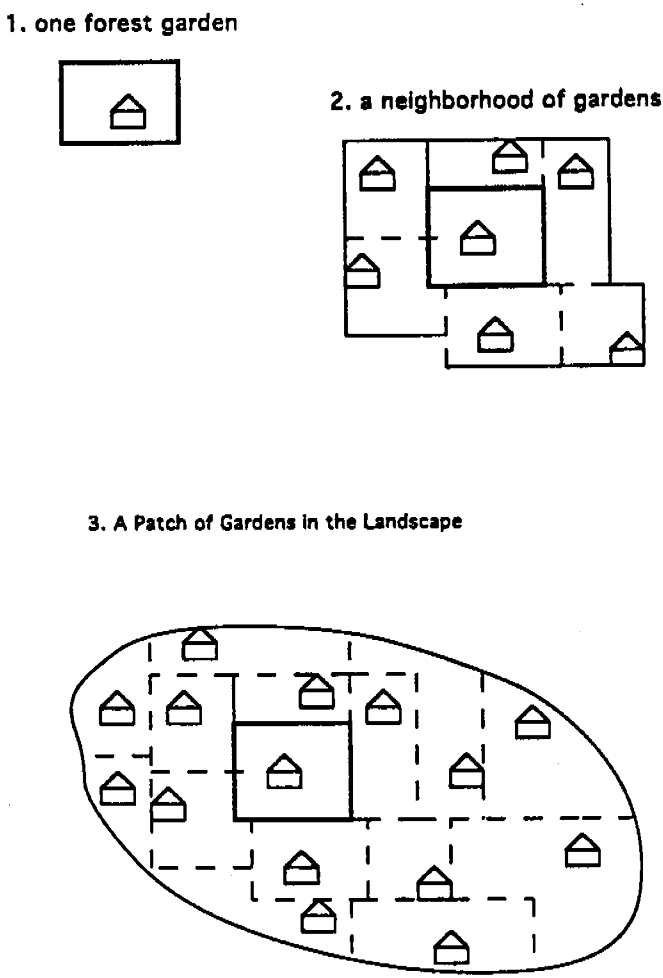
Forest Gardens

Forest gardens or homestead gardens are species diverse, uneven aged mixtures of woody perennials and herbs which people grow around their homes on land not easily irrigated. The gardens provide their owners with food, fuel, timber, fodder, fibre, medicine and cash crops as well as a pleasant buffer against the seasonally dry and windy Uva climate. Garden size ranges from a small fraction of a hectare to over one hectare, and averages less than half of one hectare. While the natural forest area is declining, the area under homestead gardens is expected to increase island wide by 13,700 ha/ year (Daily News, 1987) and their role in the landscape may thus become increasingly important. Though gardens are individually owned and managed, the structural effect of several neighboring gardens' aggregation is often like a small forest, with no clear internal boundaries (Figure 2.4). The shapes of the gardens range from round or square patches often with highly complex perimeters to lengthy corridors and hedgerow extensions. They thus provide habitat (even interior habitat if patches are large enough) and pathways for the movement of biota through the landscape. In fact, on average, 17% of the trees in the gardens are native species, not planted but regenerating naturally and allowed to grow (Everett, 1991). This perennial vegetation is also often planted around fields, where it probably contributes to filtering nutrients from agricultural chemicals as well as acting as a physical barrier to soil erosion from fields on slopes. The value of such vegetation for capturing, storing and slowly releasing precipitation is similar to forests, and likely to be proportional to its area (Forman and Godron, 1986).

2.6 The Study Areas: Eight Villages in Three Highland Regions

This study was undertaken in the Passara and Welimada divisions of Badulla district in Uva Province, and in the Kotmale division of Nuwara Eliya district in the Central Province (Fig. 2.6). The study areas were chosen along a rainfall gradient in order to study the influence of climate on vegetation patterns. The rainfall regimes in the three regions studied differ markedly. In the Kotmale villages rainfall averages 3,607 mm

Figure 2.4
Forest Garden Aggregation Pattern in the Landscape



(Bogahawatte Estate). In Passara the average lies around 2,382mm (Gonakellie Estate), and in Welimada at 1,610.4 (Dyraaba Estate)..Passara and Welimada have a two to three month dry season from June through August. The average annual rainfall measures are based on 30 years' data gathered at nearby tea estates[10].

In order to avoid confounding rainfall with other influences on climate, all gardens were sampled in villages within a narrow range of elevation between 975.3 meters (3,200 feet) and 1097.2 m (3,600 ft).

In addition to the climatic variation, there is a great deal of variability in settlement age in the regions. This factor considerably influences land use. Therefore, I sought to have both relatively old and more recent settlements in the study. In sum, eight settlements in the three regions with at least one old and one new village per climatic division were selected.

2.6.1 Central Province: Nuwara Eliya District Kotmale Villages

Nuwara Eliya district extends for 1,745 km2 and its estimated population in 1989 was 603,577 or 346 persons/km2. At 1,882 m elevation, Nuwara Eliya town's situation is the highest in the country. Its cool highland climate attracted the British who made it their Hill Station. The district's major income and the focus of activities are its vast tea plantations and its intensively managed vegetable cultivation on private land.

There are five AGA Divisions in the District, one of which is Kotmale to which the Wijebahukande, Ravanagoda and Rogersongama villages in this study belong.

The Kotmale region, including the present administrative district, lies in the rugged terrain between the Kandy plateau and Nuwara Eliya on the third peneplain. The area has been settled for many centuries and the old villages extend up from the narrow valleys onto the mountainsides . Far above the villages on high plateaus, the land is entirely under

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[10] I am very grateful to the Superintendents of Bogahawatte, Gonakellie and Dyraaba Estates for providing me with climatic data.

either active or abandoned large scale tea cultivation (including some forest plantations which provide fuelwood for the tea factories). In the villages as well, much of the land use is tea small holdings.

Table 2.4 Private Land Use in Kotmale Division

Land Use	area in ha	percent
Paddyland:	925 ha	17%
Homegardens	1750 ha	36%
Tea	2130 ha	43%
Vegetables	108 ha	3%
Division total	4913 ha	

(16% of NE district totalling 31,349 is private land)

(Source: Kotmale Division AGA Office)

The smallholders sell their tea to the factories of several large tea estates in the area. The mixed gardens produce cash crops of coffee, cardamom, cloves, nutmeg and palm sugar as well as timber. Paddy cultivation is mainly for subsistence here with water for irrigation channeled by gravity from streams via anicuts.

The Kotmale valley, once a very productive spice growing area was flooded in the 1980's when a large dam was constructed on the Kotmale river as part of the Mahaweli Development Scheme.[11] The people who lived in the valley have been resettled, partly in the surrounding high lying villages and new colonies, and partly in the newly developed Dry Zone settlements.

In my research in the Kotmale area, I was greatly assisted by the Sri Lanka Department of Export Agriculture[12]. I had explained my interest in studying land use, and forest gardens in particular, to the director in the Nuwara Eliya office and he arranged for a tour of the region to select appropriate study sites. Contacts to one village, Rogersongama had already been established by other researchers from the NeoSynthesis Research Centre

[11] Power generation is the dams' major function and its reservoir's present capacity is 174 million m3.

[12] Data for Wijebahukande from EX. AG. Dept. Extension Officer, Mr. Amerasinghe; data for Ravanagoda from the Gramasevake Niladari and from Prof. Maduma Bandara, Peradeniya University.

(NSRC), and I hoped to find others nearby. Two nearby villages, Wijebahukande and Ravanagoda proved ideal. The two villages, extend in terraced hamlets for about 1,000 meters from the Kotmale river up one mountainside to the base of the sheer cliffs of the Gangoda Mountains (300 m or more in height). Rock lined pathways and steep flights of steps connect households in the hamlets, and link hamlets to the steeply terraced paddy fields. The paddy fields and some plots of small holder tea are the only non-forested land. There are trees, mostly in forest gardens, nearly everywhere else.

Until the early 20th century Wijebahukande and Ravanagoda were one village called Dimbulgode; today both villages are independent Gramasevakke Niladari (GS) administrative divisions[13]. A swath of paddy fields divides the homesteads of the two villages. Though the villagers recognize the villages as separate settlements, most have relatives in both, intermarriage is frequent and it is common for families to own land in both villages or for a family from one village to have its paddy holdings in the other[14]. It is fairly common for a family to own both homegarden (*gewatte*), and other mixed forest plantations at a distance from the homestead (*watte*), usually further up the mountain. These were the only two villages in the survey which had this mixed forest plantation land use as distinguished from forest gardens immediately around the homestead. Paddy fields may be a good distance (a kilometer or two) away from the home. In addition to homestead, paddy and mixed forest, many people plant tea and sell their leaf to the nearby tea factories.

A paved minor road linking the towns of Hatton, with its train station and Kotmale New Town (the administrative division's seat) runs along the base of the mountain cliffs through the upper hamlets of the two villages. Several buses and private vans per day

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[13]The legendary origin of Wijebahukande and its 20th century name are linked to the time of King Vijeyababu III (?), when the settlement is believed to have been founded along a travel route to an important temple leading to and from the kingdom. The road is said to have been used by first Chinese and Arab spice traders who came to buy cloves, turmeric and pepper from local farmers.

[14]For example, I lived with a family in Wijebahukande whose paddy lands lay predominantly below Ravanagoda, about .75 km away.

serve for public transport. A second road, in poor repair and navigable by jeeps or tractors only, branches off the main road and descends into Wijebahukande, ending at the Buddhist temple. There are very few vehicles in the largely roadless villages.

Wijebahukande

The present GS division of Wijebahukande has nine hamlets with a total of 350 acres. Paddy fields extend for 98.5 acres and all other land uses (homesteads gardens, tea and private forest) cover 225 acres. There are 824 people in 192 families. Thus the average land holding is 2.39 acres per family. However, the range in plot size is high, with several large land holders owning 30-50 acres and a few families owning only the few square meters upon which their small houses stand. The 136 families living below the poverty line receive government foodstamps (Source: Dept of Export Agriculture data from pers. comm. with extension agent).[15]

Most land tenure in the village is based upon individual private ownership but there are cases of joint tenure of land. These fall into two major categories. First are homesteads which, having reached a certain minimum size, are no longer divided but are held by partners. For example, I encountered a case in which six nuclear households live on 1.5 acres. In contrast, with agricultural land, particularly paddy fields, I encountered cases in which families rotate the land among siblings on an annual or seasonal basis rather than subdividing the land to a point below marginal economic return. Village level data on these tenure relations were not available.

Ravanagoda

Ravanagoda village draws its name from Ravana rock, the cliff which towers above the village[16]. Today the village is comprised of several hamlets of varying age. Some

[15]It is likely that many of these families have been recently displaced, either by the Kotmale Dam or by landslides.

[16]This is one of many places in Sri Lanka, especially in the highlands, which link their origins to the Ramayana epic in which King Ravana stole the Indian princess Sita from her Prince, Rama, and hid her in the mountains of Sri Lanka.

have been settled within living memory (people remember their parents or grandparents buying or clearing forested land), others are said to be hundreds of years old.

Ravanagoda GS division has 108 hectares of which 50 are paddy lands and the rest homesteads and gardens. There are 160 families owning on average .7 ha of land with a range of a few square meters to over 17 ha.

A survey of a subset of 45 families in the village showed the following breakdown of land use in Table 2.5.

Beyond these old villages, further up the valley and on the first wide ledges of the plateau above, are new settlements built on abandoned tea land, now patana. Village land use is not yet established in a consistent pattern here. Most people find employment on the large tea estates just above them.

Table 2.5 Land Use in Ravanagoda

land use	total (ha)	percent	per family (ha)
highland (forest, tea)	21.15	48.7	.97
low land (paddy)	14.47	33.3	.42
homegarden	7.82	18.0	.17

(Source GS Ravanagoda).

Rogersongama

Rogersongama is a better established new settlement a few kilometers away, situated on a geologically unstable plateau above the broad Kotmale reservoir valley[17]. In the early 1930's, landslides forced the evacuation of a number of villages in the Kotmale valley. New colonies were begun in largely uninhabited forested areas on the slopes above the valley. Rogersongama, founded in 1933 and named after a British administrator, was one such colony where 30 families from the village of Wattaddora settled. According to a large landowner in the village, at the time, the settlers were granted plots of forest land by the crown and were encouraged to clear the forest, plant timber and shade trees such as

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[17]Fear of landslides had resulted in the evacuation of numerous holdings along one exposed side of the village(1988/1989). People still came to tend their tea but no longer lived in the area.

Cedrela spp. as an overstory and cardamom as a cash crop understory (Manukuleratne, pers. comm). Many settlers followed these directives, and as a result, most of the forest in and around the colony was felled. After some time, insect pest problems led to a decline in income from cardamom cultivation and caused most farmers to shift to tea planting instead.

Today the village consists primarily of 0.5 acre tea small holdings and forest gardens. As is typical for the newer settlements on steeper and more marginal lands with no access to irrigation, there are no paddy fields in Rogersongama. *Chena* lands are uncommon. Much of the government owned forest land in the vicinity has been cleared and planted to Eucalyptus. Some other natural forest land is leased on short (one year) and long term (15 year) leases to farmers who continue to plant cardamom in the understory. An estimated 20 acre lower montane evergreen forest remains relatively undisturbed near the temple at one edge of the village. In addition, one large landowner whose father at the time of settlement did not clear his forest, cultivates nine acres of cardamom under a fairly undisturbed canopy of natural forest. A large portion of the village has been abandoned recently (1988/89) due to renewed threat of landslides[18]

In general, the villages are remote and introductions from outside seem comparatively slow to change day to day existence. In the early 1990's as in centuries past, for the majority of people, life is determined by the rhythm of the planting, harvest and fallowing seasons and by the minimal diurnal variation of sunrise and sunset in proximity to the equator. Most people are farmers (or artisans who also farm) or farm laborers. Yet the villages are linked to the world outside, via the road and bus service; by electricity and radios and by the public school system.

I have already mentioned the bus service. People regularly get on the bus to travel to local towns, to Hatton or Nawalapitya for shopping or to Kotmale New Town for

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[18] Among the villagers, the renewed landslides are rumoured to be linked to instability caused by the construction of the Kotmale dam and reservoir.

government administrative services. It takes the better part of a day to go to and come from town this way.

During my first stay in February and March 1990, locally active insurgents had blown up the local transformer so that the area was without electricity for months[19]. As a result, in the numerous households linked to the grid, radios (in my experience used primarily to hear 5am and 6pm '*banne*' chanting by buddhist monks) were powered by batteries, and old oil lamps or bottle torches were quickly dusted off and put to use[20]. The only household that I encountered in the survey with greater dependence upon electricity (a refrigerator and television set belonging to a wealthy trader) soon set up a car battery and recharging system.

A more significant introduction from outside the village than electricity during this century is formal education modeled after the British school system. Ravanagoda has a pre- and primary school through grade 5, and Wijebahukande has a primary and a secondary school at which students may complete their pre-university 'A levels' in arts and commerce (one school within bussing distance also provides the A level science curriculum). The government provides housing ('quarters') for teachers in remote districts and upon completion of their university degrees, young teachers may be posted anywhere in Sri Lanka. Thus, teachers from all over the island may be posted in Wijebahukande, bringing with them news and views from outside. A number of students from the villages have gone on to university, some have returned as teachers, some live in the region's larger towns and one, a physician, has emigrated to England. Another avenue through which people, young men in particular, increasingly leave the village is military service.

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[19] The subpost offices in the region had been burned or closed to avoid such damage as well so that all telephone and telegraph links were cut off.

[20] These are fueled with kerosene. However, even the dependence upon this imported fuel for household use is not complete. During the Gulf War in 1991, when kerosene prices escalated and supplies dwindled in more remote areas, there were reports of villagers switching back to various traditional sources of light including candlenut oil (tel-kakune'), from the seeds of <u>Alcurites</u> <u>triloba</u>, a large long ago naturalized forest tree.

Fluctuating farm gate prices for agricultural cash crops (in particular for tea, coffee, cloves, cardamom and turmeric) and local traders' prices for household goods (e.g. sugar, tea, powdered milk, salt, onions, chilies, cigarettes) reflect national inflation and international markets. However, the still rice focused economy (albeit now somewhat dependent upon high yield seed (HYV's) and inputs from outside) in which larger farmers are self sufficient in their staple and have a long standing dependence upon local laborers, may somewhat insulate the local economy from externally induced fluctuations. I did not see people using machinery for harvesting which would change these labor relations (by contrast, they were beginning to be used in Mirahawatte).

Wijebahukande, Ravanagoda and Rogersongama have had considerable contact with extension services. My link to the villages was made though the Department of Export Agriculture. The local extension agent was from the area originally and was well known to farmers in the villages. Many participated in extension programs. In addition I frequently encountered other agriculture department people in the area[21].

In addition, the district level government, in particular the Department of Agrarian Services had selected Wijebahukande for attention under its Agricultural Production Village program. This program seeks to combine the services of a range of line agencies (Agriculture, Forestry, Highways, Rural Credit, etc.) and international donors (Nuwara Eliya district's IRDP is funded by the Dutch) under the direction of the local Agrarian Services extension agents working with village level committees to demonstrate ways of increasing and stabilizing small farmer income. The program in Wijebahukande, begun in September 1989, was just getting underway in early 1990 as the political situation calmed down. It included demonstration units for livestock; export agricultural crops (coffee, cardamom, cloves); bee keeping; tea; vegetable production; paddy cultivation and a collection center for marketing palm syrup and sugar (kitul treakle and jaggery). In

[21] In general, in my limited experience, extension workers were very visible in the Kotmale villages, far more so than in Maussagolla or Mirahawatte.

addition, the officer in charge of rural development banking and credit had set up a series of workshops in basic record keeping and accounting for the farmers. At this early stage in the program, only a few of the people I encountered had been directly involved in its projects. Two people had demonstration nurseries for coffee growing, two were part time employees of the palm sugar center, one was a farmer who had invested in building a cowshed and had received a cow, and I spoke with the elected leader of the village committee. All were very pleased with the benefits they received through the program.

The high visibility of extension workers in these villages correlates with the much higher degree of chemical inputs used in gardens in this area than in the Welimada villages (Table 2.6).

2.6.2 Uva Province: Badulla District - Welimada and Passara Divisions and Villages

The present day Uva Province was formed in 1886 and extends for 5,960 square km. The heart of the province and its major district of Badulla are centered in the Uva Basin. The basin, ringed by high mountain ranges.extends for a hilly and dissected 700 km2 with an average elevation of 1,000 m (Weitzel, 1971).

In 1982, the district's population was 662,000 with 92% rural in 120,000 farm families (GSL, 1986). The average annual per capita income for Badulla district was $US 375[22]. It is estimated that 61% of the families earn less than Rs. 900 per month (This is the official definition of poverty used by the government welfare programs, including the Janasaviya food stamp program). The district has one of the lowest average income levels for rural families in Sri Lanka (Ibid).

There are several urban settlements of note near the village study sites. Bandarawela town is recent by Sri Lanka standards, dating from the British period and building of the Railroad (150 years) In 1982, Bandarawela town's population was 4,941. Welimada town had a population of 2,432, and Passara town's population was 3,225

[22]The exchange rate in 1989-1991 averaged 40 Sri Lanka Rupees to the dollar.

(Statistics for Badulla District, 1982 in Dicke, 1987:150). The towns serve as marketing links, sources of government and public health services, and higher schools.

Passara Division - Maussagolla and Maussagolla -Colony

Two villages were selected in Passara Division on the Eastern Slopes of the highland Intermediate Zone. According to its inhabitants including the village GS, Maussagolla is an old settlement, which dates back for several centuries. Maussagolla colony has been established in the last decade and has been carved out of a government allottment from former tea land. These villages present a case example of settlements which are surrounded by tea estates or by uncultivable mountainside on all sides with no room for expansion.

Maussagolla

Maussagolla is one of several old villages situated in a wet pocket below Namunukula mountain (ca. 2, 200 m) on the eastern side of the Intermediate Zone, overlooking the Dry Zone. The village and its neighboring settlements skirt a low lying bowl of paddy fields. The steep cliffs of Namununkula rise above. To the Northeast between the village and the Division seat of Passara a few kilometers away there are large government managed tea estates. A limited survey of 19 households was carried out in Maussagolla and yielded the following results. A typical household had five family members. The average land holding was .58 ha with the average garden being .29 ha in size. Four households owned some paddy land (on average .20 ha) and three owned tea (.15 ha on average). The GS estimates that the village has been settled for many years, which is supported by the average garden age of 91 years provided by the surveyed households.

Maussagolla-Colony

Maussagolla Colony is a small settlement of about 20 households on a small patch of land along the road at the upper edge of Maussagolla village. The settlement is less than 10 years old and all house plots are small (<1/16 ha) in size. Of the 12 families visited, one

family owns additional tea land. The people are predominantly young families with many small children. All households have some outside source of income, mainly from working for the division on road and electricity maintenance.

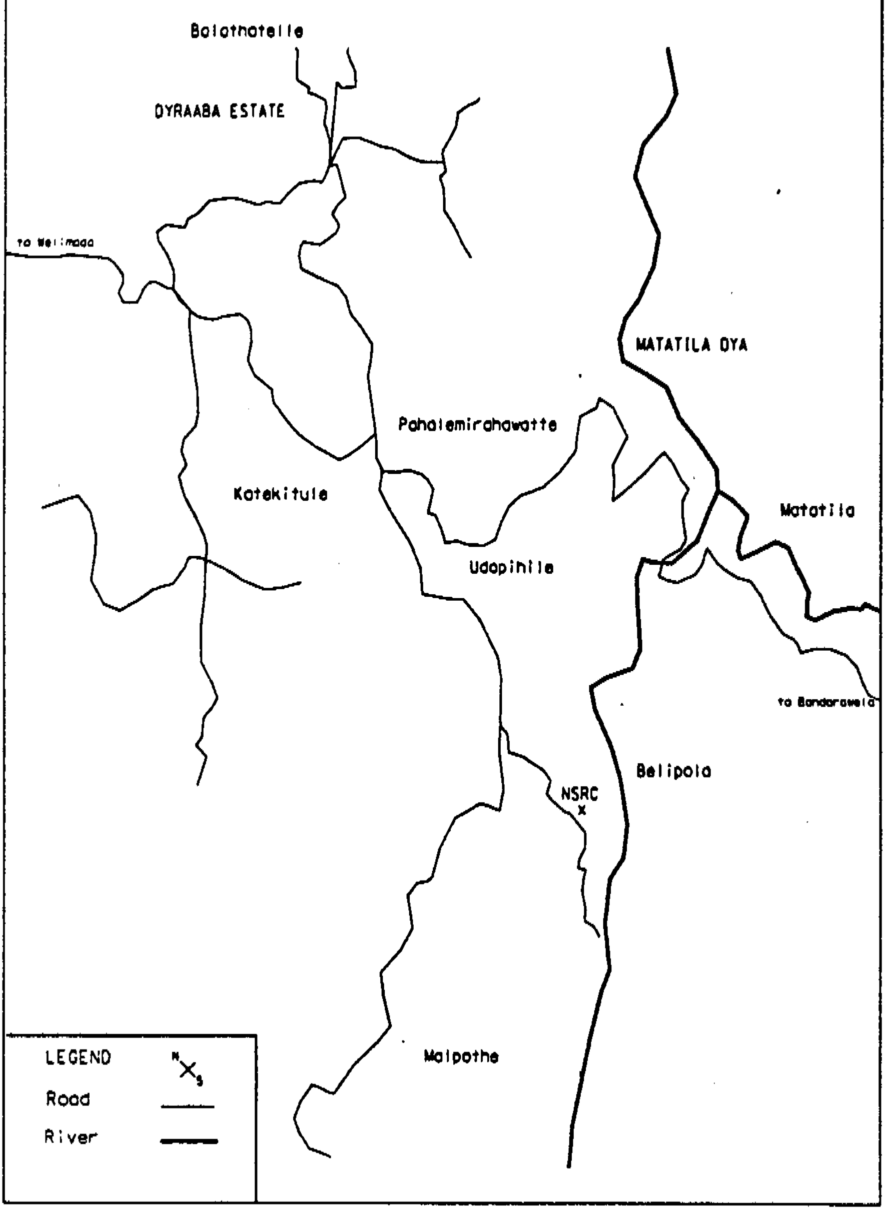
Welimada Division - Mirahawatte Village and Belipola and Balathotella

These three settlements are situated on the Matatila Oya, on the border of the Welimada and the Bandarawela divisions (Fig. 2.5). The region may have been settled before the British colonial period but according to the chief monk of the Mirahawatte village temple who grew up in the area, the present villages are of comparatively recent origin. Mirahawatte is the oldest of the villages, with some of its homesteads dating to the turn of the century.

Mirahawatte Village

Mirahawatte is made up of four hamlets lying in small, comparatively flat basins in the rolling hills above the steep and narrow channel of the Matatila River, in the Southwestern or so called "upper" Uva Basin. The range in elevation is from a low of 1,130 m at the river to an average of 1,330 m in the village proper. Houses surrounded by privately owned forest gardens or smallholder tea fields cluster on hillocks above lower lying creek drainage areas which people have converted to an interlocking network of irrigated paddy fields. On average the homestead with house and forest garden covers .33 ha (min = 0.10; max < 3.0 ha). People are likely to own an additional 0.1 - 0.5 ha of paddy fields close by. In a broken ring around the village, particularly to the South and Southwest are steeper hillsides, often with forest gardened homesteads reaching part way up the slope before giving way to *patana* or to Eucalyptus or Pinus plantations. Here in the *patana*, there are also *chena* fields where farmers practice vegetable cultivation in an annual or biennial burn, cultivate and fallow rotation. There are an average of five people per household in Mirahawatte with a resulting population density (based on the GS' figures) of 8.6 persons per hectare.

Fig. 2.5 Mirahawatte Hamlets



The Mirahawatte (literally Kitul Palm Garden) hamlets comprise two GS divisions (Fig. 2.7). Kotekitule is the heart of the old village with the Buddhist temple, school and hospital. Pahalemirahawatte (literally 'lower Mirahawatte') also has long been settled and

Table 2.6
Land Use and Population in Mirahawatte's Hamlets

hamlet	Kotekitule	Udapihile	Pahalemira'	Balathotella
area (hectares)	165	81.3	184.2	21.7
paddy	30.8	14.6	52.1	-
homesteads	65.8	37.5	91.3	13.3
tea	68.75	29.2	40.8	-
forest/patana	-	-	-	8.3
families	315	175	237	64
population	1,574	820	1,185	320

(Source: Gramasevaka Niladari's (Village Leaders), 1991)

has a broad expanse of fertile paddy fields. Udapihile is the hamlet stretching along the Welimada to Bandarawela road between the two older settlements. There, along the road, are several small shops and one neighborhood of Muslim families, largely traders. The village mosque sits above the road.

Mirahawatte lies equidistant between Bandarawela and Welimada, the two major market centers for the Uva region. East of the village, the road drops down to the the Matatila bridge, passes up through the village of Matatila on the other side of the river and heads on for another winding seven kilometers to Bandarawela. In the other direction heading Northwest on the road toward Welimada, Mirahawatte village borders the edge of Dyraaba, a large government estate renowned for its high quality tea.

Balathotelle

Balathotella is a settlement which in part developed from estate workers' encroachment on government land next to Dyraaba tea estate in the 1940's. Many families have lived here for decades but formal recognition of the area, most recently in a 1989 village expansion scheme supported by President Premadasa, is new. Some households

have been granted title to land and many have received loans for house construction or improvement. Most of the people have title to half an acre of land for a homestead. Nearly all, especially women, work as laborers on Dyraaba (tea estate) for the major portion of their income. The new young farmers clearing plots at the precipitous edge of the settlement are largely sons and daughters of existing Balathotelle households

Matatila (Belipola Settlement)

Belipola-Matatila is a very recently expanding area along the Matatila river in which young farmers from the surrounding area, especially from Matatila village are settling and farming. Belipola settlement falls under the jurisdiction of the Mirahawatte GS on the western side of the Matatila Oya and to the Matatila GS on the Eastern side. Farmers from either side of the river, depending on their location relative to road heads, may be seen fording the river to get their produce to the closest lorry pick-up points. The land in Belipola is steep and rocky. Its attraction is its proximity to the river which provides water for irrigation. Most of the farmers in Belipola plant vegetables as their major source of income. Few have been planting here for more than 15 years. Some live here permanently, others follow the traditional *chena* pattern of living in Matatila village and walking out to tend their fields.

Summary Comparisons of all Villages.

Several general comparisons can be drawn between the Kotmale, Passara and the Welimada villages. Trees truly dominate the Kotmale villages. There is a dense mixture of natural forest, forest garden and forest plantation here with some *patana* grassland and paddy and small holder tea cultivation. There are few *chena* plots and there is no commercial vegetable cultivation. While much of the newly settled land in Welimada is steep, the average slope is greater in Kotmale. Beside these differences in environmental state factors between regions, social factors including land ownership are variable (Table 2.7). The average holding is much larger in the old Kotmale villages of Wijebahukande

and Ravanagoda than elsewhere. However, a large proportion of the variation is accounted for by two or three large landowners.

Table 2.7 Land Ownership by Village - Average Holdings

	Mira*	Matatila	Balath	Wijeba	Rava	Roger	Maussa	M-Col
(n)	60	20	12	20	20	10	19	12
Total	1.45	1.43	.65	5.08	6.35	.95	1.50	.33
Garden	.63	1.18	.65	1.1	4.24	.8	.70	.13
Paddy**	.25	.11	-	2.09	1.79	-	.85	-
(n)	(27)	(11)	(14)	(9)	(10)	-	(4)	-
Tea	.25	2.0	-	4.23	1.41	1	2.25	2.5
(n)	(20)	(11)	(12)	(8)	(1)	(3)	(1)	
Age***	53.3	13	19	69	83.3	44.4	91	8.9

*Column headings: Mirahawatte; Matatila; Balathotella; Wijebahukande; Ravanagoda; Rogersongama; Maussagolla; Maussagolla-Colony)
** Note that not all households own paddy and tea land.
*** Age is average age of garden

In summary, people have clearly influenced the highland landscape over the many centuries of human inhabitence. Over time they adapted the settlement pattern of the ancient Dry zone, with its focus on rice cultivation, to the Wet zone, to build villages of paddy fields, forest gardens, tea and *chena* fields. Deforestation was kept at a minimum until the colonial period but has escalated since then despite various protection ordinances. At the same time, the population has grown and there is increased pressure on the land. Most recently, a new system of cash cropping with annual vegetables has begun to expand bringing with it fundamental changes in the settlement and land use patterns in the region as well as ecological implications for landscape level flows including water, flora and fauna. Approaches to measuring and analyzing this change and its household and landscape level implications are discussed in the next chapter.

Chapter 3 Research Methods

Introduction

This dissertation is focused on analyzing changing patterns in land use and their aggregated effects in the larger landscape. In Chapter 1, a general hypothesis based on hierarchy theory and state factor systems analysis was developed. It assumes that in aggregation, ecosystems (or land uses) can influence landscape scale ecological functions. It further suggests following Jenny (1941), that there are certain state factors from outside the ecosystem which define initial conditions for the ecosystem's (or household land use's) function. From a hierarchical perspective, these state factors are themselves hypothesized to be determined by yet larger scaled forces at the landscape level. If the proposed duality of 'top down' constraint and 'bottom up' causal linkages between levels in a hierarchical order holds, then the aggregated effects of a particular land use at time t_0 could have an impact on the landscape as a whole, which in turn would create a feedback at time t_1 to modify the landscape's state factor influences at the ecosystem level where household land use occurs (Fig 1.1). Thus in aggregate, the actions of land users at time t_0 can create an impact which changes the conditions under which they will operate at a future time t_1. The implications are that if the aggregate effects of individuals' land use on initial conditions are known, then land use, if coordinated, can be managed to maintain desired landscape ecological conditions such as water flows and biodiversity, and by implication also to support production goals, such as maintaining long term yields and minimizing short term fluctuations in yield.

Two questions were posed to address this hypothesis. The first question, of how to assess the role of an ecosystem in a larger landscape, is a problem of landscape function which can be addressed indirectly through an assessment of landscape structure and composition in time (Forman and Godron, 1986; Turner, 1991). To this end, a model of the landscape surrounding Mirahawatte village, Sri Lanka, was developed using aerial photo interpretation, Geographic Information Systems (GIS), and a series of spatial

metrics, which are discussed in detail in the first section of this chapter and then applied in Chapter 4.

The second question addresses causality. What factors influence ecosystem level patterns of vegetation and their pattern of aggregation at the landscape level? Here an approach based on a state factor systems model is developed and tested using correlation matrices and stepwise regressions to analyze a range of data which were gathered in three regional landscapes in highland Sri Lanka (described in Chapter 2.6). The field research methods and my approach to analyzing the data are discussed in the second portion of this chapter and are then applied in Chapter 5..

In the concluding discussion of implications of the findings from the earlier analyses (Chapter 6), I employ an additional GIS coverage for the Mirahawatte landscape, using methods described in this chapter for designing and processing a GIS model.

3.1 Spatial Analysis of a Landscape Using GIS

One of the difficulties in studying landscapes is the sheer size or spatial scale of the object under study. It would be very difficult, expensive and sometimes impossible for even an army of field researchers in a given landscape to accurately survey all vegetation and its change through time. Yet if one can climb to a convenient lookout point or, ideally, fly over the landscape in an airplane, one immediately gains a comprehension of landscape at a broader scale. One loses sight of individual trees in the forest and instead notes the contrast between dark green patches of forest and lighter shades of grassland and agricultural fields. One notes the shapes of these patches, their relative dominance and distribution. This added perspective is an example of what Gregory Bateson called a jump in logical type gained by triangulation. It is the addition of (literally) another point of view, a move up and out in the hierarchy of spatial scale (Bateson, 1979:76-79). With the advent of aerial photography, satellite imagery, increasing computer capability and their availability for a wide range of purposes, it is becoming possible to do quantitative research and analysis from this bird's eye view. In particular, the approach of Geographic Information

Systems (GIS) for the analysis of spatial data, though still fraught with limitations, is developing rapidly. A subset of GIS methods are applied here.

3.1.1. Geographic Information Systems

Geographic Information Systems describe material phenomena using a variety of attributes including especially the objects' location on the globe relative to known coordinate systems and the resulting spatial linkages or patterns among the phenomena (Burroughs, 1986:6). In GIS, information from maps, remote sensing, aerial photographs, census databases and so on can be combined and analyzed with the help of modern computer capabilities for handling large amounts of data. GIS can be used to quantify and analyze the spatial distribution of land uses across a landscape and for updating information and monitoring changes through time. In this case, it was employed for quantitatively comparing spatial information from two points in time, and for the development of a hypothetical model of vegetation distribution in an actual landscape.

In very simple terms, GIS is a method with which mapped information for a given area can be analyzed and/or combined with other information for the same area. One can, for example, imagine a problem concerning the location of a new housing development. Various factors need to be assessed as the decision is made about where to begin building, such as available land, soil porosity for septic systems, slope stability to avoid landslides and erosion, convenience with respect to roads, schools and so on. Each type of information might come from different sources - a county zoning map for areas of potentially available residential land, a soils map, a topographical map, a road map. This information can be entered into a computer by digitizing, a process in which the map is 'retraced' by hand on a tablet linked to a computer system, or by scanning, a process of automatic data input which is like photocopying. By accurately geopositioning and in effect, rescaling each map, GIS allows one to overlay all of these layers of information onto one map. By identifying the mapped areas for which the desired characteristics overlap, potential sites for development or changes in the landscape can be located with

great accuracy. As large volumes of information can thus be very systematically applied, this process often leads to new insights as well as making various management tasks more accurate and efficient.

There are two key spatial data structures employed in GIS, vector and raster spatial models. Raster models represent mapped information as a series of grid cells in cartesian space. Each cell has an 'x' and 'y ' coordinate and a code value for the information being mapped. (Burroughs, 1986:20). Data is very easy to enter and modify in the raster approach. However, the accuracy of raster models is limited to the smallest available grid cell size, and the data base storage requirements begin to grow exponentially as resolution increases.

The vector model, by contrast, represents information over a continuous space as points, lines and two dimensional areas called polygons. Rather than being located in cartesian space, vector data are associated by a rule of connectivity. This approach is relatively efficient in use of computer storage, and provides for more accurate imagery. Its particular strength is that the polygon data structure can represent the way in which an area's geographical elements are associated, its topology. Vector structure represents the actual boundaries between polygons much more accurately than could be done with all but the smallest of raster grid cells (compiled from Burroughs, 1986:20-34). The drawback to vector models is that any changes made in a coverage require a rebuilding of the topology (a readjustment of all points according to the connectivity rule). With increasingly powerful computers, this is becoming less of a problem, and programs for cleaning and building topology are now built into most vector based GIS software.

For a study of vegetation change such as this one, it is the precise sizes and shapes of vegetation patches and the association between elements in the landscape, which are of primary interest. A raster data structure would require a huge data base to achieve the level

of resolution required here. Therefore, the vector model and specifically software called Arc/Info (ESRI, 1992)[1] were used in this study.

3.1.2 Design and Processing of the GIS[2]

The GIS coverages for the present study were developed from an initial database of one 1:65,000 scale topographical quadrat sheet for Nuwara Eliya (Survey Department Sri Lanka, 1988) and two sets of aerial photographs from 1956 (1:40,000 scale) and 1988 (1:20,000) respectively [3]. The 1988 photos were magnified by the Sri Lanka Survey Department from the original negatives to a scale of 1:3,854 (+/-2.2%)[4]. The 1956 photos were magnified for digitizing from negatives taken from the photos to a scale of 1:5,861 (+/-4.8%).

The aerial photos of the focus area were interpreted using colored pens on acetate overlays. These acetate overlays were the base maps for digitizing from the photos. Based on Government of Sri Lanka land use typing (GSL, 1984) and on my own ground-truthing experience (I lived in this village for three years), two hierarchically nested levels of land use were identified on the acetate[5]:

a. General land use (six categories: natural forest; forest plantation; grassland; tea plantation; paddy fields; homesteads, roads, rivers).

b. Homesteads (four subcategories: trees, tea, vegetables and bare ground)

Digitizing

Upon the advice of the staff of the Berkeley GIS Lab, I chose to digitize in Microstation (Intergraph, 1988), a very interactive and accessible software package for the

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[1] Software licensed to the Laboratory for GIS, CED, University of California, Berkeley.

[2] I would like to thank Kakiko Ide, Ekta Gayani, Karen Heisler, Alfredo Andia and Fernando Marti for their support and many long hours of work in developing the GIS coverages as a class project for Prof. John Radke's LA221, Department of Landscape Architecture, UCB.

[3] I am very grateful to the Surveyor General, Sri Lanka for providing access to the photographs.

[4] Scale was determined by comparative distance measurements with known landmarks on the topographical map, a surveyor's map at 1:6,000 scale and the aerial photographs.

[5] These types are described in detail in Chapter 2.5

purpose, and then to translate the digitized data into Arc/Info (ESRI, 1992) for further analysis.

The topographic map was geopositioned following the Arc/Info guidelines for Transverse Mercator projection using meters as Master Units, centimeters as Sub-Units and millimeters as Position Units[6]. Roads, rivers and contour lines were digitized in Microstation (Intergraph, 1988) as separate coverages for the lower Matatila Oya sub-watershed working area around Mirahawatte village[7].

The acetate photo-overlays were digitized as one coverage for 1956 and 1988 respectively[8]. Each area identified from the photos as a separate land use became a polygon with a label for its land use category. The 1956 coverage includes over 900 polygons and the 1988 coverage over 2,000, polygons. The difference in the numbers of polygons alone was an early quantitative indication of the visible fragmentation of vegetation types which had occurred around Mirahawatte in this thirty year period.

Geopositioning the land use coverages from the photos was problematic. An unknown distortion was observed in the photos and their interpretation. The topographic map coverages were at 1:65,000 scale, a coarser level of detail than offered by the photos at 1: 3,000 and 1: 5,000 scale. One additional topographic map at 1:6,363 scale was available for a portion of the Mirahawatte landscape. Accurate geopositioning, a process involving matching points of known position from the topographic maps with the same visible points on the photo-overlays was not feasible. Ideally for this process, at least three points in

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[6]The high resolution of the MU, SU, PU's was selected to meet expected requirements of the within garden species placement subsection of the project. Raphael Real de Asua helped to set these up.

[7]Regarding roads and rivers: at the scale of interest (1:3,000-1:5,000) roads and rivers take on significant area. Therefore, they were treated as areas and were defined for digitizing as polygons rather than linestrings (a decision which created problems as discussed below).

[8]I had originally hoped to keep the hierarchy of general to specific homegarden land use categories as two separate coverages. This would have meant digitizing polygons for the general categories first, and filling the interior homestead categories in later as a separate coverage. However, this was a first attempt at digitizing and we neglected to make this distinction in the beginning and had already put in many hours of digitizing both categories on one level before I realized our mistake. We solved the problem (with some costs involved in the translating and editing phases) by using polygon labels as our major feature for selection in ARC/INFO. Thus, after all land use polygons had been digitized, each was labeled as one of the ten land use categories discussed above.

common are needed for positioning. Here, the only point which remained immobile on all images was the bridge across the Matatila river. On the photos, the vegetation, land use, river width and road systems changed. This is not unusual for studies involving a range of points in time, especially for small scales in rural landscapes. Once the photo overlays had been digitized, they were rotated around a reference image of the digitized coverages of roads and rivers from the 1: 65,000 and 1:6,363 topographic maps. Each overlay was positioned as closely as possible over the Matatila river using the Mirahawatte bridge as the central pivot point . At this point, the 1956 and 1988 coverages were very close to overlapping.

Further minor adjustments between the coverages were made by hand in Microstation by overlaying matching very visible and unchanging shapes in the landscape. Thus the coverages were approximately geopositioned along the river and nearly perfectly matched to one another without any internal distortion of the coverages. A border was drawn around the area of overlap between the 1956 and 1988 coverages and the non-corresponding areas were clipped from the files. This boundary enclosed the 11.2 square km working area around Mirahawatte village (See Figs. 3.1 - 3.8).

Editing and Building Coverages in Arc/Info

All vegetation types were digitized into one coverage and polygon labels were used to distinguish land uses. When the digitizing was completed, the files were transferred through the 'igdsarc' command to Arc/Info. Several iterations were required of calling up 'nodeerrors' and 'labelerrors' in Arc, Arcedit and Arcplot, editing all errors for polygons with known labels, plotting polygons with unknown labels on paper, returning to Microstation through 'arcigds' to edit errors by hand and transferring back though 'igdsarc'. The final clean up for 'nodeerrors' and missing labels was done in Arc/Edit under 'editfeature labels' and using the 'forms' aml. These difficulties were due to a

combination of error in initial digitizing[9] and a 'bug' in the translation function of the 'igdsarc' command with respect to labels[10]. Luckily, the topographic map data file, all line work, did not require this extensive editing.

Sources and Estimation of Error

Clearly in a process involving so many iterations and translations, errors are likely to occur. I assumed that error had been built into the mapping effort but sought to quantify it as closely as possible to achieve some measure of confidence for the results.

As Korzybski pointed out succinctly in his studies of communication, "The map is not the territory" (Korzybski, 1941 by Bateson, 1972:180). More recently, Mandelbrot has pointed out that the length of a coastline depends on the measure used to quantify it (Mandelbrot, 1983). Therefore, all descriptive research relies upon the understanding that our efforts at quantification, try as we might, to use the most sophisticated equipment as precisely as possible, may approach, but will always fall short of the actual phenomenon represented. Measurements are abstractions. This is the first and most fundamental source of 'error' in all research. Second, there will be technical errors due to limitations in available equipment and methods. Bolstad points out, for example, that any representation of true ground coordinates in a GIS data layer involves some geometric positional error (1992). A third source of error is human. It lies in our making mistakes while measuring or otherwise manipulating data. The accumulation of these errors represents the degree of reliability of the research results and in particular, of the quantitative data gleaned from the GIS.

Clearly, as two sources of differently scaled information (map and aerial photographs) were used by inexperienced digitizers to produce the database, I was concerned to have as reliable as possible an estimate of the technical and human error

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9 The coverages were digitized by a group of students including myself who had no prior experience (footnote 2). Errors will have resulted initially while we 'learned on the job'. In addition, there will always be some variation in accuracy when more than one person works on digitizing one coverage.

10 We were using Arc/Info version 6.0 from December 1991 to April, 1992. This problem in the software has been corrected in the updated version, 6.1.

accrued. In this case, the greatest uncertainty accumulates from use of aerial photo interpretation and digitizing acetate overlays of roads, rivers, topography and vegetation/land use. The following four factors contribute the most to this error.

First, the photos were not orthographic photos. In orthographic photos, errors due to the horizontal tilt of an airplane and focal zone distortion from the camera lense, which influence the perception of surface relief variations, are corrected (Wolf, 1983). These photos are highly accurate but also relatively expensive. They were not available for the study site.

Second, the photos' contrast and scale were not precisely known as the prints used for interpretation and digitizing had to be magnified. The 1988, 1:20,000 scale photos were magnified in Colombo from the original negatives and are of high quality and clear to interpret (individual trees and other small features can be distinguished). The 1956 photos, starting from a less detailed 1:40,000 scale, were magnified from negatives taken of designated areas on the photo prints. The results are not as clear as the 1988 photos. Trees can easily be distinguished from other land uses, but it is more difficult to differentiate among land use types such as bare ground and very recently planted or regenerating vegetation. Had such problems in interpretation for the 1988 photographs arisen, they could have been addressed by returning to Sri Lanka for ground truthing. Problems with vegetation identification in older photographs can not be so easily addressed, as it is not possible to go back in time to see the vegetation as it was in 1956. Therefore, all plots for which the land use category was unclear were classified as bare ground. The photos' post-magnification scale was determined using a 1:6,363 map of Mirahawatte. This map had been hand drawn by a professional surveyor[11], Peter Wise, in 1986 using the 1:63,363 topographic map and ground truthing. The photos' scale was found by measuring distances on the map (scale known) and on the photos (scale unknown) and solving for

[11] Beside working with me to do the ground survey, and very accurately mapping all trees in five village gardens, Mr. Peter Wise also produced this village map.

scale. The scale was converted to metric. The 1988 photos are 1: 3,854 (+/- 2.2%); the photo from 1956 is 1: 5,860.69 (+/- 4.8%). As they are not orthographic photos, distortion increases toward the edges. A grid to fit the photos' scale, match their edges and take advantage of the least distorted portions of the overlap for interpretation was developed and translated to the Microstation digitizing file[12].

The third factor for consideration of error was monoscopic photo interpretation. When viewing a two dimensional representation of a three dimensional world such as on a photograph of mountains, one's ability to gauge the depth of the relief is distorted. The flat, monoscopic view creates an illusion in which objects are displaced. Stereoscopic interpretation is a common technique for viewing pairs of air photographs in 3-D which corrects for the terrain displacement. Sets of photos with a 60% overlap, called stereopairs, are used (Wolf, 1983). In this study, the blown up prints of the size needed for interpretation and for digitizing were not stereopairs.

Despite the handicap of not having magnified stereo-pairs and therefore surely incurring some error, particularly with regard to interpreting area in the steeper terrain, I proceeded to draw borders between land use types on the acetate covered photos without a stereoscope with some confidence. As noted above, the scale of the photographs was large enough to identify individual trees, and my goal was to specify a much coarser categorization of vegetation type. I knew that the forest gardens, the land use of primary interest in this study, are found in the rolling terrain of the village and not in the most rugged terrain where relief would be a very significant factor. Finally, there is a recently developed method (Bolstad, 1992) to estimate the error incurred by this monoscopic interpretation of non-orthographic photos.

Relief displacement and camera tilt are the most significant sources of errors in interpretation from photos which are not orthographically corrected (Wolf, 1983). As

[12]Reza Ghezelbash of the Berkeley GIS Lab kindly developed this grid.

noted above, features on the photos are geometrically displaced from their plan position by the tilt of the airplane/camera or the angle of the ground terrain (Bolstad, 1992). Based on a series of simulation experiments and ground truthing, Bolstad developed a matrix to estimate error due to monoscopic interpretation of tilt and relief displacement for several photographic scales, when tilt, relief and scale of the photographs are known (Ibid:373). Camera tilt for the 1956 photo was determined by measuring control points on the topographical maps to find x, y and z coordinates and calculating the z coordinates from matching x and y points on the photos. The tilt determined was 2.4 degrees[13]. Relief estimates were taken directly from the topographic map. The maximum terrain range in the photos is less than 250m. The scale of the photographs used for interpretation was greater than 1:10,000. On the basis of combining these three indicators, according to Bolstad's matrix, the error accrued for photos with these parameters will be 15% or less (standard deviation = 2).

Finally, digitizing error was to be expected. Several people helped to enter the data and we were all beginners. Despite the constant checking and re-editing, some error will have accrued, although the literature indicates that this source of error is not likely to be very large (Bolstad and Geisler, 1990).

3.1.3 Landscape Pattern Analysis with the GIS

Two coverages, one for 1956 and one for 1988 were used in the analysis. Color-shading of the 1956 and 1988 coverages was used to highlight changes in vegetation pattern (see Figs 4.1-4.8) for each point in time. There are color-shaded interpretations for general land use (4.1; 4.2); homestead land use (4.3; 4.4); trees in the landscape (4.5; 4.6) and for slope and vegetable cultivation correlated to slope (4.6 - 4.8). Ordinarily, instead of using parallel views on separate maps, this information would have been produced by superimposing the 1956 and 1988 coverages in the GIS. However, due to the difficulty in

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[13]Tilt assessment was contracted out to Peter Ashley of Hammon, Jenson and Wallen Associates, Oakland, California.

finding adequate registration landmarks for geopositioning on the available aerial photographs (a very common problem for work with historical data, including photographs, especially for forested rural areas), the coverages were geo-positioned to marginally different points on the base map including topographical features. The resulting difference between the two coverages makes overlaying the maps very problematic. GIS allows a high degree of precision, and even small discrepancies of a few meters or less for coverages at a scale of tens of kilometers influence overlaying results. Any effort to combine the 1956 and 1988 coverages by using the 'union', or 'intersect' commands in Arc/Info leads to creation of innumerable tiny fragments which reveal the combined geopositioning and digitizing error. A commonly employed alternative method of matching coverages, called 'rubbersheeting' was not acceptable here, as efforts to force a match of the coverages without adequate control points would have entailed altering polygon shapes and area measures unpredictably.

Instead, area and perimeter measures for each polygon were downloaded for 1956 and 1988 using the 'CALC' option in INFO and transferred to Statview software (1986) for statistical analysis. The area values were summed for each land use type to find the overall area in square meters for each in 1956 and 1988 respectively. A series of spatial metrics were applied to analyze general changes in vegetation patterns in the landscape as a whole and a grid method was applied to use a known area to compare the relative changes in pattern between elements of the landscapes at both points in time.

General Measures of Pattern

Changes in distribution of vegetation in landscapes are commonly measured by studying relative patterns of fragmentation, the breaking up of contiguous areas of vegetation into smaller patches. Fragmentation of a given vegetation or land use type is a function of variations in size, shape, spatial distribution and density of land use patches (Burgess and Sharpe, 1981). Various measures have been developed to characterize landscape fragmentation and were employed here (Ripple et al, 1991; Turner, 1991).

Patch abundance and density refer to the number of patches in a study area, and the percent cover of the land use type relative to the total area respectively. This information was calculated with simple descriptive statistics from the area and perimeter data.

Patch shape, or the complexity of patch borders, is a further measure which has applied meaning, for example, in terms of relative proportions of interior or edge habitat; or vegetation's influence on patterns of wind flow. One measure of patch shape is the 'perimeter to area ratio' (P/A). In general the ratio increases as a vegetation type becomes more fragmented (Ibid). Another measure of patch shape is the patch diversity index, DI (Ripple et al, 1991).

$$DI = P/2 \quad A$$

where P is the patch perimeter and A is its area. The simplest Euclidean shape, the circle, has a DI = 1, with values for increasingly complex shapes approaching infinity.

All of the above measures (except DI) are area dependent. While useful for describing the general character of changes in a particular landscape, other measures are more valuable for analyzing overall patterns of complexity between landscapes, and for landscape characteristics occurring at different levels of scale. In particular, a series of scale independent measures have been developed from fractal geometry (Mandelbrot, 1983).

Scale Independent Metrics - Fractal Dimension

Fractal geometry provides a way of measuring structures, which appear to be random, in a mathematical framework (Orbach, 1986). A fractal structure is a geometric shape which exhibits self similarity. That is, it is made up of smaller parts which all look exactly like the larger whole. In practice a self similar structure's geometrical properties are indistinguishable as a function of length scale or resolution, so measuring it at finer and finer scales will not change its geometry (Ibid.). In other words an object is fractal, when some of its statistical properties don't change when the object is magnified (La Breque, 1992).

One way of applying the concept of fractals is to the analysis of density, porosity or 'lacunarity'[14] (Mandelbrot, 1983; Orbach, 1986). This approach has emerged from percolation theory, which was developed in physics to study spatially random processes of porous materials including ceramics (Stauffer, 1985; Milne, 1991). Objects are commonly measured in terms of their Euclidean shape or spatial dimension, d. A point and a line have $d = 1$; a plane $d = 2$ and most objects in three dimensional space have $d = 3$. Many objects are porous or have open spaces in their mass, a 'Swiss cheese effect'. The fractal dimension, D, is a measure of this 'lacunarity' which will always be less than its object's Euclidean dimension. Thus, any two dimensional shape which has a boundary more complex (say a jagged edge, or an interior hole or gap) than a rectangle, a square, or a circle, will not completely fill the plain. Its fractal dimension will lie between 2 and 1. The less dense the shape (the more 'Swiss cheese' like), the closer the fractal value to 1. Applied to the present study, one can imagine, a map of a rectangular forest block with a dimension of 2 at one point in time. Later the block of trees is partially logged and appears as a fragmented plain in a map drawn after the harvest. As a result of the logging, the fractal dimension of the vegetation pattern in the rectangular block will move from 2.0 toward 1.0. D is measured as the slope of the regression of the double logarithm of patch area on perimeter (Lovejoy et al 1982).

Forest Garden Focus

In this particular study, area independent measures are particularly useful for two reasons. First, as explained above, an alternative to measuring change in vegetation cover by superimposing the 1956 and 1988 coverages was needed. Thus, rather than comparing absolute changes, polygon by polygon, fractal analysis allows one to compare the overall pattern of relations between polygons for the land use of primary interest. If the fractal dimension changes when two maps are compared, it indicates a change in vegetation

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[14]from the Latin word , *lacuna*, a pool, pit or cleft.

pattern. Here, an important question was to analyze changes in forest garden vegetation for the landscape as a whole, and also more specifically, to focus on those areas in Mirahawatte which had already had forest gardens in 1956. A rectangular polygon of known area (5,760 m2) was overlaid in approximately the same location on the coverages in a section of the village which had mature gardens in 1956 (based on characteristic landforms). The forest garden cover in the designated area was compared by downloading the area and perimeter data for the forest garden vegetation within the rectangle and calculating its fractal dimension for 1956 and 1988 respectively. Second, the primary interest in the study is in patterns of land use aggregation across scale from ecosystems to the landscape at large.

Here a method inspired by the raster approach and the sample quadrat approach applied by vegetation ecologists (e.g., Grieg- Smith, 1983) was used to create a series of overlays of grid cells denoted here as spatial scales, ranging from 320 square meters to 40 square meters[15]. Comparative frequency of vegetation presence or absence in the grid was measured for decreasing cell size for the 1956 and 1988 coverages (Fig. 4.5).

Fractally structured phenomena exhibit statistically similar patterns across a range of spatial scales. Along with the perfect fractals created through mathematical formulae, a range of fractal patterns have been identified in nature (Mandelbrot, 1983). Natural fractal patterns are usually limited to a definable range of spatial scales above and below which the pattern breaks down. A fern for example, exhibits a certain fractal character across three levels of scale. The pattern of its leaves, leaflets and veination display very similar and characteristic dendritic pattern. Yet, on the smaller scaled end, the fractal pattern of a fern breaks down below the scale of the veins on the leaf surface as one moves to the cellular level; at the larger end of the scale, the individual plant has all shoots emerging from one

[15]A program for grid generation was developed by John Radke in PASCAL and an aml program for an Arc/Info calculation of the results was provided by Raphael Real de Asua.

central point, not in the fractal pattern of its leaves, leaflets and veination. Thus, a fern is naturally fractal for a specified range of scale.

Forests, when viewed as three dimensional surfaces from above have been termed fractal as well (Peitgen and Saupe, 1988). The pattern of a forest is like a piece of cauliflower (Mandelbrot, 1983), the shape of the crown of an individual tree. The crowns of an aggregation of trees in a stand have this cauliflower shape and texture, as does a large tract of forest. As forest gardens are aggregations of trees over a range of scales in the landscape, it is of interest to see to what degree they might exhibit such a fractal character. In particular, should they not match the analogy to forest cover for aggregated landscape effects, it will be of interest to see in what respects and at what levels of scale they diverge from the forest model.

The traditional dense block structure of forest gardens (Fig.2.4) would be expected to be analogous to forests for several key ecological functions including, soil conservation, water catchment and provision of habitat for a wide range of forest species (Everett, 1987; Senanayake, 1987). The basic unit in the forest garden pattern, like that for forests (Mandelbrot, 1983) would be the crown of an individual tree. At the next level of scale, a clump of trees exhibits a self-similar pattern of crown edge. As the canopies from clumps of trees in one garden blend with neighboring gardens, a forest-like patch emerges with a shape statistically similar to the crowns of its individual trees. Thus, the fractal dimension of forest gardens would be expected to be constant from a scale of few meters (the diameter of a tree crown) to several hundred meters (the diameter of a typical hillock of forest gardens in the village landscape). The break in pattern at the upper end in scale, the level of the hillock or patch of many gardens, would occur primarily in relation to topography. Topography tends to determine the boundary between neighborhoods of forest gardens on high ground and lower lying areas which can be irrigated and thus are managed as paddy fields. Gardens would extend up a hillside to a point where people perceive the slope as being too steep or the soil too thin to plant trees, and down to a point in elevation where

drainage in the landscape determines the point at which water can be harnessed for paddy cultivation. If there is a change in garden pattern, such as a trend toward clearing patches in gardens, this would be reflected in a change in fractal dimension for the affected range of scales. As gardens are managed privately and independently, changes would be expected to occur from within gardens at a scale of less than the .29 ha (.7 acre) size of the average garden.

A grid dimension method, based on work by Voss (1988) and Milne (1991), was employed to test for differences in the range of fractal character of gardens between 1956 and 1988. The grid dimension is measured by overlaying grids of decreasing cell size (of LxL dimension) on the vegetation map and counting the vegetation's frequency of occurrence (Fig. 3.1). "The number of occupied cells increases as a function of the extent of the map divided by L e.g. (1/L)" (Voss, 1988 by Milne, 1991). If the vegetation completely covers the map, the number of cells will grow as the square of 1/L for a grid fractal dimension (Dg) of 2. This is the pattern expected for a dense, closed canopy forest. If the vegetation does not completely cover the area, i.e. if it is fragmented, fewer cells will be filled, with Dg approaching 1 as the complexity of the fragmentation increases (or the area of the vegetation type decreases). If forest gardens are naturally fractal for a certain range of scales, the fractal dimension value Dg would be expected to be constant across this active range. Further, as a dense closed canopy forest is the hypothesized analog, the expected value for Dg would be close to 2.

To test this possibility the fractal value Dg was calculated for 1956 and 1988 from frequency values for each grid cell size. The expectation for the traditional forest garden block model is that Dg would be the same for a range of values and then diverge where the scale independent similarity ended (here, where the topographical effect takes hold). If the pattern of forest gardening has not changed, the values for Dg would be very close for the 1956 and 1988 coverages across an equal range of spatial scales. On the other hand, if the pattern has changed significantly, as suggested by the hedgerow lattice, a significant shift

of values for Dg at all scales would be expected. The results of this analysis are presented and discussed in Chapter 4.

3.1.4 Analysis of Spatial Location of Land Use

Another realm of interest in understanding landscape change is the location of land use types relative to other landscape features. The position of certain types of land use relative to slope and water flows is of particular importance in agricultural landscapes, where cultivation practices often lead to soil erosion. In this case, the marked increase in vegetable cultivation along the Matatila river was of interest.

A slope coverage for the study area was developed from the digitized topographical map. Six slope categories were defined according to a classification used in Nuwara Eliya district (Zijlstra, 1989). The slope coverage and coverages including only values for vegetable cultivation in 1956 and 1988 respectively were joined using the 'intersect' command. Parallel maps of the coverages were produced and data from the coverages were downloaded for descriptive statistical analysis. Here due to the geopositioning problem, some error arises when the topographical and the vegetation coverages are joined. Further, bare ground and vegetable planting were difficult to distinguish on the 1956 aerial photographs (though at that early date, permanent vegetable cultivation plots on the hillsides would not have been very common). Finally, there may be some distortion in the areas measured for vegetation in the rugged relief along the river from the non corrected aerial photographs. Thus the results from this analysis demonstrate a relative proportional change in area under bare ground and vegetable cultivation rather than a great degree of precision. Other, more general changes in location of land use types were noted and are discussed in detail in Chapter 4.

The remainder of this chapter is focused on methods used to gather data and build a systems model of state factors influences on forest garden vegetation.

3.2 Field Research Methods

My major interest in the field portion of the study was in village land use, and especially forest garden systems. I knew from earlier research that in the Uva Basin forest gardens are similar in density and species richness of woody perennials and approach values for canopy closure comparable to natural forest ecosystems (Everett, 1977). I wondered how representative these findings were of gardens elsewhere in the highlands. How and why might gardens vary in different places? I knew that the gardens in the Uva Basin study area were intensively managed - intensive in the sense of the knowledge required to plant and manage the systems, rather than in the amount of physical energy expended in working in them. The farmers know about uses and plant growth requirements for a wide range of species and they glean a variety of products throughout the year from their gardens. Peoples' lives seemed inextricably linked to their gardens. The gardens were their familiar home environment. What would induce people to change their gardens?

I hypothesize influences of state factors, acting as initial conditions which influence land use and particularly forest gardens. In order to assess possible correlations between state factors and vegetation for a given point in time, it was important to describe the vegetation of interest and to identify measurable variables to represent state factor influences. A common method of analysis used to study the bases for such patterns is to focus on one factor along a gradient of change while holding the others constant (e.g, Jenny's sequences, 1958; and Grieg-Smith, P. 1983). Here I sought to gather data that would allow me to apply this process, adding a hierarchical dimension to identify measures at several levels of scale for each state factor. These variables would later either be built into the analysis of forest garden (ecosystem level), local (landscape level) and regional (between landscape) variation, as likely to be critical, or if deemed less important or beyond the scope of the question asked, be held as constant as possible. Once the field data was

gathered, I could proceed to check the relative association of each state factor variable with measures for vegetation using statistical analyses.

In summary, in the field research for this project, I gathered information about variations in garden vegetation and about wide range of state factor variables that could be influencing these patterns of variation. As forest gardens were the basic unit of analysis, I approached the study by visiting as many forest gardens as I could, both to gather data on vegetation and site quality and to interview garden owners about their garden management and their households.

3.2.1 Study Design

My approach was to do the field research myself rather than rely on assistants to gather more extensive data[16]. This choice meant that I would have a smaller sample and less data, but I would be confident of the relative value of the information, as well as knowing the context in which it was gathered. To maximize the value of the data, I sought to build clear triangulation (Pelto and Pelto, 1978; Bateson, 1979) into the structure of the research wherever possible. To begin with, I had time and resources sufficient to contrast villages in three climatic regions in the mountains.

Mirahawatte village was originally selected as a research site in 1985 because the directors of the NeoSynthesis Research Centre, a non-profit environmental organization located in the village, invited me to use its research station as a base. The other villages were selected in 1989 for their common elevation, their size and location with respect to larger towns and their age (see discussion of state factor variables below). As described in Chapter 2, the villages chosen for the study were, in order of increasing annual precipitation, Mirahawatte village with the recent settlements of Matatila and Balathotella in Welimada division (1,610 mm/an); and Maussagolla village and Maussagolla Colony in

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[16]The work was in progress during the height of the JVP revolutionary counterinsurgency in 1989-91 when door to door surveying by strangers in the community less obviously foreign than myself could have been dangerous for the researchers.

Passara division (2,382 mm/an) both in Badulla district; and the three villages of Wijebahukande, Ravannagoda and Rogersongama (3,607 mm/an) in Kotmale division, Nuwara Eliya district. All villages are located at similar elevations between 975 and 1,100 meters, and their annual average temperatures range from 21C to 25C.

3.2.2. Sampling Design:

The 173 households and gardens surveyed were drawn as randomly as possible. I had no prior knowledge of village vegetation or socio-economic patterns with which to stratify samples for the majority of the villages. Mirahawatte was the exception, where a previous random sample (Everett, 1987) was further sub-sampled in a stratified random system. In four settlements, households with adult respondents at home in the course of several of my visits were selected. In the remaining three villages, extension officers from the Department of Export Agriculture and a village headman (GS) helped to select households[17].

Household Selection in the Welimada Area: (n=93)

The study focused on the old village of Mirahawatte (over 100 years) and two nearby, more recent settlements, Balathotelle hamlet in the lower Mirahawatte GS division, and the new settlement area of Belipola/Matatila along the Matatila Oya between Mirahawatte and neighboring Matatila village.

In 1985/86 a random sample (literally numbers from a hat) of 61 Mirahawatte households (10% of the then 600 households on my village sketch map[18]) was drawn as the basis for my Master's research. In October, 1989, a geographically stratified sample of 30 households from the original sample was selected for further survey, by dividing the village into six housing clusters and selecting five households at random from within each

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[17]In these cases I specified that I wanted to visit a range of large and small households with gardens of varying size. Any built in biases are likely to be based on political party affiliation - an issue of no direct interest to this study.

[18]The administrative boundaries of the village have since been changed so that each village headman (gramasevakke) in the area is responsible for ca. 250 HH. Mirahawatte has one GS for Kotekitule and Udapihile hamlets and one for Pahalemirahawatte and Balathotelle hamlets.

(five previously mapped gardens were included). From the recent colony of Balathotelle, 12 households were selected on the basis of presence of an adult who could be interviewed in the course of several visits to the hamlet[19]. In Matatila/Belipola 26 households on both sides of the Matatilla Oya were surveyed (representing ca. 80% of all households), from which 20 were included in the study based upon repeated presence of an adult who could be interviewed.

Household Selection in Kotmale Area (n=50)

Households in Wijebahukande were selected with the help of the local Department of Export Agriculture Extension officer. The officer's village map, stratified by hamlet and noting the number of households per hamlet, was used as the basis for sampling. Twenty one households, including two or three each, per hamlet were selected by visiting each area and selecting households with an adult at home. I suggested to the officer that my interest was in contrasting 'rich' and 'poor' households with 'large' and 'small' gardens in order to ensure some variability in the sample. After a brief introductory visit to all sample households with the officer, I carried on the interviews myself during repeat visits in the following weeks. During this time I dropped two households due to participants' lack of interest and added one (that I was invited into).

In Ravannagoda, 20 households were selected, this time with the help of the extension officer and the village headman who accompanied us on an initial tour of the village and made introductions in the households to be surveyed. The GS was requested to select households with gardens covering a range of ages and sizes.

In Rogersongama, I selected 10 households on the basis of adults being at home and willing to be interviewed.

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[19]People here work on the nearby Dyraaba tea estate and are often not home in the daytime. Evening visits to this area were not feasible,.

Household Selection in Passara/Maussagolla (n=31)

Beginning in September, 1990, 20 households were selected with the help of the local extension officer of the Department of Export Agriculture. Again, I requested that households have gardens and that there be a mix of large and small holdings. Nineteen households were surveyed in the older part of Maussagolla which dates back for 400 years (according to local authorities). In Maussagolla-Colony, the new government sponsored housing scheme located in the northern center of the village, 13 households were selected with the help of the Gramasevakke, and 12 were eventually surveyed. The procedure followed was the same as described for the other villages, except that all questions were asked at each household in one interview session.

3.2.3 Household and Garden Surveys

In Mirahawatte, Ravannagoda and Wijebahukande, for the households selected, a basic interview and garden/field data inventory was followed up with a second interview focusing on tree growth requirements[20]. Finally a sub-sample of particularly interesting households (expert informants) were revisited a third time (or more often) for a more detailed interview concerning tree growth requirements and garden species composition and management. In Mirahawatte, I was usually accompanied by a research assistant, but after the initial few visits, I carried on the interviews myself, turning to my assistant for clarification where necessary. In the Kotmale villages and in Maussagolla, after the initial round of introductory visits with the headman or extension agent, I carried out the interviews and garden surveys alone.

[20]In the Kotmale area villages it was quite common to find families owning forest garden land both immediately around their homes (*gewatte* 'house-garden') and in some other location, often at the edge of the village or up on the mountain (*watte* garden). Unless the *watte* was very close by, I stuck to inventorying the *gewatte*. The *wattes* had a greater preponderance of timber species and sometimes cash crops with *gewattes* providing more varied produce for subsistence.

Vegetation and Site Inventory Methods

In each garden the number of species and number of individuals per species of woody perennials (and some herbacious perennials such as bananas) were noted. Each tree was placed in one of five height classes[21].

Using a measuring tape, a forty five meter transect was laid out in most gardens[22], usually stretching from a corner of the dwelling to a corner of the garden and crossing all vegetation in the garden (ornamentals; vegetable plots; fruit trees and border areas with more timber/fuelwood species) - if the distance from a house corner to garden corner was less than 30 meters, an alternative parallel line was laid for a total of 45 meters per garden. Ground cover was measured along this transect at 1 meter and 5 meters and thereafter at five meter intervals, using a one meter square sampling frame. The percent live plants; percent litter; percent rock; and percent bare ground were noted. Crown intercept along the tape was taken as a measure of garden crown closure by noting the presence or absence of vegetation greater than one meter in height above the tape line. If vegetation was present its height was noted. In sum, the measures of vegetation taken were species of woody perennial, number of individuals per species and height class per individual, ground cover and crown closure.

Topography

In the Sri Lanka context, the general topography in the highlands is of steeply dissected mountains, a relatively constant factor at the regional and landscape scales. At the individual forest garden or household level, several measures of localized topography might however, be significant. A series of measures were taken in each garden:

Relief was classified in five categories as either 'level', 'undulating', 'rolling', 'hilly' or 'steep'. Slope was measured with a clinometer at three points for each forest garden and the

[21]It would have been valuable to collect diameter values, however with over 300 stems per acre on average, it would have been too time consuming to measure each tree individually. I felt that five height classes were easier to estimate consistently than a similar range of diameter classes would have been.

[22]In some cases gardens were too small or too steep for transect sampling and visual estimates were used.

average value was noted. Aspect was measured with a compass. Slope position was classified as lying at the top, mid or low point of a hillside.

Parent Material

Similarly, though there is a degree of local variation, the majority of soils in the highlands are classified in one great group as Ultisols (Red Yellow Podsols). The villages all lay in regions with similar soils. There are, to my knowledge, no detailed soils maps for the areas covered in this study, and it was beyond the scope of my study to carry out detailed soil analyses. Instead, I used a field kit to measure soil pH at three points along the transect line (at 5, 15 and 25 meters) in each forest garden, and took their average value as representative of the garden's relative status with respect to soil fertility (a series of descriptive data on relative soil texture, color, and rockiness were also noted). This average pH value per garden was then used in the state factor analysis as an expression of parent material at the ecosystem scale.

Climate

Climatic gradients have been used widely in vegetation ecological studies (Grieg-Smith, P. 1983). Climate is really an index summarizing precipitation, temperature and elevation. All three factors are highly variable in the highland forest garden context, and yet for the purposes of the state factor model, I sought to narrow the variables down to one while keeping the others constant. Here I was aided by the fact that the government tea estates, found throughout the region, have kept very accurate rainfall and temperature data for decades. Highland gardens are limited to an elevation range from the lower end of the definition of the highlands as a study area (600-900m), to circa 1600 m, above which temperatures cool considerably, and many trees common to gardens no longer survive and forest gardens as a land use peter out.[23]. Within the 900-1600m range, average annual temperatures vary by only a few degrees and there is no frost. While the variation in

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[23]Gardens are an important component of lowland farming systems as well, but they are not discussed here.

temperature certainly could influence the quality and quantity of garden yields, it would not be likely to be the deciding factor over whether or not to grow a particular species of tree. Thus temperature can be considered a relative constant for this study.

There are, however, very significant differences in both elevation and precipitation across the highlands. Here, elevation was the easiest variable to control. It was fairly easy to choose villages located at very similar elevations[24] with similar annual temperatures but widely diverging annual precipitation[25]. I was not able to gather statistically relevant data on more localized expressions of climate, though there are some factors which would have been important to take into account quantitatively. In the Uva Basin (Mirahawatte villages), for example, a characteristic dry wind blows during the dry season, with implications for planting and for the types of species which can survive in the area.[26]

Time

Time is an explicit factor in a study which seeks to assess change. Several time scales might be usefully applied to this analysis, others may be held constant. Clearly the long term, geological time scale is beyond the frame of reference for this study. I felt it would be most appropriate here to measure time in increments which are meaningful in terms of human land use practices. For the region, the historical patterns of inmigration from the Dry Zone and subsequent events during the Colonial period are important (Chapter 2.2). For the landscape scale, the age of village settlement is likely to be significant. Village age will, for example, influence the extent and intensity of land use (a recent settlement will not yet have well developed irrigation systems or late successional stages of managed vegetation). In this study, the general age of each village was determined by a combination of interviews with local people, especially village leaders,

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[24]Note that there are single villages, in Kotmale for example, that extend across as much a 1,000 ft (300m) range in elevation, yet no qualitative difference in gardens on this basis was noted.

[25]In order to cross check for variability along the gradient, an additional more general survey of gardens was carried out in a month long transect study all along the Kandy to Nuwara Eliya and Nuwara Eliya to Welimada and Bandarawela roads.

[26]The dessicating wind adds a particularly valued flavor to tea leaves produced during this season, making the Uva tea some of the highest priced tea grown anywhere in the world.

clerics and government representatives. At the ecosystem scale, the scale of forest gardens, the age of the garden itself is important as it determines the potential structure and maturity of vegetation. I asked garden owners how old their gardens were, and received either a direct measure of time in years, or an establishment date, or somewhat more vague estimates of 'several generations'. For estimates from adults that went beyond two generations, all gardens were called '100 years old or more'.

Organisms

Numerous biota influence initial conditions for forest gardens. However, as people plant and protect garden vegetation from various types of competition and predation from other species, factors which can be shown to determine conditions influencing peoples' choices about garden management are of primary importance here. Innumerable variables could be relevant, and there is a wide range of studies on the topic of decision making in agriculture in the fields of agricultural economics, anthropology and rural sociology. For the purpose of the state factor model, it is less important to identify all major variables influencing people, than to identify several conditions which may be taken as representative of human state factor influences in the larger model. I chose seven socially determined criteria likely to influence forest garden land use, and sought variables which could be quantified for each[27]. These are access to land, labor, agricultural inputs, information, markets, education and alternative sources of income. The importance of each variable in the context of forest gardening is briefly justified here, but a more detailed discussion follows in Chapter 5.

A survey was carried out for all selected households in each village to gather data on these variables. In order to ensure respondents' privacy, each household was given a number and noted on a sketch map. Names were not solicited.

[27]The need to find variables which could be meaningfully quantified immediately excluded a wide range of values such as religious beliefs and aesthetics which are undoubtedly factors of influence on gardens.

Tenure (Access to Land): At the national level and district levels of organization, the government of Sri Lanka owns 82% of all land. This ratio of public to private land carries down to the regional level for the districts of Badulla and Nuwara Eliya as well. In addition, the overall amount of arable land in this mountainous landscape is limited. Thus, despite land reform efforts by the government, and the ceiling on individual ownership, access to private land is very limited. At the household level, respondents were asked how much garden, paddy, vegetable field and/or tea land they cultivated and what type of tenure they held on these parcels.

Population and Social Relations including Access to Labor: Population density on the island and in the highland region are high (Ch 2). In order the assess the range in household sizes in the villages and their access to labor, respondents were asked for information concerning the number of people living permanently in the household, their ages and gender (the nuclear family unit is relatively stable in these villages).

Gender related differences in garden management were elicited. Respondents were asked who (men, women or both) clears and burns land initially before garden establishment; who tills the soil; who applies fertilizers; who plants seeds; who weeds; who applies chemicals if chemical are applied (and if women do not, then why not); who plants trees; who harvests fruits; who plants and who harvests herbs; who plants and who picks flowers; who plants, who prunes and who plucks tea; who sells vegetables, fruits and tea, and to whom are these products sold.

Another factor potentially linked to labor is social relations among neighbors with regard to gardens. I was interested in the degree to which there might be neighborhood or beyond household norms related to forest gardens and their produce. Were there social institutions explicitly supporting the landscape level forest garden aggregation pattern? Respondents were asked whether their neighbors are relatives; whether plants, seeds and produce are shared with them; who planted and who owns any trees in the border between gardens; who may pluck the fruits or cut fuelwood from these trees; whether the boundary

area and its trees are discussed among neighbors. In addition, I asked village leaders whether there are any rules or conventions pertaining to gardens in their villages.

Access to Agricultural Information and Inputs: Informants were asked when the land was first cleared, what was planted first; what followed; and where seeds and seedlings came from. People were asked whether they applied any fertilizers or other inputs; whether there were ever pest problems with their trees and if so, what they did about them. As I had identified households in most villages through Department of Export Agriculture extension agents, I could assume some presence of extension workers, but it was difficult to ask more detailed questions concerning contact with the agents under the circumstances (I did not wish to be perceived by either the farmers or the extension agents as evaluating extension). From informal discussion with the extension workers and farmers, it was clear that certain woody perennial species and chemical inputs to enhance their yields were being promoted.

I asked about each person's place of birth and distance from the home-village. This gives an indication of the relative homogeneity of villages, including once source of peoples' access to information about plants. Inmigration as an indicator is sometimes reflected directly in garden species composition when people have plants from their far away ancestral villages otherwise unknown to an area (e.g., only one family in Mirahawatte was found to grow and sell cinnamon, and the wife is from Matara in the South, a major cinnamon growing area).

Access to markets: The villages were all located within at most an hours' bus ride of a major market town. For individual households in the villages, the distance of the house to the nearest lorry stop (produce collection point in the truck marketing system) or the main road was noted.

Access to education and alternative sources of income: I asked each person how many years of education they had completed. Each person was asked to name their occupation.

3.3. Statistical Analysis

Data for all variables were summarized and for the case of continuous data were entered into a correlation matrix. Those variables which showed no significant correlation with measures for vegetation (the dependent variables) were dropped from the analysis. The remaining variables were tested for correlations with each other. For variables found to be correlated in obvious ways (e.g. number of members in a household and number of children), the correlation of each with the vegetation variables was compared and the less correlated variable was dropped. The remaining variables were the potential independent variables for the state factor model. A series of stepwise regression analyses were run to test the fit of the independent variables in the state factor model. Several variables were categorical (e.g., occupation) and were tested against vegetation parameters in separate analyses of variance (ANOVA). The state factor model analysis and results are discussed in detail in Chapter 5.

In the following chapter, the results of the spatial analysis of changes in the Mirahawatte landscape are presented.

CHAPTER 4

Landscape Structure and Change in the Sri Lanka Highlands - A Spatial Analysis Using GIS

In theory, as landscape vegetation changes, landscape level flows of energy and matter will change as well (Forman and Godron, 1986). As hypothesized in Chapter 1, the aggregated effect of individual landuses has a landscape level impact which again feeds back to change the conditions under which people will carry out their landuse in the future. In this chapter spatial analysis is applied to quantify vegetation and landuse change in a case study of one landscape in the Sri Lanka highlands, and questions are raised about some of the possible ecological feedbacks of these changes at the household and the landscape levels.

Over time, people have had a profound impact on the landscape in the highlands. As population increased, there was a general trend of expanding agricultural landuse and settlement while natural forests and other wildland ecosystems declined in area[1].

Today, two very different categories of land management organization work in parallel, one directed by government agencies, as on large tea estates and forest plantations, and the other by rural people in individual households on small private holdings[2] The estates and plantations are managed as centralized large units at a near landscape level. Of greater interest here are landuse practices on the much smaller parcels of private lands which are individually managed but are expected to have aggregated effects in the landscape at large (Govil, 1991).

A quantitative analysis of changes in vegetation over the thirty-two year period from 1956 to 1988 is presented here for one village, Mirahawatte, and its immediate landscape,

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[1] When human populations decreased, as occurred, for example, after the Uva Rebellion in 1817, the extent of unmanaged wildland in the Uva increased again. Yet, as in the example of the *patana* grassland replacing abandoned agricultural land, the original forest vegetation did not recover.

[2]A third category, temple lands, are managed by the Sangha and cultivated under specialized tenure relations for the Sangha. The role of temple lands and temple forests in village landscapes is an interesting issue, especially in regard to the temples' traditional leadership role in village affairs and the potential for temples' organizing landuse activities. However, these issues lie beyond the scope of this enquiry.

including the settlements of Matatila-Belipola and Balathotella. The analysis is based on field research and two Geographic Information System (GIS) landuse coverages developed from air photographs of the area. In the analysis, particular attention is paid to the rapid expansion of two private landuse practices, vegetable cultivation and forest gardening, an indigenous agroforestry system. Drawing upon results from this analysis and examples of neighboring landscapes in the region, I examine likely scenarios for this landscape's future, particularly in regard to the ecological functions of water flows and provision of habitat for native flora and fauna.

4.1 Changes in the Landscape 1956-1988

On a human scale, much changes in a thirty year period, a generation in our manner of accounting. The changes in and around Mirahawatte have been profound. The population in the region has increased by 24%. Roads have been paved and the once-a-day bus service to the nearest market towns of Bandarawela and Welimada has expanded to one bus or van per half hour. Many children commute to Bandarawela for school every day[3]. There is electricity in the village, there are radios and television sets, and a few families have water taps inside their houses. The economy has shifted from a largely subsistence-based production system, in which nearly everyone grew their own food, to a cash economy in which farmers grow produce for sale and the surpluses generated support many small business and professional people as well as public servants. All of these changes, and many not mentioned here, have had a profound effect on the landscape.

How have the vegetation types in this landscape changed in area and distribution in thirty years? Which changes are most noticeable? Where are these changes occurring? Are there any identifiable patterns in the process? Finally, what are the probable ecological implications for the landscape?

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[3]There are village schools, but particularly for secondary school-aged children, there are more courses offered in the larger schools in town.

The 11 km2 study area was defined as the area of overlap on the available air photos which included the village and representative areas of the surrounding Uva landscape, such as the river and patches of riparian forest, the patana and forest plantation covered hills, and the nearby tea estates (Fig 4.1). The area is representative of a typical Uva village landscape, though in the Uva Basin at large, the relative area and dominance of tea and patana are greater (Table 2.3).

In the Mirahawatte landscape, changes in area for different vegetation and landuse types have been significant (Table 4.1). In 1956, *patana* grassland was by far the most extensive vegetation type, covering 45% of the study area (Fig 4.2 and 4.3). By 1988, half of this grassland had been converted to other landuses. Though the grassland is grazed by village cattle and provides habitat to many plants and animals (Mueller-Dombois and Perera, 1971), there are no direct cash returns to be gleaned from this type of vegetation cover. *Patana* is the only 'open space' available for settlement. Government policy for the *patana* beside the afforestation mentioned earlier, has been to give out some land, close to existing settlements, for village expansion. Other plots, on which people have farmed without a title for a period of years, may be granted to them, if they can prove their long standing residence on the land. In addition to such formalized settlements, much government owned patana continues to be converted to vegetable cultivation by small farmers who have no legal rights to the land. By 1979, 45,918 ha had been illegally encroached upon in Uva province, nearly half of which was under non-paddy crop cultivation. From 1979 to 1985 a 13% increase was noted as 5,608 ha were added to the count (GSL, 1991:226).[4]

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[4]There is also the question of individuals using government owned resources, for example through grazing or through encroachment. In my surveys, I asked people about the type of tenure held on their lands, but I did not ask for evidence of title. Some people living on the edge of what is clearly government land are encroachers and are very open about it, others may have been less forthright in their responses. For the purpose of this study therefore, land that was being actively managed which people professed to own was treated as private land.

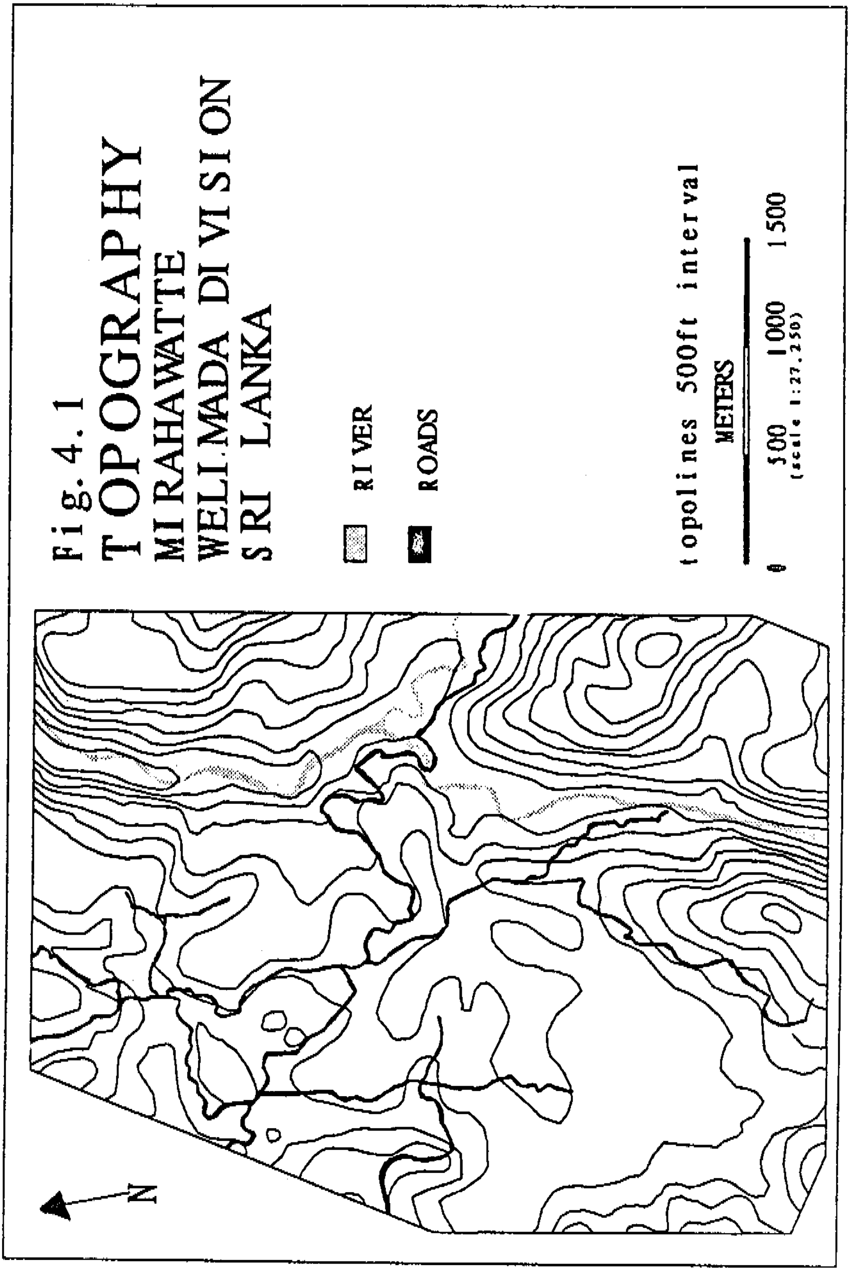
Fig. 4.1
TOPOGRAPHY
MIRAHAWATTE
WELIMADA DIVISION
SRI LANKA
RIVER
ROADS
topolines 500ft interval
METERS
0 500 1000 1500
(scale 1:27,250)
N

Fig. 4.2

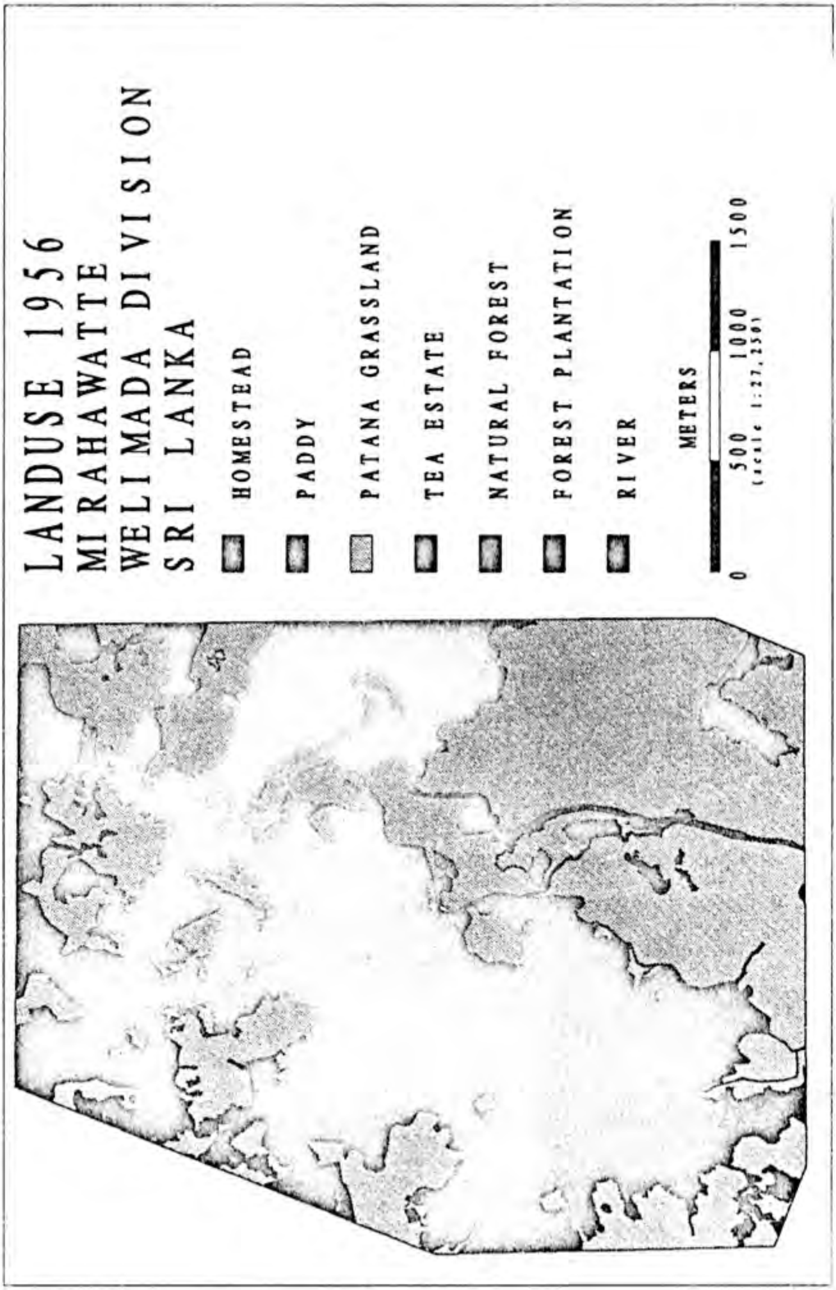
LANDUSE 1956
MIRAHAWATTE
WELIMADA DIVISION
SRI LANKA
HOMESTEAD
PADDY
PATANA GRASSLAND
TEA ESTATE
NATURAL FOREST
FOREST PLANTATION
RIVER
METERS
0
500
1000
1500

Fig. 4.3

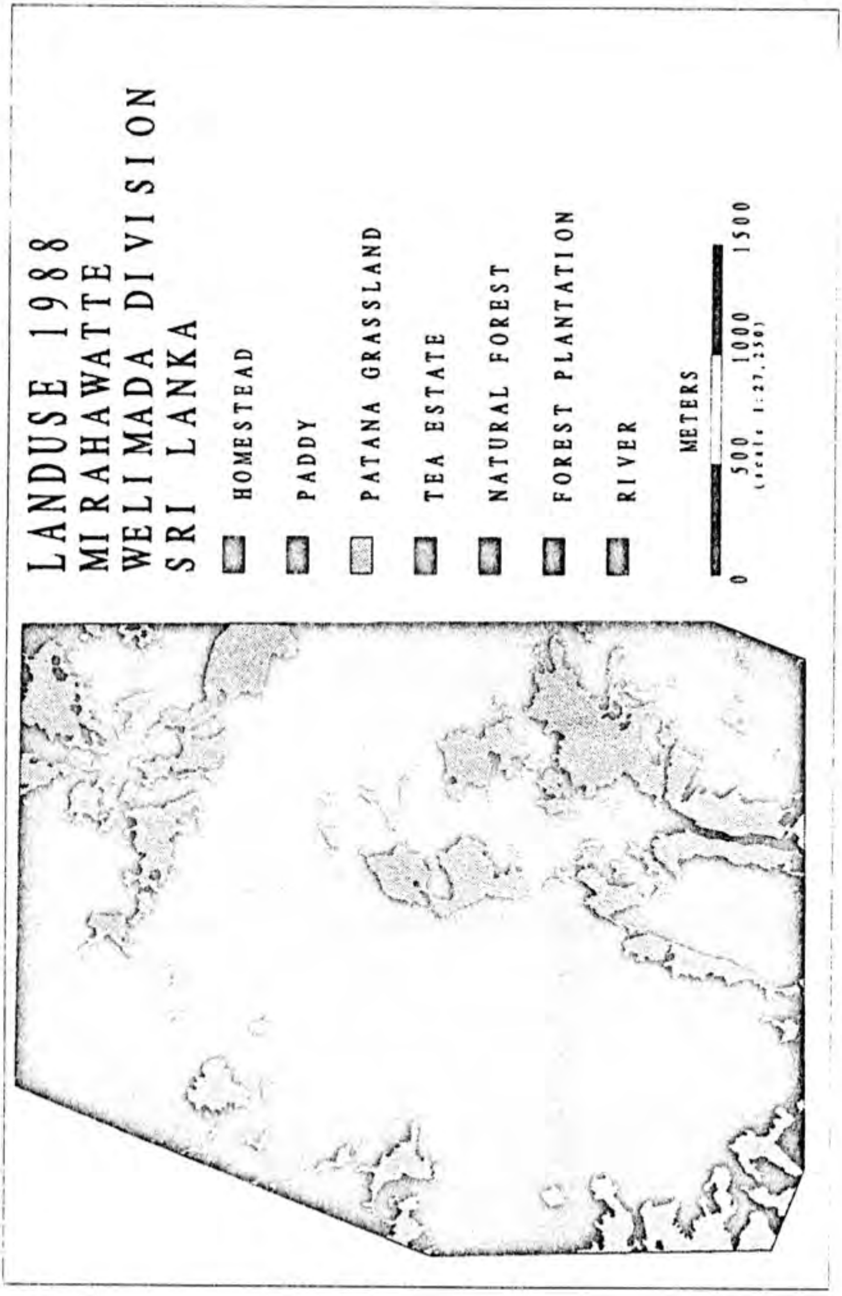
LANDUSE 1988
MIRAHAWATTE
WELIMADA DIVISION
SRI LANKA
HOMESTEAD
PADDY
PATANA GRASSLAND
TEA ESTATE
NATURAL FOREST
FOREST PLANTATION
RIVER
METERS
0
500
1000
1500
(scale 1:27,250)

Table 4.1.
Assessment of Area Changes in Landuse in Mirahawatte Village 1956-1988

Landuse	m2 in 1956	% of total	m2 in 1988	% of total	%change
Grassland	5,089,120	45	2,516,074	22	- 51
Natural Forest	446,584	4	305,345	3	- 32
Forest Plant*	62,040	1	847,754	8	+1366
Estate Tea	885,679	8	905,733	8	+ 2
Paddy fields	1,317,753	12	1,245,357	11	- 5
Trees**	1,598,213	14	2,596,941	23	+ 38
Private Tea	1,154,354	10	1,445,899	13	+ 20
Vegetables[5]	na	-	1,072,272	10	-
Bare Ground	423,291	3.5	81,934	.7	-
TOTAL[6]	10,977,034		11,017,309		(- .004)

(Error value from aerial photograph interpretation, relief, tilt is at maximum 15%)
* 'Forest plantation' refers to pine and eucalyptus blocks planted on government land.
** 'Trees' refer to trees planted by farmers on private land, usually in forest gardens.

Surprisingly, given the overall trend of increasing deforestation in the highlands, trees planted by people on private land, predominantly in forest gardens, constituted the most significant increase in area of any landuse, making forest gardens the largest vegetation type in 1988, now covering 23% of the land (Fig. 4.4; 4.5). Private tea estates increased as well. A very visible change was in forest plantations, which increased 13 times in area as the Forest Department established pine and eucalyptus plantations on the government-owned grassland hilltops surrounding the village. While the overall perennial cover thus increased significantly in planted systems, natural forests, a minor vegetation type in 1956, further declined by over 30% and now make up only 3% of the vegetation cover.

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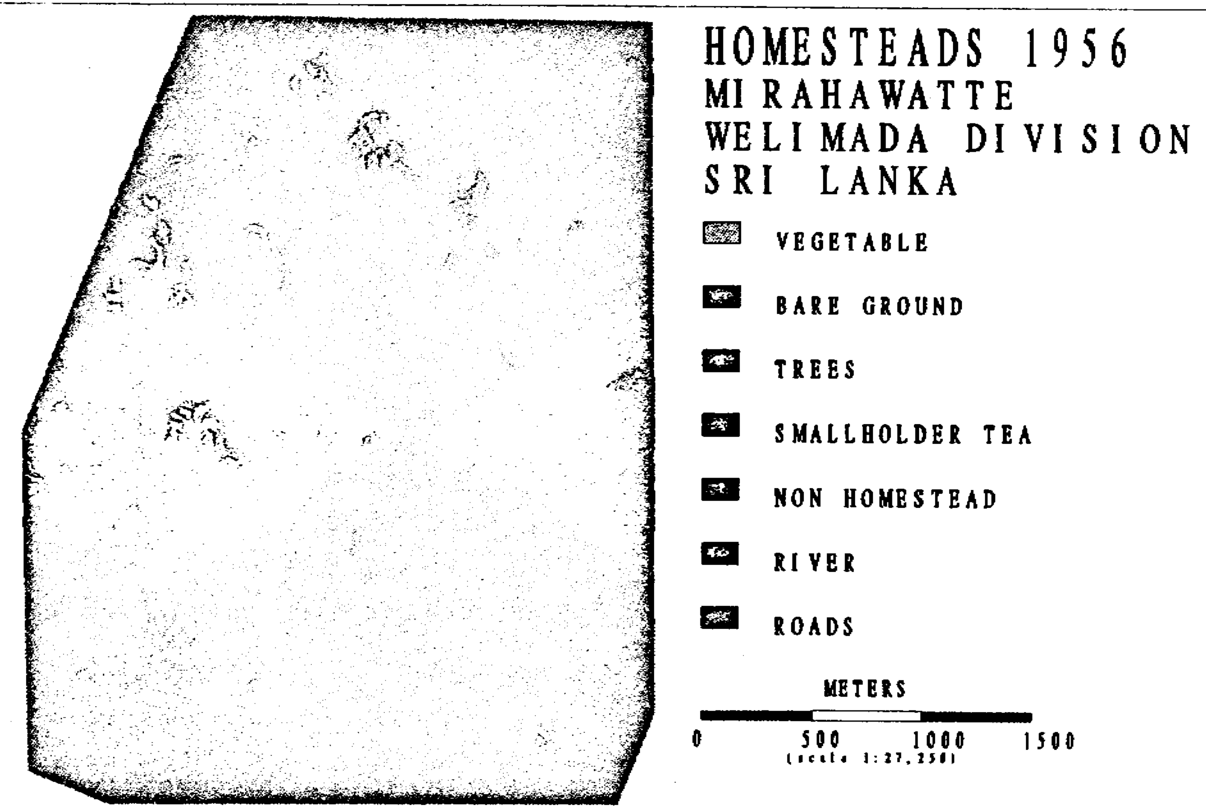
[5]I was not able to distinguish vegetable cultivation from bare ground on the 1956 photographs, and therefore called all cleared land with no cover bare ground (paddy fields are more easily distinguishable). As the major vegetable boom did not begin until at least five years later, it is not likely that there were many plots under vegetable cultivation at the time. On the 1988 photos by contrast, rows of cultivated vegetables can be seen and, in addition, I had recent ground truthing experience in the village (1986; 1989-1991) to help in defining cover types.
[6]Roads and the Matatila River were also digitized as polygons (visible on the maps figs. 4.1-4.8) which later proved problematic as errors in digitizing these linear features grew disproportionately.


HOMESTEADS 1956
MIRAHAWATTE
WELIMADA DIVISION
SRI LANKA
VEGETABLE
BARE GROUND
TREES
SMALLHOLDER TEA
NON HOMESTEAD
RIVER
ROADS
METERS
0
500
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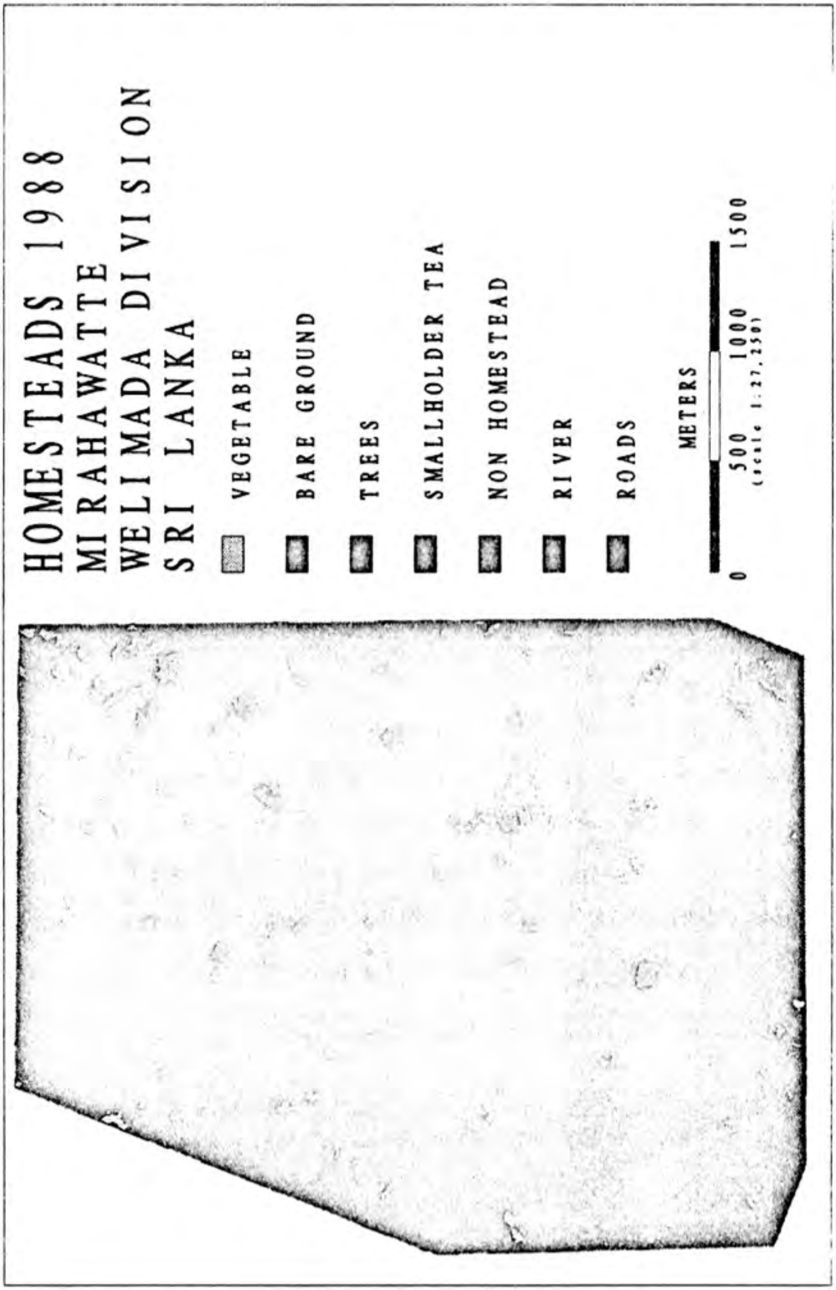
1500
(scale 1:27,250)

Fig. 4.4

Fig. 4.5


HOMESTEADS 1988
MIRAHAWATTE
WELIMADA DIVISION
SRI LANKA
VEGETABLE
BARE GROUND
TREES
SMALLHOLDER TEA
NON HOMESTEAD
RIVER
ROADS
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(scale 1:27,250)

In a second trend, competing with the increase in area under managed perennials, annual vegetable cultivation also grew exponentially and now accounts for fully 10% of landuse. As noted in Ch 2, the major increase in vegetable cultivation in Badulla district dates from the early 1960's, when their potential as a cash crop for the area was recognized both by the Department of Agriculture, which carried out research and development efforts to extend the crops, and by farmers who began cultivating them at a rapid rate.

Government tea estates and private paddy fields, remained stable in their extent. Again, these results are to be expected. Government estates are not subject to much conversion due to local population increase (it is difficult to encroach on intensively managed and therefore guarded estate land), and tea remains Sri Lanka's most important export crop, so the area under tea would not be expected to change. For the case of paddy lands, areas in which irrigated paddy fields can be located in the rugged mountain terrain are limited and would have been the first chosen by earlier settlers. In fact, perusal of the 1956 photos and maps indicates that there was little or no suitable area not yet converted to paddy at that time[7].

Thus, the primary conversion in landuse was from unmanaged grassland and natural forest toward planted perennial vegetation, in private forest gardens and government forest plantations, with a second trend toward increasing vegetable cultivation appearing as well.

4.2. Changes in Distribution and Patterns of Landuse

The distribution of changes in the landscape may indicate varying intensities or rates of change for different vegetation types or for specific locations, for example, relative to settlement patterns along roads. By 1956, the most desirable land from a farmer's perspective had been settled. These are areas with relatively flat terrain, deeper soils and easy access to perennial streams which can be channeled for rice cultivation, and proximity

[7]Dry land rice cultivation is not common here. Traditional dry land (chena) crops are usually other grains.

to roads. After 1956, the largest conversions in vegetation occurred where new land was settled. According to my survey of over 90 households in these villages, this expansion in landuse was largely due to population growth from within a localized radius of 25 kilometers (87%), with immigrants from outside, including spouses marrying into the village, making up 13% of the villages' population.

Two phenomena were particularly evident in the land conversion (Fig. 4.4 and 4.5). First, vegetable cultivation expanded along the river, where young farmers chose to take on the difficulties of steep slopes and often very rocky land to take advantage of the water to grow cash crops. Second, homesteads with their forest gardens and plots of tea expanded out from the earlier settled lands into more remote areas away from the main roads and onto drier, steeper and generally more marginal land. This expansion of small-holder settlement is largely responsible for an increased fragmentation of vegetation patches in the landscape, particularly of the grasslands.

4.2.1. Vegetable Cultivation

Vegetable cultivation on homestead land and in fields, often on dry land, is a fairly recent type of cash cropping with some traditional basis in *chena* shifting cultivation on dry hillsides. In 1956 there was little if any vegetable cash cropping in Mirahawatte, though in some areas, farmers in clearing land in the *patana* for their new homes may have also been growing some field crops. These areas were categorized as 'bare land' on the GIS maps for 1956, and covered 423,291. In 1988 with most of the available land for settlement already taken, 'bare land' was a far less significant category and consisted largely of small openings around peoples' homes, the village school yard, cemitaries and so on. By 1988, vegetable cultivation had become a major landuse, covering 1,072,270 m2. Much of this shift in settlement and landuse occurred on previously unsettled, steep patana lands, especially along the Matatila Oya (Table 4.2; Fig 4.6, 4.7). The maps show the high correlation between vegetable cultivation and the river, and the resulting degree to which

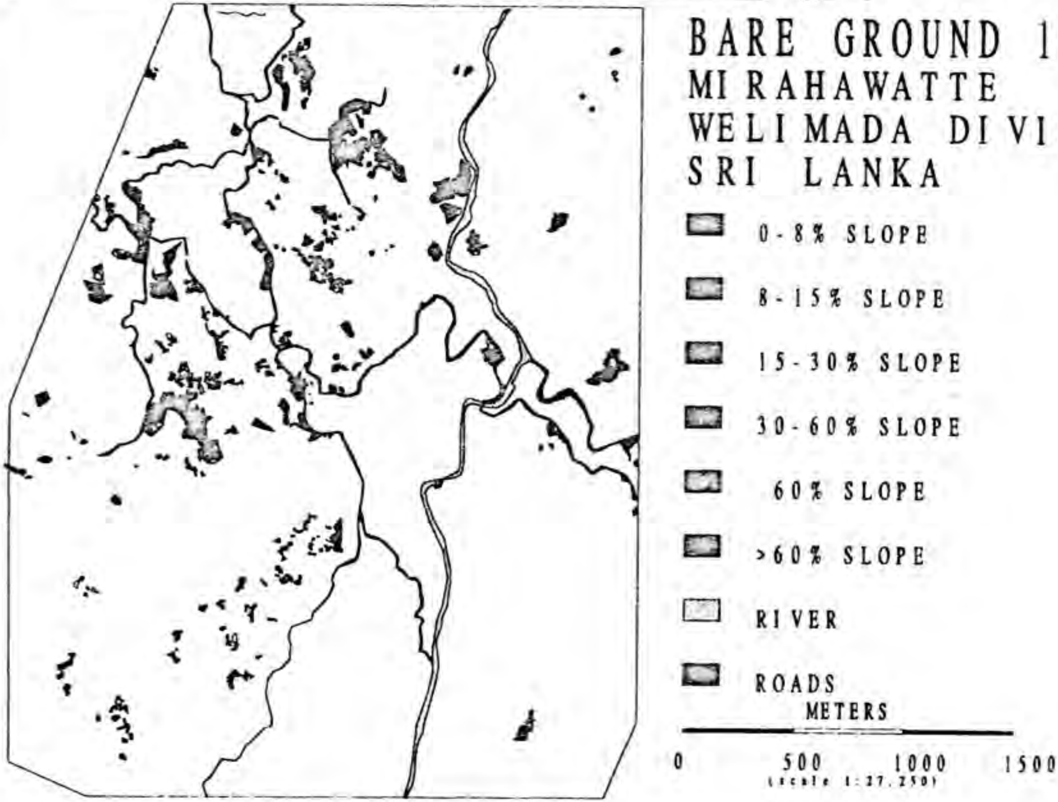
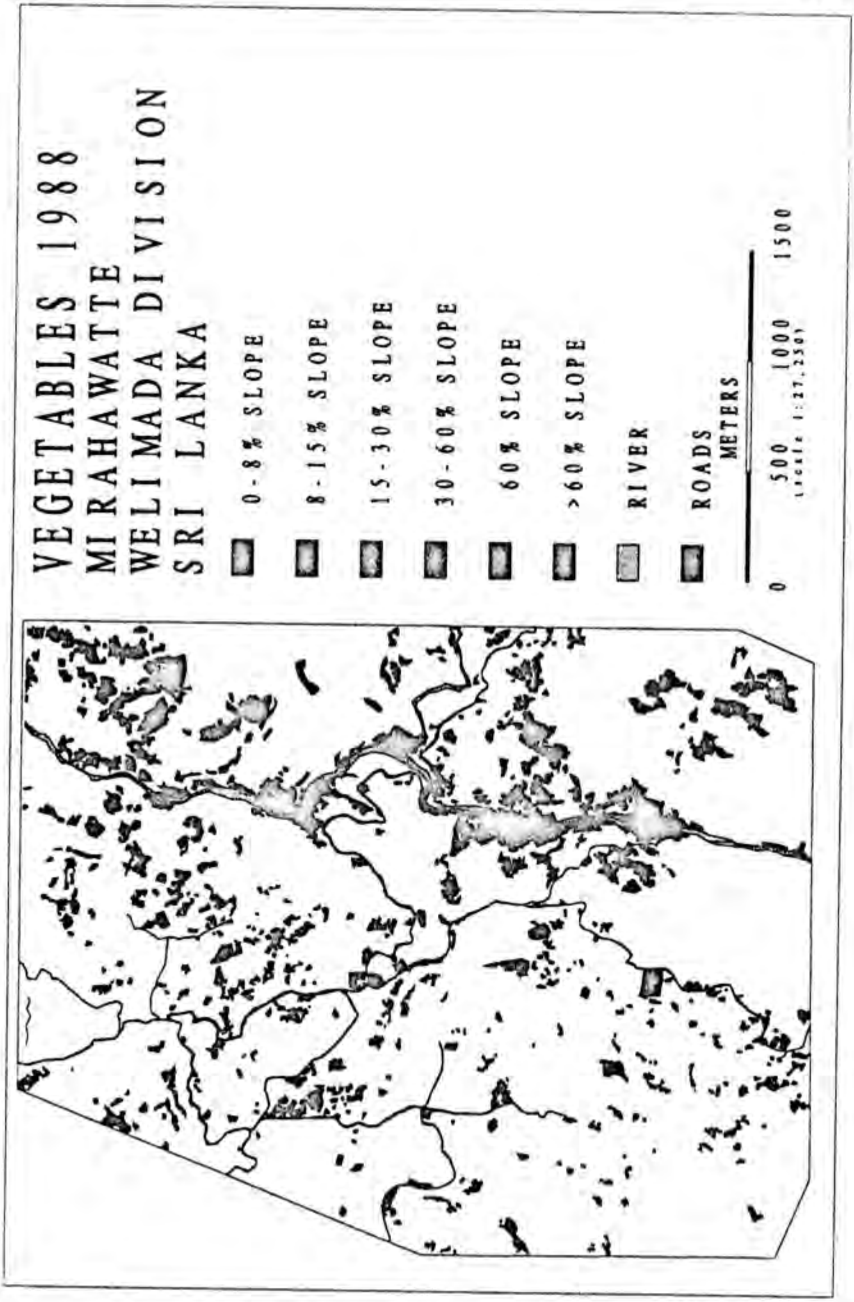

BARE GROUND 1956
MIRAHAWATTE
WELIMADA DIVISION
SRI LANKA
0-8% SLOPE
8-15% SLOPE
15-30% SLOPE
30-60% SLOPE
60% SLOPE
>60% SLOPE
RIVER
ROADS
METERS
0
500
1000
1500
(scale 1:27,250)

Fig. 4.7


VEGETABLES 1988
MIRAHAWATTE
WELIMADA DIVISION
SRI LANKA
0-8% SLOPE
8-15% SLOPE
15-30% SLOPE
30-60% SLOPE
60% SLOPE
>60% SLOPE
RIVER
ROADS
METERS
0
500
1000
1500

vegetables are cultivated on steep slopes. Over half of the cultivation occurs on slopes of 60% or more. The type of vegetable cultivated does not vary with slope.

Table 4.2 Distribution of Vegetables across Slope Categories

	1956		1988	
slope class	bare ground (m2)	# polygons (n)	vegetables (m2)	#polygons
1 (0-8%)	109,330	134	284,209	305
2 (8-15%)	15,132	96	24,420	143
3 (15-30%)	16,949	75	24,684	135
4 (30-60%)	21,656	127	45,284	206
5 (60-100%)	89,977	159	156,084	353
6 (>100%)	170,238	152	537,589	906
TOTAL	423,283	743	1,072,270	2,048

The typical pattern of vegetable cultivation is for a farmer to burn fallowed grassland or stubble left from the previous crop just prior to the rainy season, to till the soil by hand, plant, apply fertilizers, irrigate with water from an irrigation channel or pumped up from a stream with small kerosene pumps, weed the crop and watch it grow with several more applications of fertilizer, pesticides and/or fungicides before the harvest. After the harvest, the field lies fallow sometimes for a year, but normally for a few months until just before the second annual rainy season.

There are a series of probable ecological implications of these practices, often carried out immediately adjacent to streams. Present vegetable cultivation practices, which remove perennial vegetation along streams and involve loosening and cultivating soil, conflict with riparian zone conservation.[8] This effect is well understood by government,

[8]In stretches where a few trees and brush undergrowth remain along the Matatila river, diverse wildlife persist. There are fishing cats, otters, barking deer and many other mammals as well as a range of reptiles and amphibians living on the banks or visiting frequently. Black eagles, kites, hawks and kingfishers all hunting from the cliffs along the water course. Some fish still survive the periodically choking loads of silt and find shelter in the cool spots in the shade of the overhanging vegetation (Descriptions based on NSRC staff and personal sightings).

and there are ordinances requiring maintenance of uncultivated buffers along streams[9]. However, enforcing the ordinance requires considerable effort and cost on the part of the government and is not always achieved. I have no direct measure of this erosion tied expressly to vegetable cultivation, beyond noting that the silt load in the Matatila river, which is bordered by vegetable cultivation for several miles in the vicinity I'm familiar with, is very high on rainy days.[10] In general, this type of cultivation is very extensive in the Uva Basin half of the Mahaweli watershed (especially in Welimada division). It would be very important to pursue research to quantify cultivation impacts on highland stream flows, in view of the high levels of siltation that have been noted for the Mahaweli reservoirs. The siltation is expected to greatly reduce the originally estimated working lifespan of the new Mahaweli dams (NARESA, 1991:150).

The additional effects of chemical inputs, especially fungicides and pesticides, remain unquantified for this area to date. Further, some of the conversion from wildland has come at the expense of the last remnants of lower montane evergreen forest at this elevation.

4.2.2. Distribution of Trees

The general summary of landscape changes (Table 4.1) indicates four major trends in tree distribution. First, the area under tree cover in private forest gardens and in forest plantations has increased significantly. The general increase in tree planting on private land demonstrates that an increase in population does not always imply corresponding deforestation. Furthermore, the forest gardens are proof that, contrary to the generally held opinion that grasslands are nearly impossible to reforest except with fast growing exotic species, diverse tree cover can be established in just a few years. The expansion of tree planting on private land has occurred in small patches wherever new households have

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[9] I spoke with farmers in Matatila who had been fined for cultivating right down to the stream.

[10] Sand banks in the Matatila river shifted considerably and it would take at least a day, sometimes longer before the water cleared after a significant rain.

settled. In 1956, the plots were primarily close to roads, but the 1988 coverage shows settlement expanding into less accessible areas, as population increases and land becomes scarce (Fig. 4.4-4.5). In contrast to the incremental pattern of forest gardening, forest plantations managed by the Forest Department on government land tend to be arranged in large blocks restricted to hilltop and hillsides previously under grassland cover. Forest plantations are dense monocultures, either of Eucalyptus spp. or Pinus caribbaea. The shapes of these vegetation patches are overridingly rectangular blocks, and there has been little fragmentation in this type other than small localized disturbance caused by fire.

Countering the trend of increasing tree cover, the area of natural forest has declined. Natural forests typically hug ravines or the river course and are often long and narrow in shape. They are dense, with interior gaps usually not larger than those created by single trees falling or dropping branches. The forests' borders have been encroached upon by human users, creating some complexity along their boundaries and increasing the proportion of edge. As they are commonly located in ravines, the area estimates for natural forests from the monoscopically interpreted air photographs are not very reliable. Still, a clearly visible reduction in cover took place between 1956 and 1988, and has been quantified here as an estimated 32% loss in natural forest (Table 4.1).

In a third trend, the maps show that the reduction of perennial cover, particularly in natural forests, has been especially linked to riparian areas, where vegetable cultivation has expanded (see 4.2.1).

Finally, despite the increase in area under trees, close study of the pattern of trees' distribution in forest gardens shows what may be a change in garden configuration occurring with increasing numbers of gaps in garden blocks where people are growing vegetables (4.8; 4.9). The pattern of gardens on the map in 1988 seems more fragmented, with many small gaps occurring in places where there was complete canopy closure in 1956. If this is a significant trend it might have ecological implications for the landscape as a whole.

Fig. 4.8

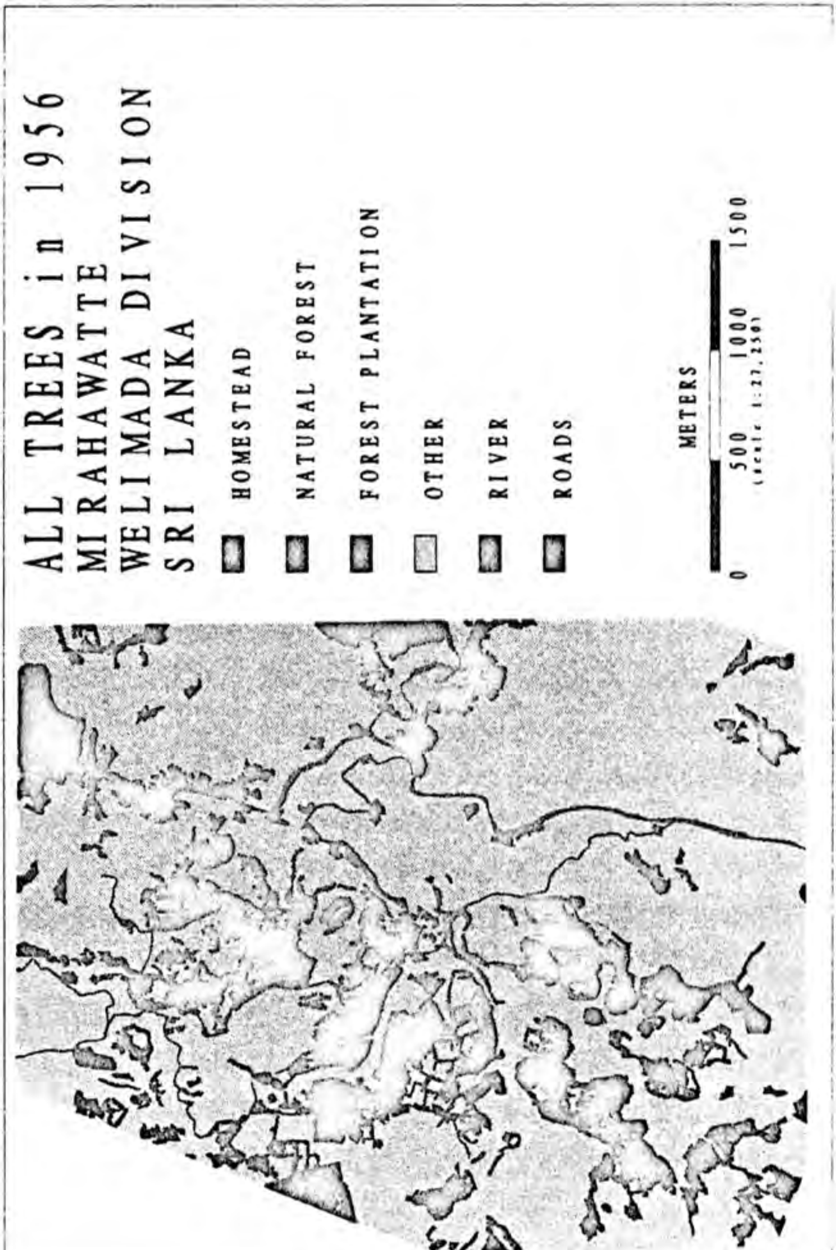
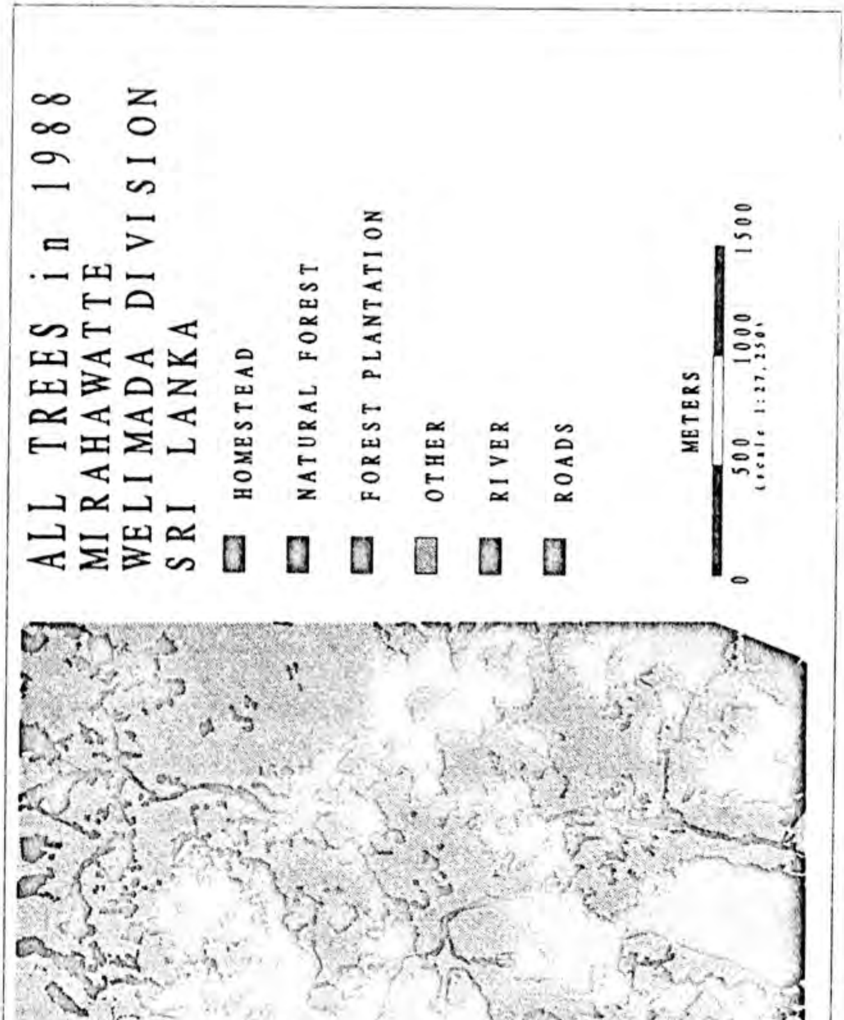

ALL TREES in 1956
MIRAHAWATTE
WELIMADA DIVISION
SRI LANKA
HOMESTEAD
NATURAL FOREST
FOREST PLANTATION
OTHER
RIVER
ROADS
METERS
0
500
1000
1500

Fig. 4.9


ALL TREES in 1988
MIRAHAWATTE
WELIMADA DIVISION
SRI LANKA
HOMESTEAD
NATURAL FOREST
FOREST PLANTATION
OTHER
RIVER
ROADS
METERS
0
500
1000
1500
(scale 1:27,250)

In general, the maps indicated an increased degree of patchiness or 'fragmentation' for most of the vegetation types in the landscape. A series of spatial metrics were used to begin to quantify these changes in pattern occurring in the landscape at large, and in particular, in forest gardens.

4.2.3. Fragmentation in the Landscape

Fragmentation is a process of change in landscapes affecting the distribution of vegetation types and the size and shape of patches of a given type (Burgess and Sharpe, 1981). In general, fragmentation results in an increase in abundance of patches of a given vegetation type and a corresponding decrease in average patch size and distance between patches (Forman and Godron, 1986). Fragmentation studies largely deal with the effects of decreasing size and connectedness among patches of a specific (often desired) vegetation type on ecological functions, rather than on the corresponding increase in converted landuse. From the perspective of a biologist, for example:

" fragmentation implies that a species' habitat is dissected into smaller units separated by strips of land which are unsuitable or even inhospitable for the species concerned" (Opdam, 1991).

However one chooses to assess its effects, fragmentation, as a process of vegetation change, alters the dynamics of energy, water, nutrients and organisms' flow through the landscape.

4.2.4. Measures of Landscape Change

In the Mirahawatte landscape, fragmentation was measured at two scales. First, fragmentation of vegetation patches for the landscape as a whole was measured using the area and perimeter data from the GIS coverages for 1956 and 1988 (Chapter 3). Following the landscape level view, more detailed analysis of forest gardens was undertaken.

Several measures have been used to describe the degree of a landscape's fragmentation (Milne, 1991; Ripple et al, 1991). One is the number of vegetation patches in the landscape. In the Mirahawatte area there were 935 polygons or distinct vegetation

patches in 1956. By 1988 there were nearly three times as many, totalling 2,414 patches. A second measure is the average size of a patch. In 1956, the average area per patch was 12,010 m2. By 1988, the average had declined drastically to an area of 4,652 m2 (Table 4.3). This trend held for most of the individual vegetation or landuse types. Thus by 1988, the landscape was characterized by many small patches, and therefore exhibited a more fragmented pattern of vegetation than in 1956.

Several further measures address the shape of individual patches which, for example, provides an indication of the amount of edge vs interior habitat quality for biota. Patch shape is a function of both area and perimeter. In this case the average area per patch had declined and therefore a correlated change in perimeter was expected. Indeed, the average perimeter of patches dropped from 542 m in 1956 to 374 in 1988. The perimeter to area ratio (P/A) is an indication of the proportion of perimeter to area with implications for the relative importance of edge effects on patch interiors, with larger ratios indicating larger edge effects (Forman and Godron, 1986). Here the growth in the P/A from .045 to .081 indicates a very significant increase in edge. In order to quantify this change in spatial patterns, area independent measures were applied.

Table 4.3
Measures of Fragmentation in the Landscape

year	area (m2)	# patches	area	perim	P/A	fractal D
1956	10,977,034	935	12,010	542	.045	1.503
1988	11,017,309	2,414	4,615	375	.081	1.434

As discussed in detail in Chapter 3, there is an increasing number of approaches to measuring changing patterns of ecosystem fragmentation and their landscape level effects with the development of fractal geometry (Mandelbrot, 1982). In this case, the value of the fractal dimension, D, for the landscape as a whole changed to some degree over the

thirty year period. Several important landuses, including tea estates and paddy fields, remained fairly constant in extent (Table 4.4). The paddy fields are in many cases now used for vegetable cultivation in the drier season. While ground level experience and photographs indicate that this is a very widespread phenomenon, it is not possible to quantify it without further data. Therefore paddy fields are classified only on the basis of rice cultivation here and this additional seasonal vegetable cultivation is not added into the figures for extent of vegetable cultivation. This result supports the other measures in indicating changing patterns in the Mirahawatte landscape.

Here, with the hypothesized trend of forest garden fragmentation, it is of interest to apply the approach specifically to quantifying patterns in forest gardens.

4.2.5. Fragmentation in Forest Gardens

A comparison of average patch perimeter, average area and P/A shows that the average size of clusters of trees in gardens has decreased (Table 4.5). An increasing edge effect is indicated by the larger P/A ratio measure for 1988. The complexity of garden perimeters as measured by the diversity index, DI, increased from 1.905 to 1.941 from 1956 to 1988, indicating an increase in fragmentation from 1956-1988.

The data indicate a general pattern of fragmentation occurring in forest gardens. However, as forest gardens are characterized by perennial vegetation, and as a large proportion of gardens have been established very recently, when measured against the time period necessary for trees' maturation, these results, averaged for all gardens in the landscape, are not conclusive by themselves. One would expect early succession stage gardens to be patchy, with few mature trees and incomplete crown closure. Therefore, patterns of garden establishment in the newer gardens, planted since 1956, were studied, and an additional analysis of changes in patterns in 'mature' gardens already well established in 1956 from the oldest part of Mirahawatte was undertaken.

Table 4.4
Measures of Fragmentation in All Forest Gardens in 1956 and 1988

Measure	1956	1988
Number of Patches	226	689
Avg. Patch Perimeter (m)	686	465
Avg. Patch Area (m2)	7,072	3,769
Perimeter/Area	.21	.308
Fractal Dimension (D)	1.373	1.336
Diversity Index (DI)	1.905	1.941

I first sought to understand the process of garden establishment and to find out whether there were any general categories of variation. I discussed garden establishment and management with over 96 garden owners in the area and found that two primary patterns of garden establishment and management can be distinguished; a traditional pattern forming dense blocks of trees around every house; and a new pattern in which fewer trees are established and a large proportion of the homestead is used for vegetable cultivation.

In the past, when a homestead and garden were established in the *patana*, the grass and scrub were cleared and burned, leaving any existing trees standing. A house was built and often a well would be dug. Fast growing perennials would be planted along the borders of the homestead; Gliricidia sepium, Erythrina lithosperma and Hibiscus spp. were commonly used. Certain highly valued trees were planted soon after the house was built. These included jak (Artocarpus integrifolia), coconut, and other fruit trees such as mango, citrus and avocado. Fast growing species, like banana and papaya which would yield fruit quickly were also planted early on. Longer lived fruit trees might later be planted in the protective shade of these nurse plants to grow up and take over the site once the nurse plants had borne their fruit. Sometimes timber species such as Cedrela toona or Michelia champaca were planted. Ornamentals were commonly planted close to the house, particularly Jasmine bushes. Native species of trees and shrubs sprouting on the site from seed carried in by wind and animals were usually allowed to grow, or if competing with other plants, were transplanted to the border area. Incumbants like these, many endemic

remnants from the natural forests, made up 17% of all woody perennials in the gardens in my 1986 survey (Everett, 1987). Some small areas, especially in front of the house, would be kept for ornamentals and a kitchen vegetable plot, but the major cropland was elsewhere, in the paddy fields or on chena land. The gardens were dominated by trees providing fruits, timber and fuel. Family and neighbors provided seed or seedlings for valued species. Over time, in a combination of new planting and natural succession, the garden land filled in and became an uneven-aged block of trees. This process would be well underway after a decade or two. For example, an 18 year-old garden surveyed in Mirahawatte in 1986 had over 25 species of woody perennials, many maturing late succession stage trees, and a nearly closed canopy. Each house was situated in its own small forest stand which adjoined the stands of neighbors' trees on the property line. All the gardens on a given hill aggregated into a dense forest patch and the landscape was dotted with such patches on high ground (Fig.2.4).

Today, as new households become established, instead of following the old pattern, people often plant a dense border of fast growing trees and shrubs along their property line and a few fruit trees immediately around the house, leaving the center of the garden open. Vegetables are commonly planted in this opening.

In order to test whether this pattern is really an alternative version of the old pattern, or just a phase in the establishment process, I compared tree planting and density in 20 households in the Matatila-Belipola area, some of which have now been on site for 20 years. Here, even the oldest households, that have had time to develop traditionally structured gardens, have not planted many trees. As the new pattern would suggest, they have border plantings and a few valued fruit trees close to the house, while using the bulk of their land to cultivate vegetables. This indicates that the vegetable plots are permanent, and not simply a short term successional stage in managing toward dense tree-dominated forest gardens. The expected aggregated effect of this household level innovation on a landscape scale would be to create a grid of hedgerows along property boundaries.

In addition to such patterns emerging on new homesteads, there are changes in long standing forest gardens as well. The village survey shows that many people have cut down patches of trees in old forest gardens and now plant vegetables instead. Thus, the 'moth-eaten' fragmentation pattern, or decreased density of trees in older gardens parallels the fence-border pattern of tree planting on the new homesteads. As the aggregations of trees are increasingly distributed as interlocking hedgerow border-plantings, there are fewer large patches of contiguous blocks of trees in the landscape. The forest-like quality of garden landuse is being lost.

One quantitative measure of this trend is to overlay a series of grids on the 1956 and 1988 coverages of tree distribution and compare the relative proportions of cover in cells of varying scale at the two points in time. Grids with cells of 40x40 m, 80x80 and 160x160 meter cells were overlaid on a 5,760 meter square area of forest gardens in the oldest settled area of the village. The number of cells with complete cover are compared in Table 4.6, showing a much larger number of blocks of dense tree cover in 1956.

Table 4.5
Number of Grid Cells with Complete Cover for Several Ranges in Scale

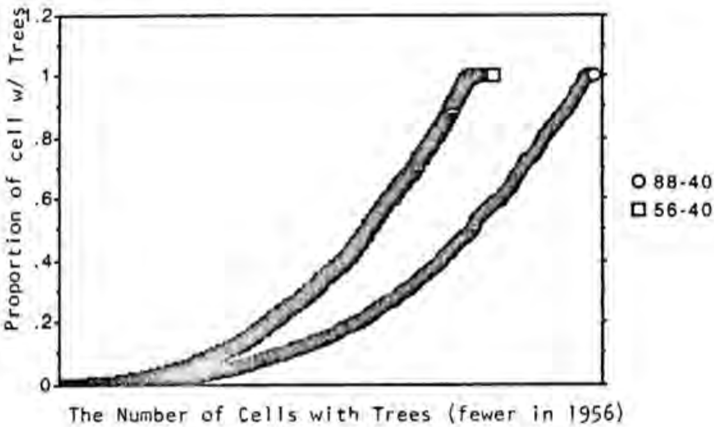
cell size	contiguous area	1956	1988
40 x 40	40 sq. m	63	19
80 x 80	80 sq. m	3	0
160 x 160	160 sq. m	0	0

In 1956, 5.98% of the grid cells were 99-100% filled (closed canopy for 40x40 meter blocks); in 1988 only 1.87% of all cells had complete cover. In 1956 27% of all cells were at least 55% filled. By 1988 only 21% had over half of each cell under dense cover (Table 4.6). A line chart comparing relative percent infilling in the grid for cell size 40x40 shows the greater average density per cell in 1956 (Fig. 4.10).

Table 4.6 Proportions of Completely and Partially Filled Cells

% cell filled	1956	1988
99-100	5.98	1.87
> 55%	27	21

Fig. 4.10 Percent Forest Garden Fill (Crown Closure) under a 40x40 Grid



(x axis: number of cells ; y axis: the proportion of the cell filled)

If this shift in forest garden planting pattern occurs widely in the landscape, it is likely to have an impact on some of the landscapes' ecological functions, in some ways analogous to a forest fragmentation process. In view of the possible importance for landscape ecological functions, I asked three questions: How can the pattern of fragmentation in this landscape be characterized? How extensive or significant is the change? What are likely implications for the ecological functions of water flows and habitat maintenance for the Mirahawatte landscape in future?

4.2.6 Changes in Garden Fractal Pattern

If a significant change in vegetation pattern in old gardens was occurring, this would be reflected in a difference in the fractal dimension, D, for these gardens when

compared on the 1956 and 1988 coverages. If there are significant gaps in gardens emerging, the value of D in 1988 would shift toward 1. A sample of forest gardens in an area of 5,760 square meters centered on the oldest part of Mirahawatte village was taken from the 1956 and 1988 coverages. The fractal dimension was calculated by regressing the log of the polygons' perimeter values on the log of the area values (Milne, 1991, Ripple et al, 1991, Lovejoy, 1982). The resulting fractal dimension values of $D = 1.595$ in 1956, and $D = 1.48$ in 1988 demonstrate the reduction in vegetation density in gardens. Thus, it appears that indeed, the pattern of forest gardening is changing.

Further, the household survey indicated that this was a clear example of a large-scale landscape pattern emerging as a result of the uncoordinated actions of many individual farmers. An alternative form of fractal analysis was applied in an attempt to define the scale of the disturbance causing this shift in vegetation pattern.

Several scenarios might be hypothesized to explain the pattern, assuming that population is growing, people are building more houses and agricultural landuse is expanding. Existing mature forest gardens might change in one of four ways: First, they might remain as they are in dense blocks of trees, on maps creating patches of relatively Euclidean shape, with fractal dimensions close to 2. Second, vegetation density and tree configuration might change as people plant vegetable crops inside and at the edges of garden blocks. The crown closure in such gardens would be expected to decrease, the perimeters become more complex, and when measured they would have a fractal dimension approaching 1. Other gardens might be divided as the next generation inherits a share of the land and builds houses without felling many trees. This would lead to a smaller average ownership plot of forest garden, but only a marginal increase in gaps and a minor shift away from a fractal dimension of 2. Finally, in some cases, families might divide gardens and shift toward vegetable cultivation at the same time, greatly reducing the tree cover toward a hedgerow pattern, and shifting the fractal dimension value toward 1. Which

of these processes (or others) is occurring is not discernable from the aerial photographs and GIS coverages as they do not show property boundaries.

Field level observations indicate that the second type of fragmentation of gardens was most common here, though there were a few cases in which gardens were being divided among siblings. A family would clear part of their garden for seasonal vegetable cultivation, usually leaving many trees along garden borders. The scale of the clearings would thus be expected to be contained within the average garden size of .33 hectares, probably as gaps of less than .25 ha. If the pattern is significant, one would expect the gardens' fractal dimension to change in this scale range.

As discussed in Chapter 3, the traditional pattern of gardening in dense blocks of trees would be expected to have a fractal character somewhat analogous to a natural forest. There the pattern of self-similarity extends from a single tree crown through stands of trees to a large extent of forest. Here in gardens with gaps for vegetable cropping, the smallest scaled fractal shape would no longer be a single tree crown. Instead the pattern would change toward a hedgerow or lattice pattern of alternating rows of trees and vegetable plot gaps. The smallest unit in the pattern would be a garden gap (somewhat larger than a tree crown) with a surrounding hedgerow, like a cell in a grid. One would expect the degree of density in garden pattern to shift proportionally across all levels of scale.

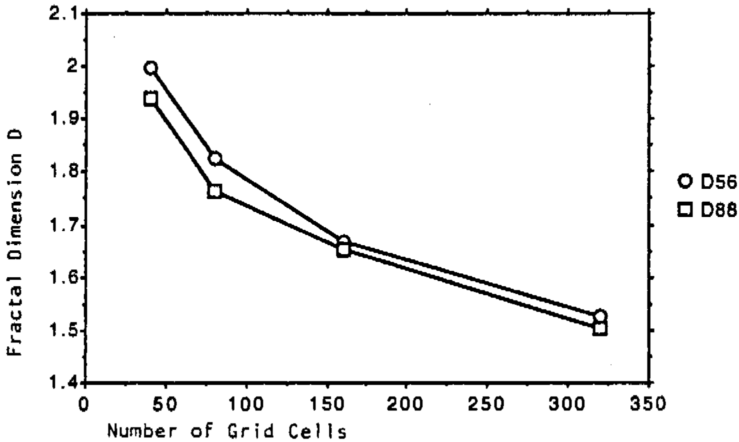
To test this proposition, grids with cells ranging in size from 320x320, 160x160, 80x80 and 40x40 were overlaid to test for differences in 30 year fractal pattern among forest garden polygons over several spatial scales. The results show a clear shift in D toward 1 for all scales, demonstrating an overall reduction in density in garden planting patterns over time (Fig. 4.11).

4.3 Landscape Ecological Implications of Change in Forest Garden Pattern:

In Mirahawatte, this process of forest garden fragmentation has implications both for landscape hydrology and for biodiversity. For the case of hydrology, different vegetation types have different capacities to capture and filter water flows depending on

their structure, density and species composition (Kattelman, 1987). Therefore, an increase or decrease for a given type (unless replaced by a type of similar character relative to

Fig. 4.11 Fractal Dimension for Mature Forest Gardens in 1956 and 1988



hydrological flows) will have an impact, most significantly in direct proportion to the area of change (Forman and Godron, 1986). Thus for the case of perennial vegetation (forests, forest plantations and forest gardens), the hydrological effect is primarily expected to be proportional to area for factors such as capture of precipitation, surface run off and infiltration.

While it is beyond the scope of this study to attempt to quantify hydrologic relationships, one might expect the increase in perennial cover to lead to increased water capture and infiltration into subsurface flows and reduced surface water flows in the landscape (the opposite of the results measured for the highlands as a whole[11]). In several interviews with farmers as well as managerial staff on tea estates, people noted decreases in

[11]Stream flows have not been monitored as extensively as rainfall in Sri Lanka, but increases in runoff/rainfall ratios have been measured and are attributed to deforestation in the mountains. These include increased discharges in the rainy season and reductions in dry season flows, including an overall increase in flows of the Mahaweli river (NARESA, 1991; Professor Maduma Bandara, personal communication).

surface water flows after forest plantations were established. On one large tea estate near Passara, the result was so significant that a long existing nursery station had to be moved for better access to water. At the same time, the localized elements of deforestation may be disproportionally significant, such as when annual cultivation with soil disturbance replaces soil stabilizing perennial vegetation along a stream (e.g. 4.3.1). Thus, an assessment of the influence of woody perennial vegetation's landscape level implications for hydrological flows could be very useful in placement and/or conservation of stands in spatial configurations which contribute to maintaining flows of clear water.

Similarly, changes in forest garden vegetation pattern are likely to affect habitat values for native plants and animals. As patches decrease in size, or as their shapes are altered, the area to perimeter ratio changes with corresponding reductions in interior conditions and increases in edge conditions. Researchers have found significant in many cases, the effects of reduced patch size and increased edge effects on plant and animal species composition, richness, distribution and recruitment patterns (e.g., Burgess and Sharpe, 1981; Opdam et al. 1985). Certain species are interior habitat specialists. It has been shown for a case in the United States, that bird species specialized on the forest interior become extinct in small woodlots due to competition with edge species for food and nest sites, or because of predation by predators from the surrounding landscape (Ambuel and Temple, 1983). Certain forest plants require microclimatic conditions characteristic of the forest interior for germination and seedling growth (Oldeman and van Dijk, 1991). Further, if trees are being removed from gardens, which species are removed? Are people more likely to remove the trees of lesser perceived utility, the volunteers from the forests which have germinated naturally, or the often more economically valuable planted trees?

In addition, as hypothesized in island biogeography theory, populations confined to small habitat patches are most likely to be susceptible to stochastic perturbations in their numbers (MacArthur and Wilson, 1967). Here the degree of connectedness and distance between patches is important for many species (Forman and Godron, 1986; Schreiber,

1988). Connectedness is a quantitative measure of the links between mappable elements (Baudry and Merriam, 1988). Connectivity is a measure of the process of animals moving among landscape elements (Ibid). Distances between habitat patches have been shown to be significant for inter-patch dispersal among birds (Lynch and Wigham, 1984). The richness of carabid beetle species from forest habitats in hedgerows in Europe, for example, has been shown to be significantly linked to distance from forests and connectedness of hedgerows (Burel, 1992). This latter work and other efforts that focused on hedgerows (e.g. Baudry, 1984; Burel and Baudry, 1990) may have significant implications for efforts to maintain the existing high degree of biodiversity in the Mirahawatte landscape's emerging pattern of forest garden fragmentation. While some species are likely to disappear from this landscape with the loss of interior habitats landscape, others may yet survive, as long as a high degree of connectedness of woody perennial vegetation is maintained through hedgerow or lattice planting.

While such maintenance would be desirable, there are signs that the rate of tree planting, having reached a peak, is now on the decline and that fewer and fewer trees will be planted as population grows further. In an example of the method of substituting space for time, the Mirahawatte landscape can be compared with neighboring landscapes in which similar processes of change may be at a different stages of development. A visit to the nearby centers from which vegetable cultivation has radiated, ranging from Welimada and Keppetipola up to Nuwara Eliya, just 10 -25 km away, provides a glimpse of the likely future for Mirahawatte, if present trends continue. There, vegetable plots take up nearly all land. Perennials are limited to thin and often broken chains of hedgerows. Above, on hillside after hillside, the land has been converted to vegetable plots, few with contour terracing to hold the soil. Trees and perennial vegetation are a very minor component of the landscapes.

A further issue of general concern for biodiversity and human health should this trend be substantiated, is the increased use of chemical inputs for vegetable cultivation both

in hillside fields and increasingly in forest garden clearings. The vegetables are temperate climate varieties of potatoes, tomatoes, cabbages, green beans among others. Repeated cultivation extracts nutrients from the soil and farmers are required to replace them to maintain production. No alternative farming practices have been developed in Sri Lanka, and farmers depend upon petro-chemical based, imported fertilizers. Further, the seasonally high levels of humidity are a breeding ground for numerous fungi, mildews and other disease problems which attack the plants. There are numerous insects ready to feast on the crops if heavy doses of biocides are not applied. Again, biological control methods for such problems are just beginning to be developed here (e.g., Integrated Pest Management of insect pests on cabbage by the Agricultural Experiment Station in Bandarawela). I do not have quantitative information on chemical use in Sri Lanka, studies from agroecosystems in other parts of the tropics, such as Thailand, show disturbing increases in pest resistence and in farmers' attempts to deal with the problem by over-applying chemicals, which only makes the problem worse (Rerkasem and Rerkasem, 1989) indirect indicators show rampant abuse of biocides. People generally apply chemicals from backpack sprayers in short sleeves with bare legs and without protective gloves, shoes or masks. Incidences of chemical poisoning are a common and severe health problem in rural areas (Dr. Mahen Muddanayake, M.D. pers. communication). I am not aware of any studies of possible long term effects of the chemical load on human health in Sri Lanka, but similar issues have arisen and have been studied in the uplands in the Philippines and in Thailand. (REFS) The effects on wildlife, particularly on the rich bird life are, so far, also undocumented in Sri Lanka.

In the discussion of Uva vegetation and landuse types presented above, the emphasis was on describing changes in landuse patterns and some possible implications for the landscape's hydrology and its biodiversity. As yet no effort has been made to assess why these changes are occurring. Clearly, changes in homestead management can be expected to reflect environmental and social change such as population growth in villages,

evolution in economic circumstances of private landowners, and government policies directed at agriculture and land management. These will be discussed in the framework of a state factor model in the following chapter.

CHAPTER 5

State Factor Analysis Applied to Hierarchical Aggregations of Forest Garden Vegetation in the Highland Landscape.

Introduction

In the previous chapter, landuse change in the Sri Lanka highlands was discussed using a case study of the Mirahawatte village landscape where vegetation patterns are changing visibly, with likely implications for landscape ecological functions. Forest gardens were highlighted as one type of land use which is managed at the individual household level but which, in aggregation, has influence on flows between ecosystems in the landscape as a whole. In this chapter, I seek to identify factors which may contribute to garden structure and composition and especially to the gardens' changing pattern in the Mirahawatte area. I apply a state factor model to analyze links between forest garden vegetation and various hierarchically scaled phenomena.

After a brief review of homegarden studies in general and forest garden research in Sri Lanka, the first step undertaken here is to provide a quantitative description of highland forest garden vegetation and its variability. This provides a basis for comparing forest gardens in Mirahawatte and their change in pattern with forest gardens across the highlands. Further, it allows for determination of suitable measures of vegetation for state factor analysis. The variables thus defined are then carried on to represent vegetation, the dependent variable in the model.

The second step is to define the state factors which are expected to influence forest garden vegetation and to discuss measures for each factor that will serve as independent variables in the model. In general, the factors of climate (regional, local) and time (village age, garden age), topography (slope, relief, aspect, slope position) and parent material (soil type, soil pH) as well as social organization (access to land, labor, inputs, information, markets and social services) provide a unique set of initial conditions for each garden. Correlation matrices and analyses of variance are applied to narrow the range of

meaningful variables to those correlated with the measures of vegetation. Stepwise regression is used to assess the degree to which the variables chosen fit the model and describe the vegetation.

The influence of these sets of variables is analyzed for various categories or groups of gardens. Thus, for example, I determine how these variables might be correlated with vegetation in gardens of several age classes or in different climatic conditions. In particular, I compare variables for the gardens showing conversion to vegetables and for gardens maintaining the character of dense forest blocks.

The next step in the analysis is an attempt to link implications from the analysis of individual gardens to the effects of state factors on garden aggregation patterns in the landscape at large. In modeling a landscape conceived of as a hierarchically integrated cybernetic system, a large number of potential feedback loops operate at various spatial and temporal scales. For example, the state factors operating on one defined scale (A) can be expected to influence the expression of the state factors creating initial conditions on the scales contained within A. At one scale, for example, climate and parent material are two state factors creating the conditions for a regional biome. Shifting focal level, to a shorter interval in time and a smaller spatial scale, localized climate and a particular soil are two state factors creating initial conditions for a forest stand. Each state factor has expression (or takes a form) commensurate with the scale of the focal level. As in the case of a specific local climate or soil, state factors at smaller scales are determined by (or are localized expressions of) state factors at larger scales.

At the same time, while all factors are expected to play a role in ecosystem forming processes, it is possible that what is a key state factor at one scale is no longer statistically significant at a different scale. If so, then questions about significant factors affecting such issues as landuse may have to be addressed at levels specific to the questions' scale.

As hypothesized by Salthe (1984); Allen and Starr (1982) and others, it is also possible that operating in the reverse direction of increasing scale, the 'dependent ' variable

in aggregation over spatial scale has some feedback which may affect the 'independent' state factor variables. This could include, for example, the question of how, and at what scales of aggregation, groups of organisms such as "vegetation" influence local and regional climate [1], or water flows or movements of wildlife. While at present, it is beyond the scope of this model to incorporate this dynamic feedback, it is the potential to identify and ultimately manipulate the feedbacks for sustainable landuse which are at the core of this effort.

Clearly, a large number of variables could be chosen to fully test this model. Limitations in available time and data restrict this analysis. The results are not intended to be conclusive, but rather to demonstrate the possibility of this approach and its potential utility. The state factor analysis focuses on one landuse, forest garden ecosystems, occurring in several landscapes in one region, at one point in time, and the influence of state factors at several scales of expression as forest gardens are aggregated in the landscape.

In theory, the sample of gardens in this study could be aggregated in any number of ways. The method of aggregation has been shown to strongly influence results of analyses (Govil, 1991). Therefore, certain rules are needed to define meaningful sets of aggregation for the purpose at hand. Here the focus of interest is on hierarchically nested aggregations of gardens in space and time, from the individual garden through the regional landscape, and the degree to which the critical state factors might change as the scale of aggregation changes. Thus, the aggregation method must be hierarchical according to the principles of individuality, nesting, constraint capability, incommensurateness and robustness (Chapter 1). Three types of aggregation with landscape ecological meaning which fulfill this constraint are relevant here. These are hierarchies of human organization (household,

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[1] One often debated question in this regard is whether deforestation leads to reductions in rainfall and further vegetation change toward more xeric types (for a detailed discussion of this issue for the case of India see Puri et al, 1990).

village, division, district, province, nation), of spatial scale (garden, patch of gardens, landscape, region) and hierarchies in time (new gardens and homesteads less than 20 years old; gardens 21 - 99 years old and gardens over 100 years). In addition, as each increase in scale of aggregation includes more cases, one set of regressions for completely randomized small (30), medium (90) and large (173) clusters of gardens is analysed as a control. Particular emphasis is given to contrasting results for aggregating gardens in the Mirahawatte landscape with those from the other regions of the highlands. These aggregations, their analysis and the results are discussed in 5.4. Variation in results is important because it may have implications for landuse planning and policy such as, in Mirahawatte, efforts to promote perennial cropping or other environmental conservation measures. The implications of the analyses will be discussed in Chapter 6.

5.1 Homegarden and Forest Garden Research

Gardens and horticultural traditions are common to many cultures, often playing significant cosmological and political as well as socio-cultural and economic roles (e.g., the Garden of Eden; the Hanging gardens, French formal and English gardens). Study of gardens in horticulture, landscape design, art history and other fields has a long history. Focus on tropical homegardens and mixed perennial cropping systems in anthropology and ecology is more recent. Yet, there are by now detailed descriptions of garden agro-ecosystems from Africa (Fernandes et al, 1984; Campbell et al, 1991); South America (Alcorn, 1984; Deneven and Padoch,1987; Posey, 1984; Gliessman et al, 1981); and for Asia from Bangladesh (Leuschner and Khaleque, 1987), from Indonesia (Terra, 1953; Wiersum, 1982; Anderson, 1982; Michon et al, 1986), from the Philippines (Conklin, 1957), and from Papua New Guinea (Rappaport, 1984), to name only a few.

Mixed cropping with perennials in homestead gardens is an ancient practice in Sri Lanka (Chapter 2). Such gardens are found throughout the island, varying in structure and composition with elevation and climate. Today, the most commonly described model for the forest garden in Sri Lanka is the Kandyan garden. Kandy district, situated in the

middle hills with a warm climate averaging 24.3 C (Domros, 1974), and high average rainfall of 2,656 mm per year (GSL, 1990), is an ideal location for many perennial horticultural crops including cloves, nutmeg, pepper, cardamom and coffee, as well as many marketable fruits (Weragoda, 1987).

The majority of the recent interest in the forest gardens, particularly regarding their potential economic value, has focused in Kandy (McConnell and Darmapala, 1973; Illangasinghe, 1979, Jacob and Alles, 1987, Perera and Rajapakse, 1991). The Department of Export Agriculture (DEA, earlier the Department of Minor Export Crops), which is in charge of horticultural crop extension, is headquartered in Kandy. Much of its research is undertaken nearby at the Central Research Center, Wariapola, Matale. The DEA staff have developed a mixed species agroforestry cropping model in Delpitiya (Kandy District) which has been the subject of several detailed studies, primarily focused on economic yield (Bavappa and Jacob, 1986; de Silva and Premaratne, 1985).

In addition, there have been several descriptive studies inventorying garden systems in other areas, such as the North Central Province of the Dry Zone (Weerakoon, 1991); and Gampaha in the lowland Wet Zone (Kendaragama, 1983). A study on intercropping systems under coconuts (Liyanage et al, 1984) was supported by the Coconut Research Institute in the lowland Wet Zone. There have been studies comparing forest gardens with natural forests. Rajapaksa (1987) inventoried forest gardens in several villages in Kandy district and compared their structure and composition with values for Udavattekalle Forest Reserve in Kandy. Senanayake (1987) presented reports on fauna for several vegetation and landuse categories including forest gardens and natural forests in the upper Uva Basin. Everett (1987) compared structure, composition and management of homegardens in one village in the upper Uva Basin with an idealized model of forest structure and function to assess the ecological sustainability of forest garden land use.

A series of studies of homegardens as a traditional landuse practice from an interdisciplinary, ecological and socio-economic perspective, primarily based on

comparative data from two villages in the Knuckles area of Kandy District, have been undertaken by Wickramasinghe. She has researched homegardens as a traditional landuse practice (1990 a, b); studied participatory selection of trees for improvement (1991c; 1992); discussed gender issues in management (1991a); and compared homegardens in Sri Lanka, Bangladesh and Nepal (1991b). The research presented here draws much from the ideas and suggestions raised in this latter work and on Wickramasinghe's earlier reports on the ecological impacts of farming in the hill country (1988; 1989).

5.2. Forest Garden Vegetation - An Inter-Regional Comparison

Two purposes are pursued in this section. Results presented in Chapter 4 indicate that a change in forest garden pattern is occurring in the Mirahawatte landscape. Before any departure from an established pattern can be proposed, it is important to discuss in greater depth what forest gardens are and their general level of variation in structure and composition. Therefore, commonality and variability in highland garden vegetation structure and composition are analyzed within and between villages, and regionally between landscapes. The most widely applicable qualitative and quantitative measures of garden vegetation from these analyses are then selected as variables to represent vegetation in the model. Vegetation parameters, including species composition, frequency, abundance, structure, density, canopy closure and ground cover, are compared for 173 gardens surveyed in eight highland villages.

5.2.1. Species Composition:

A total of 143 species of woody perennials[2] were identified in the 173 gardens surveyed (Appendix 2: Species Lists).

The average number of species per garden decreases with decline in regional rainfall and average temperature. Thus, there are an average of 40 tree species per garden

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[2]A few non-woody species which are classified by farmers as 'tree' and which are grown in clumps were included (banana, manioc and sugar cane).

in the Wijebahukande and Ravanagoda[3], 39 species in Maussagolla and 30 species in Mirahawatte (Table 5.1).

Of 48 families, Leguminosae is represented by the most species (13), followed by Myrtaceae (9) ; Rutaceae (9); Guttiferae (7), Moraceae (7); and Euphorbiaceae with 6 species. There are five species each for the Lauraceae, Palmae and Rubiaceae; Anacardiaceae and Zingiberaceae have four each. Families represented by three species are Apocynaceae, Meliaceae, Solanaceae and Sapindacea. The Annonaceae, Araliaceae, Bignoniaceae, Elaeocarpaceae, Malvaceae, Myristicaceae, Piperaceae, Sapotaceae, Sterculiaceae, Tiliaceae and Verbenaceae are each represented by two species. The remaining 22 families have one species each found in gardens.

TABLE 5.1
Average Values for Key Garden Vegetation Parameters in Village Gardens

village	village age	#spp	#ind	canopy (%)	ground (%)	size (ha)	gdn age
Ravanagoda	400	40	437	86.6	78.1	.42	83
Wijebahukande	400	39.5	349	77.1	78.9	.38	69
Maussagolla	400	38.8	283	79.4	78.3	.29	91
Mirahawatte	100	30	245	56.1	72.6	.29	52
Rogersongama	35	37.2	207	68.2	83.2	.33	44
Balathotelle	25	24.1	103	20.3	53.8	.29	19
Matatila	20	13.9	44	11.2	59.8	.54	12
Maussagolla-C	10	16.3	42	30.0	na	.04	9

spp refers to the number of species per garden; #-nd refers to the number of individual trees per garden; canopy is the percent crown cover in the garden; ground is the percent litter and plant cover below 1 meter; size refers to garden area in hectares; gdn age is garden age.

5.2.2. Frequency and Abundance: A Classification of Species According to Occurrence along a Climate Gradient

The fifteen most commonly occurring woody perennial species, based on full census counts in gardens in the survey, are noted by village in Table 5.2. While several of the most abundant species are found throughout the regions in the study, others are very

[3]Older villages have more mature and species diverse gardens, a key issue here discussed in detail below.

restricted in their distribution along the climatic gradient between the villages in Welimada, Passara, and Kotmale divisions. In order to assess the gradient's influence on species composition, each species was classified according to its relative frequency and abundance (Appendix 2: Species List).

Some species such as Artocarpus heterophylla (jak) are both frequent in that they occur in many gardens all along the gradient, and abundant in that they have numerous individuals in each garden in all villages and may be categorized as Frequent/Abundant. Others are less numerous but still common all along the gradient and could be called Frequent/Less Abundant, for example, Callophyllum tomentosum or Flacourtia ramontchii; still others are found in all villages but are not frequent nor are they very abundant, these are termed Infrequent/Less Abundant. Yet other species are very numerous in one or two localized regions, but not in all three and are called Localized/Abundant, for example, Garcinea cambogia or Litsea ovalifolia. Finally, there are species, such as Phyllanthus emblica, which are narrowly localized in occurrence and are not very numerous in the areas studied here and are termed Local/Infrequent. See, for example, graphs for Artocarpus heterophylla, Cedrella toona and Litsea ovalifolia (Fig. 5.1). Within the categories there is still room for variation. For example in the Frequent/Abundant group, some species are evenly distributed (Artocarpus heterophylla, Mangifera indica), while others reflect the climatic gradient in their local numbers (e.g., Cedrela toona). In general, the microclimatic variability is reflected particularly clearly in the regionally limited distribution of indigenous tree species in gardens (Litsea ovalifolia).

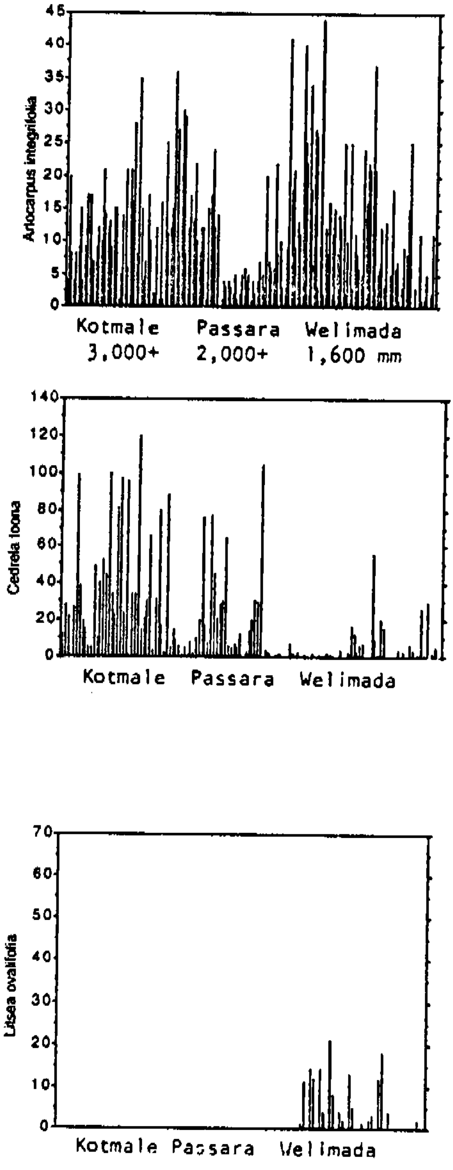
There are additional methods of analyzing such variation in greater detail (Grieg-Smith, 1983; Mueller-Dombois and Ellenberg, 1974). However, for the purposes of this study these results demonstrate that there are considerable variations in species composition occurring along the climate gradient. The climate significantly influences the potential choice of species, including potential cash crops, in gardens along the gradient.

Table 5.2.The Fifteen Most Frequently Occurring Garden Perennials by Village*

overall frequency (n=173 gardens)	Wijebahukande Ravanagoda (40)	Rogersongama (n=10)	Maussagolla (n=19)	Maussa-col (n=12)	Mirahawatte (n=63)	Balathotella (n=12)	Belipola (n= 20)
1. Musa spp.	Areca catechu	Artocarp. het	Caryota uren .	Artocar het	Artocar. h.	Persea am.	Psidium gu.
2. Artocarpus hete.	Artocarpus heter.	Caryota urens	Areca catec.	Musa spp.	Musa sap.	Artocarp. h.	Gliricidia
3. Persea amer.	Caryota urens	Cedrela spp.	Artocarp. het.	Mangifera .	Persea amer.	Mangifera	Musa spp.
4. Psidium guajava	Cedrela spp.	Coffea spp.	Cedrela spp.	Manihot es	Psidium gu.	Musa spp.	Wendlandia
5. Mangifera indica	Coffea spp.	Michelia cha.	Litsea ovalifo	Cocos nuci	Litsea oval.	Psidium gu.	Artocarpus
5. Michelia champa.	Michelia champ.	Musa spp.	Mangifera in.	Garcinea ec.	Neolitsea in.	Gliricidia	Carica pap.
6. Carica papaya	Musa spp.	Mangifera	Musa spp.	Persea am.	Anona sq.	Eucalyptus	Manihot
7. Cedrela spp.	Mangifera indic.	Macaranga	Persea ameri.	Punica gr	Michelia ch.	Cedrela spp.	Persea amer.
8. Coffea spp.	Chrysoph. rox	Citrus sinen. .	Coffea spp.	Cedrela sp.	Carica papa.	Phyllan. em.	Michelia ch.
9. Caryota urens	Psidium guajava	Eriobotria jap.	Chrysoph. rox	Areca cat.	Mangifera	Wendlandia	Neolitsea in.
10. Chrysophell. rox	Erythrina litho.	Chrysoph. rox.	Michelia cha.	Hibiscus	Eucalyptus	Anona sq.	Erythrina lith.
11. Neolitsea invol.	Eugenia caryoph.	Persea ameri.	Punica gran.	Psidium gu.	Grevillea r.	Grevillea rob.	Grevillea rob.
11. Erythrina litho.	Carica papaya	Albizzia falc.	Carica papa.	Cassia sp.	Gliricidia s.	Carica pa.	Phyllanthus sp.
12. Areca catechu	Persea amer.	Eugenia cary.	Cocos nucifera	Erythrina	Coffea spp.	Cassia sp.	Anona squam.
13. Anona squamosa	Citrus sinensis	Passiflora ed.	Psidium guaj.	Carica pa.	Caryota ur.	Michelia ch.	Eucalyptus
	Neolitsea involuc	Psidium guaja.		Michelia ch.			
	Elettaria cardam.						

*See Appendix 1: Species Lists for full names.

Fig 5.1 Distribution of Several Species Along the Climate Gradient



(x axes are individual gardens. y axes are numbers of trees of the species per garden)

Villagers in the Kotmale area, for example, commonly grow cloves and nutmeg (among other crops) for cash income. These species will not yield much in the climatic conditions prevailing in Mirahawatte, in fact it is difficult even to keep them alive. It is seasonally too dry and windy (NSRC field data). Water availability will influence the maximum density and standing biomass capacity on a site as well as growth rates for timber production. Cedrella toona (Toona), for example, is a common tree in all villages surveyed. Based on my interviews with farmers in both regions, however, the estimated average rotation age for 18" diameter Toona in Kotmale is 15-20 yrs, while in Mirahawatte it is over 30 years[4]. Such variation influences the potential economic yield from forest gardens. In Wijebahukande and Ravanagoda there are a number of people employed in logging, carpentry and furniture making, and forest garden owners can expect to make a periodic income from sustained yield harvesting. In Mirahawatte, most forest gardens also have trees valued for timber. However, they are harvested irregularly, either for a household's own use for construction, or for sale in an emergency situation when cash is needed. They serve as security rather than as a source of steady income. This influence of climate on crop potential has important implications, e.g., for agricultural extension related to forest gardens.

5.2.3. Density and Species Richness: Area Dependent Measures

In forest ecology, density is defined as the number of individuals per unit area (Grieg-Smith, 1983). Quantifying density and other area dependent values such as species richness (the number of species per unit area) for gardens poses some analytical problems.

In inventory plots of equal size in a natural forest, one would expect fairly continuous between-plot density relationships and a predictable species/area curve for a given forest type (Lamprecht, 1989; Whitmore, 1975). In my study, the garden was the unit of analysis, and since the size of gardens varies, the area to be inventoried is not the

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[4]Growth and yield data for Cedrela toona or other non-exotic tree species for highland Sri Lanka are not available (pers comm. Forest Department Archives)

same for all cases. The smallest 'gardens' are on small house plots of 1/20 hectare in size. The largest gardens cover 1.25 ha.

In an earlier study, I found that multiplying the number of species or individuals by garden area to achieve parallel plot size does not result in the expected forest-like species/area or density relationships (Everett, 1987 here Fig 5.2; 5.3). A 'species/area' curve for gardens shows that garden size influences species composition very differently than forest plot size. The curve has a more extreme shape than typical for natural forests, with the number of species and individuals very high for small and mid range gardens and flattening (and even dropping) for large gardens. In other words, there are a larger number of very small gardens with high diversity and density and there are large gardens with lower species diversity and relative density than would be expected for data from natural forest ecosystems. These results indicate that people with less land (smaller gardens) use available space more intensively. Therefore, sampling with equal plot sizes would obscure the importance of land tenure for forest garden vegetation. Instead, both the total number of individual trees and the number of species of woody perennials were counted for each garden.

Fig.5.2 Average Number of Species per Area by Garden Size*

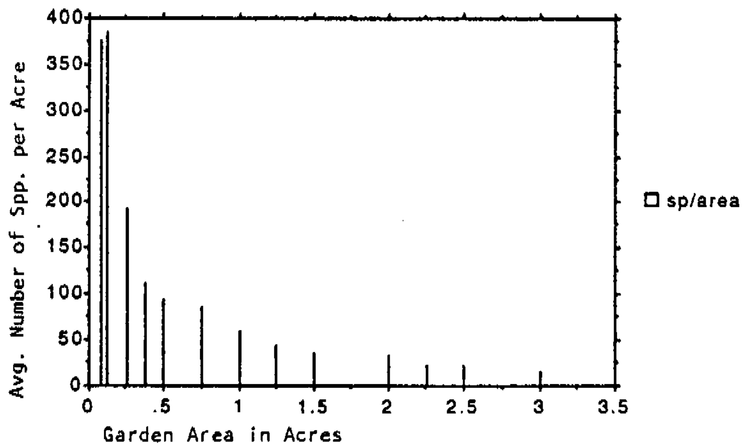
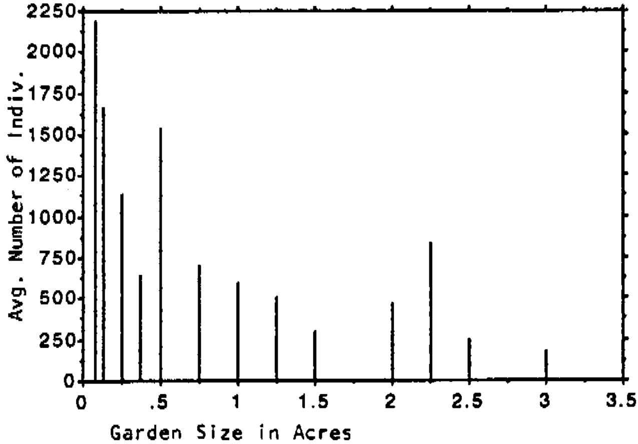


Fig. 5.3 Average Number of Individuals per Area by Garden Size*



*values for garden size are in acres

Fig 5.4 Average Number of Species per Garden by Garden Size

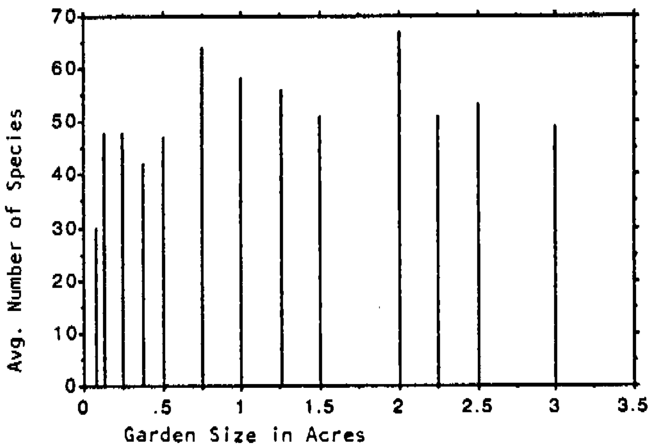
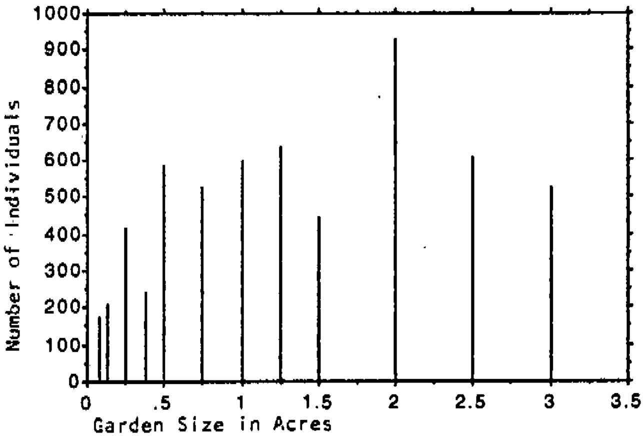


Fig. 5.5 Average Number of Individuals per Garden by Garden Size



Size of gardens is not necessarily the most important factor related to the number of individuals and species richness per garden (Fig 5.4; 5.5). However, a trend toward lower density in drier areas is visible. There is further a clear trend toward lower density in the newer colonies than in the older villages (analysis of variance shows significant differences at the 95% level). Here, a variety of socio-economic factors may be influential.

5.2.4. Structure

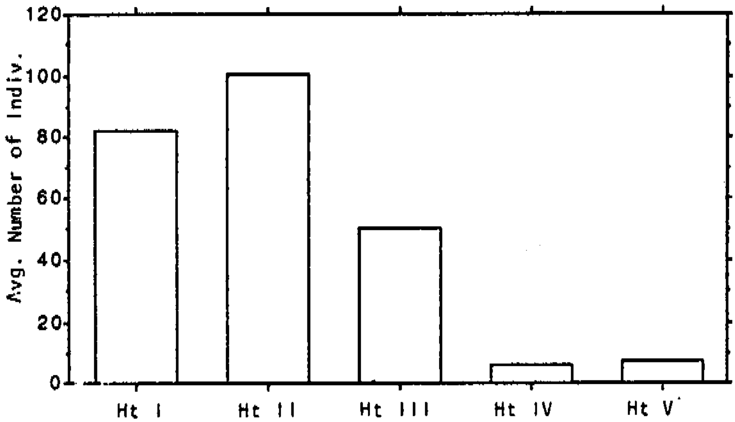
Garden structure, as represented by height class distribution of trees, is an important descriptor of vegetation. In the tropics, height classes are used also as an indirect measure of age class distribution, because age classes are difficult to estimate by coring and counting annual growth rings of trees in less seasonally distinctive climates (Lamprecht, 1989; Richards, 1952).

In the Kotmale area the data averaged in four classes for all gardens create a curve shaped like a reversed 'J' - an age/height class distribution one would expect from an uneven aged, mixed species forest (Lamprecht, 1989; Whitmore, 1975; Daniel et al, 1979). In Mirahawatte and in Maussagolla, the first height class (0-2 meters) is less well represented and the 2-5m height class predominates (Figs. 5.6 - 5.8). In the very densely

planted Maussagolla gardens, the understory shade and deep litter layer [5] may reduce the number of seedlings in the ground layer. In Mirahawatte, the more xeric climate may reduce germination success.

In general, the upper canopy of the gardens is higher in the wetter areas, but the height classes chosen, especially the 15-25 m class, do not allow for a very precise quantitative assessment. In the more xeric Bandarawela/ Welimada area, most of the tall trees are Eucalyptus spp. while the height range of taller tree species is greater in the other areas. In addition, there is phenotypic variability: trees such as jak grow taller in wetter, more densely planted gardens. The low numbers of regenerating trees (Ht I) may be a result of the increased tendency to clear land around trees and grow vegetables.

Fig.5.6 Average Height Classes for All Gardens



Height class I = 0-2 meters; II = 2-5 meters; III = 5-15 meters; IV = 15-25 Meters and V - > 25 meters. The label '#indI' refers to the average number of individual trees per garden of height class I.

[5]Deep litter layers in moist conditions inhibit germination and promote fungal attacks (e.g., damping off).

Fig.5.7 Average Height Classes for Trees in Gardens in Welimada

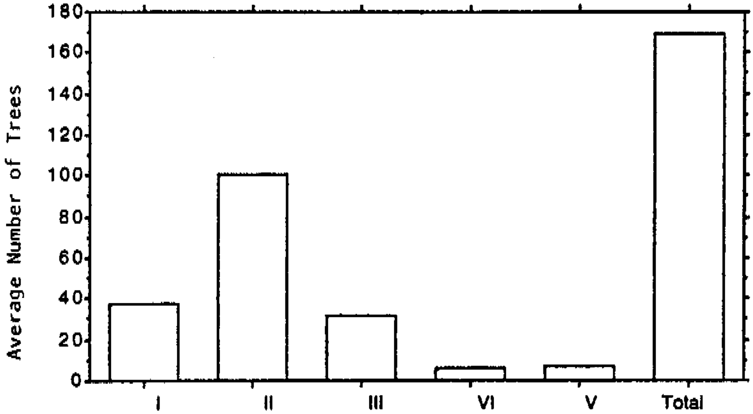
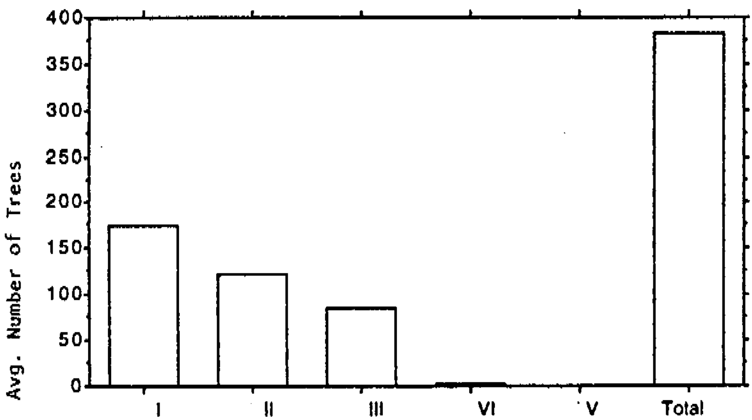


Fig.5.8 Average Height Classes for Trees in Gardens in Kotmale Villages



In general, however, these data show that the gardens on average have a loose three tiered structure with an open canopy at 15-25 meters, with a dense understory of trees with

a more closed canopy at 2-15 meters, and a large number of ground level plants. The ground level plants are a mix of regenerating trees and many smaller shrubs and herbacious plants such as coffee and bananas.

5.2.5. Crown Closure and Ground Cover

There are other indications of the forest-like structure of the gardens. Crown closure (measured with the line intercept method) and ground cover (percent leaf litter and percent live plants measured in quadrats along the transect) are quite high (Table 5.1), particularly when one considers that 70% canopy closure is a commonly applied (though arbitrary) criterion for 'closed' forests (Richards, 1952). The values for crown closure are significantly lower in the more recently settled colonies in each region.

5.2.6. Summary of Variation in Forest Garden Vegetation

While the basic pattern of forest gardens as blocks of mixed species gardens of predominantly woody perennials around a house is common to all villages, it is evident (Table 5.1), that there are significant degrees of variation in garden vegetation, especially in species composition, across the regions surveyed. Gardens in the Welimada study area, even in the comparatively old village of Mirahawatte, are less dense, less species rich and have a lower percentage of closed canopy than the average in other villages. Furthermore, the species composition changes considerably from the wetter villages to the settlements in this relatively dry landscape. In Table 5.1 gardens were grouped or aggregated by village; other choices of aggregation variables may be equally interesting. In particular, factors such as climate and village age seem to influence regional garden structure and composition.

5.3 State Factors for a Model of Forest Garden Vegetation

In the following section, variables of interest for a state factor model of initial conditions for forest garden ecosystems are introduced. Climate, Time, Organisms, Topography and Parent Material are discussed as state factors. I attempt to integrate

variation in the form taken by state factors at different scales. Average values for all variables are listed by village in Table 5.10.

5.3.1 Vegetation Parameters for the Model - The Dependent Variables

In selecting the variables suited to represent vegetation, I sought measures with ecological meaning for the questions of landscape fluxes and flows for biodiversity and water movement. Species richness and density are two commonly applied measures for vegetation from which ecological meaning can be inferred.

Tree species richness in gardens has qualitative implications for the ability of an ecosystem to support a diversity of life forms. Forest plantation systems with low tree species diversity in the Upper Uva Basin, for example, have been shown to support few birds and a very limited soil invertebrate diversity, while the numbers of such fauna are quite high in forest gardens (Senanayake, 1987). The variation in garden size affects species richness but not significantly (the correlation between species per garden and garden size is +.143 for all cases). Therefore species richness is a good variable to represent qualitative values of diversity in vegetation.

Density is a quantitative indication of structure and biomass in a garden, with implications for nutrient cycling, interception and filtering of precipitation, and habitat values, such as proportion of shade for understory plant species or cover for animals. Yet, for the density measure of number of individual trees per garden, an area dependency linked to land tenure is present. Therefore an accepted and area independent measure for cover, canopy closure, will be used as an alternative to density (Barbour, Burke and Pitts, 1980:172-176). These variables may be seen as indicators of the ecological structure and function of vegetation in forest gardens (Everett, 1987).

5.3.2. State Factors - The Independent Variables

Correlation analyses were run for all variables. A matrix was used to compare correlations between dependent and independent variables, and among independent variables under consideration for the state factor model. Analysis of variance was carried

out for more detailed study of categorical variables. Those variables with the highest correlation to the vegetation parameters of species richness and canopy closure, and the lowest mutual correlation were selected for step-wise multiple regression. Staview software (Brainpower Inc., 1986) was used for statistical analyses.

The process applied to select variables is described separately for each of the five state factors. In order to emphasize implications for the Welimada landscape (Mirahawatte, Balathotelle and Matatila villages), particular reference is made to the expression of the variables there.

State Factor Topography

In general, the topography in the highlands is steeply dissected, with little average regional or landscape level variation for the three (administrative) divisions chosen. Thus topography is a constant for analysis at these levels of scale. Variation is more apparent at a localized level, where it is expected to influence conditions for individual forest gardens. Variables measured to represent localized topography were slope position, relief, aspect, and angle of slope. Initially, frequency distributions were run for all variables.

Slope position, has three categories top, mid and lower slope. Eighty-two percent of all gardens are situated in mid slope. This finding supports earlier descriptions of the general settlement pattern for the highlands at large, in which the lower lying land is more likely to be irrigable and used for field crops, while homesteads are situated above, on mid slope. This pattern holds for the Welimada villages, though the recent colony of Balathotelle has a larger than typical proportion of households (44%) situated at the top of the slope (probably an artifact of land available). The highly skewed tendency toward mid-slope position limited this variables' explanatory value for the state factor model and it was removed from further consideration.

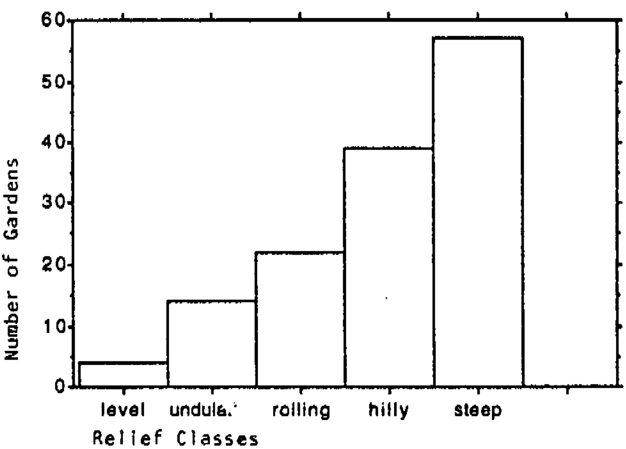
Relief, classified into five categories of 'level', 'undulating', 'rolling', 'hilly' and 'steep', was a more promising variable. Relief categories are indications of the localized topography, the relative ruggedness of the terrain. Gardens on flat land are classed as

'level'. 'Undulating' is applied to gardens with slightly sloped and uneven ground. Gardens are defined as being in 'rolling' terrain when the ground is still relatively gentle in average slope but with clear rises and drops in the terrain. 'Hilly' is a more extreme case, for steeper slopes and landforms including hillocks and draws. The category steep was applied to more dissected terrain with abrupt slopes. The frequency distribution showed 87% of all gardens on terrain in the rolling, hilly and steep categories (again, flatter land is less likely to be used for gardens (Fig. 5.9). Analysis of variance for terrain and canopy closure shows statistically significant differences at the 95% level for closure between rolling and steep, as well as between hilly and steep terrain.

This pattern is consistent with that found in Mirahawatte. Both Matatila and Balathotelle, however, have the great majority of their gardens in steep terrain (80% and 92% respectively). Relief was carried forward for the analysis of all topographical variables in the correlation matrix.

'Aspect' proved to be an interesting variable. Frequency distributions show that people prefer to locate gardens on South, East and Southeast facing slopes (Table 5.3). There is a significant correlation between aspect and garden

Fig. 5.9 Frequency Distribution of Gardens by Relief Category



age (at the 95% level) with the older gardens on average found facing South and East. This indicates that people chose sites with these more desirable aspects first. There may be several reasons for this preference. In the Uva Basin villages, protection from the wind may be one reason; the strong summer dry winds come over the mountains from the West (e.g., Domros, 1974)[6].

Location of gardens in Mirahawatte corresponds with this trend toward South and East facing aspect. In Matatila, where the driving force behind the recent settlement seems to be the potential for vegetable cultivation in proximity to the river (Fig. 4.4 and 4.5), and in Balathotelle, where the settlement is restricted to an area set aside for village expansion from the Dyraaba tea estate, the link between aspect and settlement does not hold. 'Aspect' was carried on as a variable for the state factor model.

Table 5.3 Frequency Distribution of Gardens by Aspect, Average Crown Closure and Garden Age.

Aspect	No. of Gardens	Percent	Crown Closure %	Garden Age
E	41	29	77	70
S	24	17	75	77
SE	24	17	38	32
NW	15	11	27	25
N	14	10	57	30
NE	13	9	60	53
W	6	4	32	30
SW	3	2	55	100

(note: W and SW have very low n)

Slope was measured as a continuous variable and showed a significant correlation with crown closure (-.306) and species richness (-.298). Regression analysis for percent slope and crown closure is significantly positive at the 90% level in Ravanagoda,

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[6]There may also be a cosmological significance. East is seen as having a beneficial influence and the front doorway of a house usually faces this direction. West is commonly held to be the direction of death and, for example, one avoids sleeping with one's head to the West. (K. Yappa, pers. comm). The influence of spiritual beliefs on landuse location in landscapes has been documented elsewhere (e.g. Lovelace, 1985).

Maussagolla and Maussagolla-Colony. The regression is negative at the 95% level for the Welimada villages (the regressions are positive but insignificant for Wijebahukande and Rogersongama). The former villages are all in high rainfall areas. Here it is possible to grow trees on very steep slopes as moisture is not limiting. Further, in the Kotmale area, landslides are common. Rogersongama, for example was founded by relocating settlers after landslides had destroyed several villages in the valley, and in the late 1980's many Rogersongama households were again forced to resettle due to slope instability. These hazards may prompt people to keep dense tree cover to stabilize the soil wherever possible. In the drier Welimada villages, moisture is limiting in the shallow soils on the steeper slopes, and it is much more difficult to establish trees.

'Slope' and 'relief' are inter-correlated variables, as relative slope was one of the decision criteria in defining 'relief'. When correlations between values for vegetation and 'slope' and vegetation and 'relief' were compared for all cases, 'relief' was less correlated with the vegetation than 'slope' (-.149 to -.306; and -.298 and -.221 respectively). In summary, 'slope' and 'aspect' are the variables selected to represent topography. In general, the preferred topographical locations for gardens with high values for vegetation variables are moderate slopes with eastern and/or southern exposure.

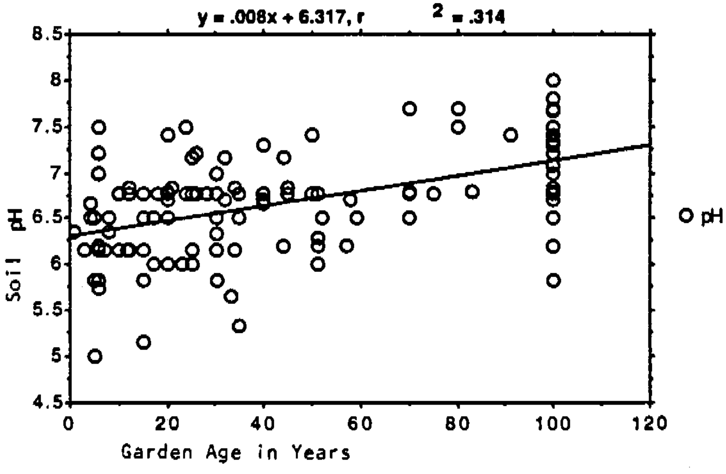
State Factor Parent Material :

Most of Hill Country, including the areas in this study, belongs geologically to the Highland Series, a Pre-Cambrian formation of metasedimentary rocks (e.g., quartzites, marble, garnet-sillimanite schists) and chemockitic gneisses (Cooray, 1967). Despite the age of the parent material, much relatively recent uplifting has exposed new weathering surfaces and the mineral content of present day soils is higher than would be expected in this tropical climate (Panabokke, 1977). Climate is the major factor which has led to the development of several major soil types on this parent material (Cooray, 1967; Panabokke, 1977). In the landscapes studied here, Red-Yellow Podzolic soils (Ultisols) predominate (Femando, K.S. 1969). In Sri Lanka these are typical Wet to Intermediate climate forest

soils in which the moisture profile rarely dries out below a 75 cm rooting depth. In general, especially under forest or perennial cover (including mixed forest gardens), this soil is associated with low erosion rates, though soil creep in steep terrain in high rainfall areas occurs (Panabokke, 1977). Erosion occurs where farmers cultivate on steep slopes (Ibid.).

I measured soil pH in each garden as an indicator of localized soil fertility representative of the parent material and soil formation processes in the area. This provided interesting information, but proved to be a poor choice of measure for an independent variable representative of initial conditions for vegetation. Soil pH is highly correlated with vegetation, especially canopy closure. It is difficult to separate the influence of soil on vegetation and vegetation on soil. Garden age is clearly linked to soil pH as demonstrated by the regression of garden age and pH (Fig. 5.10). Older gardens, with longer periods of vegetation establishment have significantly higher soil pH values ($r2 = .314$; sign. at 95%)[7].

Fig 5.10. Regression of Garden Age and Soil pH Values



[7] New gardens are frequently established on steep slopes of *patana* grassland which have very thin, hard soils of a very reddish, oxidized color suggesting little organic matter and low fertility.

Table 5.4 One Way ANOVA of Measures of Vegetation by Climatic Zone

village*	rainfall(mm)	#spp/gard	crown closure %
WET	3,607	39.2**	79.1*
INT	2,382	30.2	60.3*
DRY	1,610	26.2	42.8*

* WET = Kotmale villages; INT = Passara; DRY = Welimada
** statistically significant between region differences (95%)

The differences between categories are significant at 95% for the number of species per acre between Wet and Intermediate villages, and between Wet and Dry villages. Species richness is not significantly different in Intermediate and Dry region climates. Crown closure increases significantly from the Dry to the Intermediate and Wet village categories.

At the scale of individual garden ecosystems, climate is expressed as microclimate determined by a combination of slope position and aspect (exposure), elevation, season (wind), vegetation and other variables. In the Uva Basin, the dry season wind dessicates vegetation and for tea cultivators produces what is known as the 'flavour season' during which the highest quality tea is harvested (Domros, 1974).

I use rainfall data from tea estates neighboring the village study areas to quantify climate. These data represent rainfall averages from 30 years of daily measurements. These data are representative at the landscape scale. At the sub-landscape level, a great degree of variation at the microclimatic level is expected in this steeply dissected topography. I do not have data at this scale. In future, in order to begin to quantify this variation, rain gauges would have to be set up and monitored concurrently in as many locations as possible in each village. In the state factor model climate is held constant for the localized and within landscape levels and rainfall is applied as a measure of climate between landscapes.

State Factor Time

Time horizons of human landuse are limited to relatively short periods when compared to scales appropriate for geologic or evolutionary change. Forest gardens have emerged as people have begun to settle in the mountains. In some cases, people have had several centuries to adapt the system to their environment. In other areas, settlements are only a decade or two old with few gardens having mature trees. Thus, the age of settlement, here called 'village age', is likely to be significant as a factor correlated with vegetation between villages in a given landscape and between landscapes in different regions.

The second time scale of interest, particularly at the within-village scale, is garden age. The two scales are correlated (.625), even nested in a hierarchical sense (a garden cannot be older than the settlement). Both variables are correlated with species richness (village age = .577; garden age = .493) and with canopy closure (village age = .7; and garden age = .573).

Age of village settlement is likely to affect a range of variables linked to landuse. In a new settlement socio-economic relationships are less well developed (Perera, 1985), which may influence flows of labor, seeds, and knowledge regarding forest gardens. In order to ensure that the influence of village age on vegetation could be distinguished from that of other state factors, such as climate, old and new settlements were chosen in each of the three regions studied. In all three cases, there was at least one main village of focus, a relatively old, established settlement, as well as at least one relatively recent colony (Table 5.1).

To check the association of village age with vegetation, villages were grouped into two categories, 'OLD' and 'NEW'. Rogersongama, Maussagolla-Colony, Balathotelle and

Matatila were 'NEW' villages, the rest fell into the 'OLD' group[1]. The values for each factor were averaged.

Table 5.5 ANOVA of Vegetation Variables by Village Age

Factor	Age	Species Richness	Crown Closure
OLD	> 99 years	34	66.3
NEW	< 99 years	26	42.3

(Species richness refers to the number of species per garden, crown closure is the % of canopy closure per garden.)

The differences in values between old and new villages are significant at the 95% level for both vegetation variables.

The only measure available for garden age was based on interview responses from garden owners. When garden establishment predates present owners it is difficult to gain an accurate assessment of garden age. Often people say their gardens are many generations old. In gathering this information, I wrote down peoples' estimates and when they said that a garden was 'generations old', I put it into a category of '100 years or more'. The frequency distribution for garden age reflects this difficulty in its bimodal skew (Fig. 5.11). The frequency distribution for Mirahawatte, by contrast, shows a surge in settlement in the 1950's and 1960's (Fig. 5.12). This trend is reflected clearly in the GIS coverages in Chapter 4.

State Factor Organisms

The state factor 'organisms' includes plants, animals and people. Vegetation is strongly affected by soil invertebrates and micro-organisms, by herbivory, by animal pollination, and by seed dispersal agents. For animals and especially for plants, the potential sources of propagules for a garden are global (e.g., with agricultural crops), though given the laissez-faire management style of most forest garden owners, propagules from species already existing

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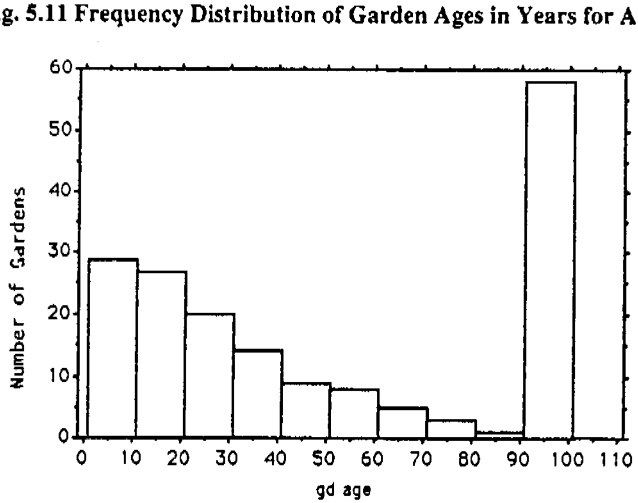
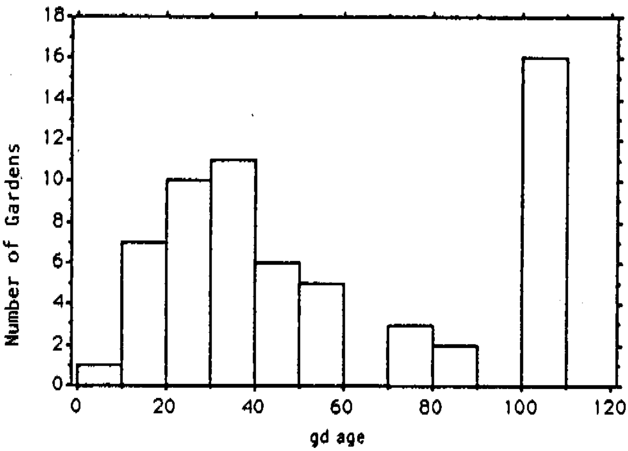
[1]Note that 'old' is a relative term. Mirahawatte at 100 years is new by comparison with Wijebahukande at over 400 years. Still for the historical reasons described in CH2, Mirahawatte is the oldest settlement in its area. (It may therefore be difficult to separate impacts of village age and and climate between regions)

Fig. 5.11 Frequency Distribution of Garden Ages in Years for All Villages*



*Count indicates the number of gardens for each of 10 age classes (90-100 = 90-100+).

Figure 5.12 Frequency Distribution of Garden Ages in Mirahawatte



in the surrounding larger scaled area (landscape, region and island respectively) will be most likely to predominate. A great number of such organisms influence initial conditions in any ecosystem. However, in an agroecosystem or an agroforestry system

such as forest gardens, people are also very influential. People select which species to plant, where and when, as well as which ones to weed out or allow to grow. They often import species from beyond the otherwise expected species pool. People harvest biomass and may protect plants from pests and diseases. Therefore, the emphasis in the treatment of the state factor organisms here is placed on humans.

A wide range of variables might be appropriate to assess influences on human behavior that affect conditions for garden vegetation patterns. It is beyond the scope of this treatment to go into great depth. The goal, rather than being exhaustive, is to identify several meaningful variables for the state factor model. The approach taken here is to define a range of inputs needed for landuse management and to assess each household's access to these inputs. The inputs are land, labor, materials (e.g., propagules, fertilizers or compost), information (e.g., agricultural extension and education), markets, and alternative sources of income. I attempt to show how access to these inputs is affected by social, political and economic institutions at several levels of human organizational scale. A logical hierarchy for human organization across scales is the political-administrative system, in which households belong to hamlets in villages which are grouped in divisions forming districts of provinces.

LAND TENURE

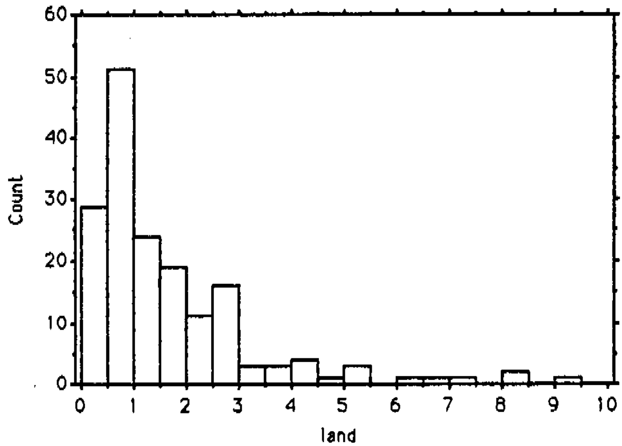
Eighty-two percent of all land in Sri Lanka belongs to the government, largely removing it from general access for settlement[2]. Further, population density is very high. With the increase in population, access to enough land of adequate quality is a major problem and a fundamental constraint to agricultural production. The degree to which people have access to land will in part determine their involvement in landuse, including garden vegetation management.

While land tenure is tightly constrained at the regional and landscape levels, it varies somewhat in distribution at the local scale. Thus, the first variable of importance is

[2]Note the earlier discussion of encroachment (Chapter 2).

the amount of all types of land available to a household[3] . Land ownership is somewhat skewed, however. As a result of the 1971 land reform, the ceiling for maximum individual ownership lies at 50 acres (20.8 ha) of non-paddy land. Very few people in the survey own or lease more than 10 acres (4.16 ha). In Fig. 5.13, four large landowners in the Kotmale area, owning 21, 30, 35 and 50 acres each (8.75, 12.5, 14.6 and 20.8 ha respectively) were excluded to show the distribution among smaller landowners more clearly. None of the households surveyed in Welimada or Passara Divisions owned or leased more than 8 acres of land.

Fig 5.13 Land Ownership for 173 Households Surveyed



(Count refers to the number of gardens of each size. Land refers to area in acres.)

The second relevant measure of access to land is the size of the garden itself[4]. Surprisingly, the average garden size does not vary greatly, even across regions (the large Kotmale land owners were not excluded for the graph of garden frequency distribution (Fig. 5.14). Few forest gardens are larger than one hectare. Where there is more land, it

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[3]See discussion of tenure in Chapter 2 for applicable categories of tenure.

[4]Forest gardens are equated with homesteads and are the last land to be sold. It is common to find families who own only their house and garden, but rare to find people who own paddy fields or tea fields but not their own house.

is likely to be used for tea cultivation; or alternatively, in the Kotmale area, three households kept other land under mixed tree cover (*watte* - land holdings away from the homestead) as opposed to the *gewatte* (the homestead garden). In the villages around Mirahawatte, 55% of all gardens are less than or equal to .5 acres in size, a slightly less than the average for all villages.

Thus, it is possible that management of perennials could be influenced by the type and overall quantity of other land available to a household. One might expect, for example, that a family with land in addition to a garden will grow cash crops and food grains on this other land and be less inclined (less need) or able (less labor available) to clear their garden trees to grow vegetables for cash. Land ownership and garden ownership were both carried forward as variables to test in the state factor model.

LABOR AND VILLAGE SOCIAL RELATIONS

Access to labor to work on the land is an important input for landuse. In this region, there is very little mechanization in agriculture[5]. Buffaloes are used for some plowing and threshing. Human labor is required for all other tasks. The number of people in a household is significant both for the number that must be supported and the number that are available to support them. Beside the absolute number of people per household, the skew in age classes may influence labor availability. A family with many small children will be in a different position than one made up of working aged adults. A family with three generations under one roof has different opportunities and constraints than one with one or two generations. Figures 5.15 and 5.16 show frequency distributions for number of people per household (#mem) and number of children per household (#child - children were all those under 15 years of age). In Mirahawatte, Balathotelle and Matatila the distribution of household members follows a similar pattern.

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[5]The fields here are too small for most tractors and I have seen only two portable threshers used in Mirahawatte and none in the other villages.

Fig. 5.14 Garden Ownership for 173 Households Surveyed

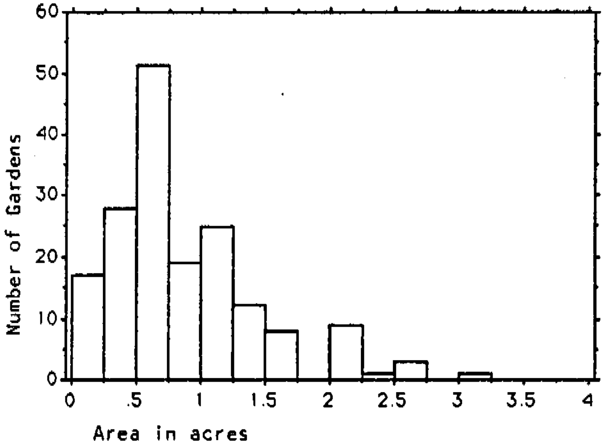

Fig 5.15 Frequency Distribution of Number of People per Household

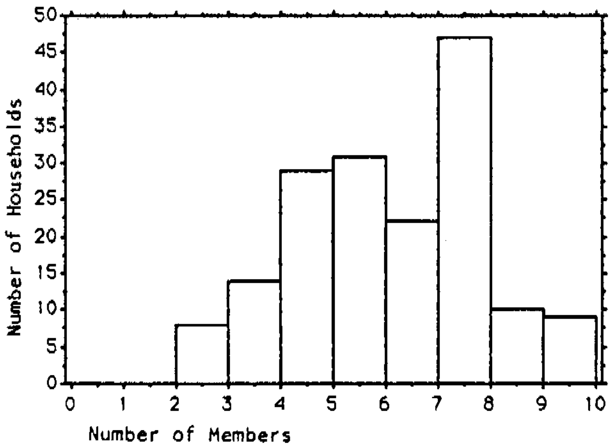

Fig. 5.16 Frequency Distribution of Number of Children per Household

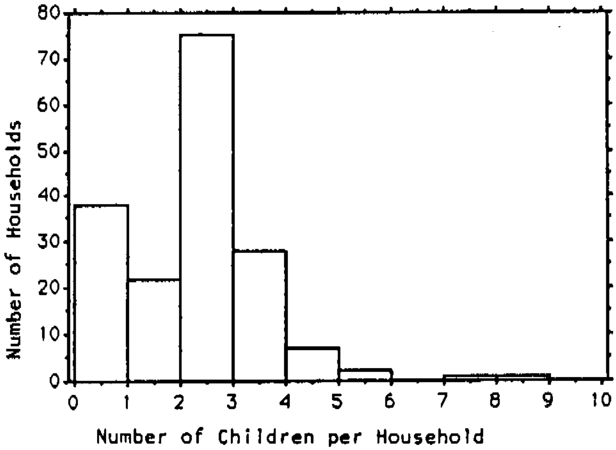

Table 5.6 Gender Roles in Garden Management Tasks

Task	Men (n)	%	Both (n)	%	Women (n)	%
prune tea	48	98	1	2	0	0
biocides	45	79	8	14	4	7
plant tea	38	78	10	20	1	2
clearing	83	64	43	33	3	2
plant trees	72	55	53	40	6	5
fertilizing	51	52	37	37	11	11
sell leaf	29	48	22	36	10	16
plant seeds	14	38	17	46	6	16
harvest fruit	35	31	75	66	3	3
hrvs't gen'l	32	24	87	65	14	11
plant herbs	22	19	31	26	64	55
hvst herbs	17	15	35	30	63	55
plant flowers	10	8	23	18	92	74
cut flowers	8	7	22	18	93	76
pluck tea	0	0	4	8	45	92

While establishing forest gardens on grassland is initially labor intensive, once a number of trees have been planted, other expenditure of labor is limited.

Slope has been discussed as a measure for topography. Slope may also be considered an indicator for soil quality, especially for soil depth. Soil depth in turn has implications for vegetation because of its correlations with soil moisture retention, stability and fertility. Particularly in the case of garden establishment on long deforested, abandoned coffee or tea estate land and *patana* grassland which predominates in the highlands, the remaining top soil on steeper slopes is in general, likely to be very thin, while it may be quite deep at the base of slopes to which soil has been displaced (the irrigable bottom lands are the preferred place for paddy cultivation). One would expect the initial conditions for a garden on moderate slopes to be better with respect to soil depth and quality than conditions would be on steeper slopes.

Thus, while at the regional and landscape level, the soil great group, Ultisols, is a constant for state factor 'parent material', in the state factor model percent slope serves as a variable for parent material.

State Factor Climate

Climate can be expected to influence ecosystems at differing levels of scale in space and time (Delcourt and Delcourt, 1988). At the regional scale for the highlands, climate reflects the topographically modified monsoon pattern which broadly divides the country into Wet, Intermediate and Dry Zones. The particular climatic conditions in an area will determine which species grow to their full potential, including producing for the subsistence or cash economy [8]

In order to test for statistical significance of these observations, the gardens were grouped by climate into three categories. Gardens in the Kotmale villages were called 'Wet', from the Passara Villages 'Intermediate', and in the Welimada Villages 'Dry'. One-way Analysis of Variance was run for number of species and canopy closure in each of the climatic categories (Table 5.4).

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[8] Of course, many tree species will survive beyond their ideal range, however they might yield little or no fruit, grow slowly and/or be otherwise susceptible to climatic conditions.

Harvesting is the major activity, though there are a number of other tasks as well. People were asked who did what tasks in the garden. Tasks surveyed were: clearing the garden plot for initial planting; planting seeds; planting trees; weeding (clearing weeds every few months); applying fertilizers (including manure, compost, and chemicals); applying biocides (many people don't do this at all); harvesting all products; harvesting fruits from large trees; planting herbs and household vegetables; harvesting herbs and vegetables; planting flowers and ornamentals; cutting flowers; planting tea (not all households have tea, but people have ideas about who should do what); pruning tea; plucking tea; selling tea leaf.

In general, people said that there are no major differences in mens' or womens' work, though they indicated that men were more likely to do the heavier labor (like clearing land for a garden, or digging a hole to plant a tree). However, the more specific questions about each task did result in some more distinctive trends (Table 5.6). For example, chemicals (fertilizers and biocides) are commonly applied with a back-pack sprayer which is heavy and perceived therefore to be difficult for women to use. For the case of biocides in particular, people often said that women should stay away from poisons since they could affect child bearing. In a very few cases men suggested (as their wives nodded) that applying chemicals is too complicated for women. In my experience, this kind of gender chauvinism is very rare. Instead, people perceive the relatively loose gender divisions in village labor (demonstrated by the high proportion of tasks shared by man and women) as practical and are mutually respectful of each others' roles. Harvesting is generally a shared task, but especially for fruit, boys often climb trees to

trees to gather the yield. Growing and harvesting household medicinal plants and vegetables is more commonly a womens' task. However, in the Kotmale area, where herbs, such as cardamom, ginger and turmeric, can be more extensive garden understory cash crops (requiring more labor), men are often involved as well. In addition, ayurvedic medicinal doctors and veterinarians[6] are usually men and they commonly grow a wide range of medicinals in their gardens. Ornamentals are usually the womens' domain (often school-aged girls). Tea cultivation[7] is interesting in that it provides an exception to the otherwise informal distribution of labor. The rigid labor distribution practiced on the large estates is largely maintained in the small private holdings in the villages. Men plant and prune the tea, women pluck the leaves. While men are more likely to carry out the economic transaction of selling the leaf (delivering it to the pick up point), women often take on this role as well (women are not excluded from economic transactions).

Correlation was low between numbers of household members and canopy closure in all gardens (.053) and a negative tendency for children per household (-.187). This relationship was slightly stronger for species richness (.069 for all members, -.237 for children). The influence of children is difficult to interpret on the basis of one variable alone. Certainly the number of children is higher in proportion in newly settled villages with young families. These settlements, especially Maussagolla-Colony also have very small plots of land available per household. Because of the complex of factors related to this variable and their skewness, I chose to use the overall number of household members as a variable in the state factor model, despite its lower correlation with the vegetation variables.

A further area of interest is household relations with other households for labor or other activities which may influence garden structure and composition. Casual sharing of

[6]The South Asian ayurvedic medical system is the most widespread system of health care in rural Sri Lanka, though there are dispensaries and clinics providing western medical treatment in many villages. There are hospitals for both medical systems in larger towns.

[7] Tea is often a crop integrated into forest gardens, as well as being planted in separate blocks.

labor is common among relations and friends. For larger tasks such as harvesting field crops, both sharing of labor and more formal labor relations are common. Only in three cases, all in the old Kotmale villages, did I encounter wage labor or labor from outside the household employed in gardens. These were cases where large landowners employed workers for a variety of tasks around their homesteads.

An additional form of labor, very common in highland gardens, is tapping of kitul palms (Caryota urens) for nectar or sweet toddy, which is further processed into syrup, sugar and alcoholic beverages. An occupational caste of toddy tappers customarily carries out this function in each village and receives a set proportion of the harvested toddy in payment. Tappers are men. Kitul palms bloom at the end of their lifespan (ca 15-20 years). One palm may bear several flowers in succession, each yielding toddy for up to three months. In the Mirahawatte area, the tapper is called when a kitul palm begins to flower. The tapper prepares the inflorescence for tapping and, once the tree begins to yield, he takes half the toddy as his share (often on the basis of one day's yield for the tapper, the next day for the palm owner). In other parts of Sri Lanka, such as in the lowland Wet Zone, where palms in the natural forest may be tapped as well, the tappers' proportion of the harvest may be larger[8].

While people share circa 30% of garden produce with relatives and neighbors (Everett, 1987), inter-household relations regarding forest garden management are minimal and restricted to issues concerning garden borders or margins of private land. Private homestead land ownership in most cases includes rights to vegetation[9]. Discussions with farmers revealed that in case of damages or disputes over trees on borders that people could not resolve among themselves, the village headman would be

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[8]A paper which discusses the ethnobotany of Caryota urens in greater detail was presented at the 1991 Society for Ethnobiology Conference in Washington D.C. and is in preparation for publication.
[9] There are some limitations such as licensing for harvest and transport of certain timbers and for tapping sugar palms (alcohol production). Tenure on valuable timber trees may be divided into shares.

called in to mediate. In extreme cases, such as an argument over rights to a valuable timber tree, the dispute might be taken to court.

People generally avoid potential problems by not planting valuable trees (e.g. hybrid mangoes, cloves, coffee, citrus fruits) on the margins to avoid fruits and flowers being stolen or eaten by passing livestock. It is commonly accepted that less valuable fruits (e.g. loquats, mulberries, guavas, jam-fruits) will be eaten by children from the neighborhood. There are a wide range of additional customs regarding placement of particular species in gardens. Larger timber species or good shade trees, for example, are not generally planted near the house, especially not in front of the house, because they could damage the house if they blow over or drop a limb, and because the front of a house is customarily kept open and full of light. Certain plants are believed to have protective power. Mango trees are said to keep illness away from the house. Others have special relationships to people. In Mirahawatte several informants said that papayas bear more fruit if grown in proximity to the house where the trees can 'hear' voices.

It would be of interest to note how the conversion of garden plots to vegetable cultivation affects species distribution and placement in gardens. I did not study this question systematically. However, in most gardens with larger vegetable plots, some large and valuable trees, especially jak, mango and sapu (Michelia champaca - timber) trees, are kept even if they are in an inconvenient place. These trees are then very heavily lopped to reduce shading.

In discussions with a wide range of villagers, including village headmen, I found no evidence of larger scaled village level or regional rules or institutions regarding garden management. Further social variables which could be significant are differences in ethnicity or religious affiliation among villagers. The villagers in the highlands are predominantly Sinhalese Buddhists, with some Muslim sub-communities. There is a large Hindu Tamil population, but most of the Tamil people live on or immediately adjacent to the large tea estates where they are employed. They are not, for the most part,

integrated into 'village life' outside the estates. Therefore, most people in the study villages, are ethnic Sinhalese and follow the Buddhist faith. There are a number of Muslim families in Mirahawatte (5% of the population). Differences in ethnicity or religious beliefs did not correlate with vegetation variables in this village.[10] In summary, while a wider range of variables was reviewed, the number of household members was the single measure carried on to represent labor and social relations in the state factor model.

INFORMATION, EDUCATION and MARKETS

The increased scarcity of land indicates the growing importance to farmers of reaping a cash profit from their gardens. Access to information about markets, crops, and cultivation practices is an important factor here. Information comes from a variety of sources which can be distinguished hierarchically.

Government institutions influence national and regional agricultural and agroforestry practices through establishment of price policies, market structures and agricultural extension programs. Agricultural extension in Sri Lanka has been largely focused on research and development of rice and high yield varieties of field crops, including vegetable cultivars, and in the past has combined distribution of propagules with offers of subsidized inputs of fertilizers and biocides.[11] Vegetable cultivation in Badulla district and especially in high elevation areas of Nuwara Eliya district has increased dramatically since the 1960's (Fig. 2.3). No effort of comparable extent has gone into developing and improving trees (Wickramasinghe, 1990). Minor export crops (including spices and coffee) for example, made up 7% of the value of agricultural production in 1982 and 1983 but received only 2.5% of the research expenditures (Weragoda, 1987 citing data from data from FAO, 1986). The Department of Export Agriculture has focused on a few species (e.g., coffee, pepper, cloves, cardamom,

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[10] There are certain species characteristic of the different groups. Henna, for example is used by Hindu and Muslim women for cosmetic purposes, but is not typically found in a Buddhist's garden.

[11] Many agricultural subsidies were cut suddenly in 1991 in an effort to stem a national budgetary crisis.

nutmeg), largely suited to the Kandy area (e.g. the Delpitiya model noted in 5.1). Agricultural extension efforts with perennials in other areas in the hill country, such as Passara, have promoted a limited number of species, predominantly pepper (Piper nigrum) and lime (Citrus spp).

As a major effort by extension workers is to promote new crop varieties and inputs of fertilizers to increase crop yields, and as it was very uncommon for people to use such inputs on trees in gardens in the past, one measure of the influence of agricultural extension in forest gardens is the degree to which farmers use chemical inputs there. All farmers in the survey have access to and use improved seed and chemical inputs for paddy cultivation; in the Welimada villages they also have access to and use a wide range of chemical inputs for their vegetable crops. Farmers in the survey were asked whether they used inputs for several key species in their gardens, and if so, of what type.

Table 5.7 Comparison of Fertilizer Inputs for Key Species in Welimada and Kotmale Division Gardens

Coffee

	no input	compost mix	chemical mix
WELIMADA	41% (n=22)	43% (23)	13% (7)
KOTMALE	16% (n=8)	24% (12)	60% (30)

Citrus

	no input	compost mix	chemical mix
WELIMADA	42% (22)	44% (23)	13% (7)
KOTMALE	20% (10)	56% (28)	24% (12)

Banana

	no input	compost mix	chemical mix
WELIMADA	48% (24)	44% (22)	8% (4)
KOTMALE	42% (21)	40% (20)	18% (9)

The significantly higher proportions of chemical inputs used in Kotmale are an indication of agricultural extension efforts in forest gardens in this area as well as of access to improved varieties of forest garden perennials and markets for garden crops. In the long run one might expect the encouragement of conversion to a limited number of

cash crops to reduce the species richness in gardens. However, no significant relationships are evident here between canopy closure and species richness with application of chemicals. This variable was not carried on to the state factor model.

A more easily quantifiable measure of access to information is education. One would expect that literate people are able to gather information, for example, through newspapers and labels on agricultural supplies. Further, the better their basic arithmetic skills, the more able farmers are to assess costs and benefits in quantitative terms in the growing market economy.

In all villages selected, there was a primary school in the village, and a secondary school either in the village or nearby. Further, in all cases some children traveled daily to larger towns for higher education. Among the wealthier families it was very common for children to attend boarding school. Thus, while there are marked inter-generational differences in years of school completed (particularly among women), they do not seem to differ by the villages selected. All children in the study have a good degree of access to schools and many attend through the 10th grade and beyond.

Table 5.8 Years of Education Completed by Gender and Age Group

Years	men under 30		men over 30		women under 30		women over 30	
completed	count	%	count	%	count	%	count	%
0-2	0	0	1	2	2	4	7	16
2-4	1	2	3	6	0	0	2	4
4-6	2	6	3	6	6	12	8	18
6-8	6	17	9	18	4	8	7	16
8-10	8	22	16	31	13	27	8	18
10-12	11	31	9	18	13	27	7	16
over 12	8	22	10	19	11	22	6	13
total	36		51		49		45	

People were asked how many years of education they had completed. The results show that some differences in access to education existed in the past. Few men now over 30 years of age completed secondary school education, and even fewer women over 30

did. These differences have largely been erased and most people under 30 have gone through secondary school education at least to the 10th grade ("O-Levels" in the British system). Many have gone on for additional training. In general, literacy rates are known to be very high in Sri Lanka in proportion to other indicators of national wealth such as Gross Domestic Product. Education levels were not found to be significantly correlated with vegetation variables. Education was not carried further as a variable for the state factor model.

OCCUPATION AND HOUSEHOLD INCOME

The primary source of a family's income is expected to affect garden vegetation. Farmers depend on their land and vegetation management skills for their livelihood and are expected to know more about and invest more time in growing plants than someone employed in town. In all villages there were a significant number of people employed in non-agricultural activities as well as people employed as agricultural laborers on others' land, or on nearby tea estates. Maussagolla colony is a bit of an anomaly; here nearly all men are employed by the county on road and electrical maintenance work.

An analysis of links between peoples' occupations and the status of vegetation in their gardens was undertaken as follows. Seven categories of occupation are defined. Farmers are people who work full time as farmers on their own land (FARMER). Agricultural laborers gain part or all of their income from working on others' land; tea estate laborers are especially common here (LABORER). Workers are defined as people in low to unskilled, non-agricultural employment situations (e.g., bus conductors, road maintenance (WORKER). Skilled workers and self employed trades people are grouped under the heading (CRAFT). This distinction is made under the assumption that their income is likely to be higher than that of less skilled workers . Clerical and professional employees, such as teachers and other government staff are lumped into one group (PROF). Business people, particularly shopkeepers, were called traders (TRADER). Many women and some retired men stated that they do not work but stay at home

(HOME). This latter category for women is difficult to distinguish from that of FARMER; in cases where the husband is a farmer, many women label themselves farmers as well (Table 5.9). The distribution of occupations in Mirahawatte mirrors the average across all regions. In Balathotelle, 50% of the men work as laborers on Dyraaba estate while 25% are farmers. In Matatila, 80% of all men are farmers.

The results from analysis of variance for occupations' correlation to vegetation parameters proved insignificant. Source of income was therefore not included in the state factor model.

Access to larger towns and transportation influences peoples' economic opportunities (and therefore their landuse) as towns represent markets, centers of education and a wider range of employment possibilities than found in a typical village. For this study I selected villages linked to regional service centers, but with predominantly agriculturally based community relations. Produce marketing in all three cases was undertaken in four similar ways. Tea leaf was sold to tea factories on nearby tea estates. In all cases, the leaf is picked up on a regular basis by a lorry from the estate[12].[13] Other

Table 5.9 Occupations by Gender

occupation	men: count	%	women: count	percent
farmer	64	36.8	37	21.3
laborer	24	13.8	17	9.8
trader	13	7.5	1	.6
craft	10	5.7	2	1.1
worker	17	9.8	1	.6
professional	11	6.3	5	2.9
home	3	1.7	80	46
other*	32	18.4	31	17.8

(other is for missing values)

[12]Tea production including leaf collection was strongly affected by the political insurgency during 1989-1990 as many factories and vehicles were burned.
[13]

major produce ranging from vegetables and fruit in the Mirahawatte area to coffee, cloves and cardamom in Maussagolla and the Kotmale villages were similarly collected during harvest season by lorries and traders on a regular route with stops along the main roads[14]. Milk is sold to milk cooperatives via early morning pick ups from the main road in the Welimada and Kotmale areas. I did not see this practiced in Maussagolla. Farmers sold smaller amounts of produce, such as a bunch of bananas or a small amount of palm sugar through village market stalls, or sometimes by taking the produce by bus to the regional market town. Thus, at a general level, it seems that both wholesale and cooperative marketing opportunities for already existing cash crops are well developed and similar in all three regions and consequently can be treated as constants in this study.

In summary, several variables were selected to represent the state factor 'organisms' in the state factor model. Land tenure, is represented by one variable for all land available to a household, 'land', and one variable for garden size, 'garden size'. Labor availability is represented by the number of members in a household, 'members'.

Summary of Discussion of Variables Pre-Screened for the State Factor Model

Certain general characteristics of gardens are summarized in Table 5.9. Older villages in rainier climates have greater species richness, density and crown closure.

Except for Rogersongama, newer colonies tend to be located on steeper slopes (more marginal land) than older villages. Soil pH is significantly higher in older villages and gardens than in new colonies (at 95% probability). Households in older villages tend on average to have more land than do people living in new colonies, but garden size does not vary significantly across villages (except for Matatila's field plots and Maussagolla-Colony's tiny house plots). Household sizes are fairly constant across villages, though

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[14]I did not study this aspect of the system in detail. In general, based on discussions with local farmers, I understand that the collectors are either from village based or local marketing cooperatives, or more commonly hired by wholesalers in larger towns, especially in Kandy and Colombo. The cooperatives' farm-gate price is often a bit higher, however, the wholesalers pay cash on receipt while the farmers have to wait longer to see their returns through the cooperatives. In the Mirahawatte/Matatila area, farmers preferred the wholesalers.

there is a slight trend toward more children in new colonies (younger families on average). Variables selected for inclusion in the state factor model are highlighted

Table 5.10
Comparison of Average Values for Key Variables by Village

Independent		KOTMALE		PASSARA		WELIMADA		
Variables	Rav*	Wije	Rog	Maussa	M-C	Mira	Balat	Mat
rainfall (mm)	3,607	3,607	3,607	2,382	2,382	1,610	1,610	1,610
village age (years)	400	400	60	400	10	100	50	20
garden age (years)	83	69	44	91	9	52	19	12
all land (ac)**	6.4	5.1	1.0	1.5	.3	1.4	.7	1.5
gard size (ac)	1.0	.9	.8	.7	.1	.7	.7	1.3
slope (%)	33.4	28.5	25	25.8	40	20	43.8	43
soil pH	7.07	6.84	6.35	7.4	-	6.78	6.36	6.17
members***	5.6	5.1	4.8	4.8	5.2	7.1	4.3	4.2
children	1.4	1.1	1.8	1.0	2.7	2.1	1.7	2.2
Dependent Variables								
species per gard	40	39.5	37.2	38.8	16.3	30	24.1	13.9
trees per gard	437	349	207	283	42	245	103	44
canopy (%)	86.7	77.1	68.2	79.4	30	56.1	20.3	11.1

* Abbreviations for village names: Wije = Wijebahukande; Rav = Ravanagoda; Rog = Rogersongama; Maussa = Maussagolla; M-C = Maussagolla Colony; Mira = Mirahawatte; Bala = Balathotelle; Mat = Matatila.
** The category 'all land' includes acreage of all land owned per household
***All members and children refer to the number of people per household. Children are not tested in the model, but their numbers were included here to show the skew by village.

(aspect is a categorical variable and not included in the table).

Based on the analyses of suitability of variables for testing in the state factor model, many clearly relevant measures have been excluded. Nevertheless, at least one variable per state factor was found suited for the model. The weakest variable is the measure of slope as an indirect indicator of the state factor parent material. Slope is a strong indicator for topography and is further supported by aspect. Climate is not represented at the garden level, but is measured as rainfall at the landscape scale. Time is represented by garden age at the garden level and by village age at larger levels of scale.

Organisms are represented as the human state factor at the garden level with the variables land ownership, garden ownership and number of members per household.

In the state factor analysis in 5.4, the relative importance of these selected variables, based on their correlation with vegetation variables in stepwise regression analyses, will be assessed for various modes of garden aggregation.

5.4 A State Factor Model for Forest Garden Vegetation

State factors are hypothesized to create initial conditions for ecosystem and landscape processes and to have variable influence in space and time. Ideally, for the dependent variable 'vegetation', one would expect that excellent measures for each of the five state factors at a given scale would perfectly correlate with excellent measures for vegetation in the system at time t_0[1]. A shift in scale would require a commensurate shift in the expression of the state factors and again would lead to high correlation with a more aggregated unit of vegetation. Once these correlations had been established, one would then begin to work out quantitative feedbacks created by aggregations across scales. An additional issue to be considered is that the mode of aggregation across scale may influence the results for the analysis (Govil, 1991). Vegetation could, for example, be aggregated according to spatial scale or according to a range of time frames or according to a measure of social or economic importance.

This effort is limited and seeks to test three hypotheses:

1. The state factors represented by the chosen variables correlate highly with variables representing vegetation.

2. State factor expression varies with scale.

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[1]What 'excellent' might mean again would vary under different circumstances (e.g., choice of variable to measure state factors and vegetation at a given scale for a given purpose). For a discussion of the implications of choice of variable and measurement method see Euphrat, 1992 for a hydrological study.

3. Results vary with mode of aggregation.

I do not have measures for each state factor at the three levels of scale which are of interest here. However the available data serve to test the approach. There are no data to provide measures of variables from different points in time (t_0, t_1, t_2 ...) which could begin to be applied to assess feedback dynamics using the model[2].

Variables in the State Factor Model

After the initial analysis above, several variables, at least one per state factor, except climate, remain to test the model at the individual household / forest garden scale (slope is a variable both for topography and for parent material). The available measures for each state factor are listed according to their scale of expression in Table 5.11.

The variables are highlighted. For the landscape, regional and all island scales, the variables available to quantify the state factors are more limited, and most are held constant.

At the all-island scale, all state factors are treated as constants. At the regional scale, the central highlands are the focus. Here there is a distinction in climate between the island-wide divisions of Wet, Intermediate and Dry Zones, of which the Wet and Intermediate Zones are represented in the study areas. For the state factor organisms (political divisions), two provinces (Central and Uva) are included. The parent material in the areas studied is a mixture of chernockitic gneiss and metasedimentary rock. The topography is mountainous and steeply dissected. Modern human settlement patterns in the region, which define the time period of interest, have been significant since the 12th century.

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[2]Instead, feedback dynamics are inferred for the Mirahawatte landscape from the changes in landuse patterns described in Chapter 4

Table 5.11. Variation in State Factor Expression with Scale

Spatial Scale	STATE FACTORS Climate	Organisms	Parent Material	Relief	Time*
All Island	island wide	national	various	various	pre-historic
Regional	regional (W,I,D)**	provincial	rock type	mountains	from 12th century
1. Highlands	Wet and Intermediate	**Central/Uva Provinces**	chem. gneiss metasediment	steeply dissected	from 12th century
		Badulla / Nuwara Eliya Districts			
Landscape (Macroscale)	**rainfall**	**Division**	soil	steeply dissected	from 12th century
1. Welimada	**1,600mm**	**Welimada**	ultisol	steeply dissected	from 12th century
2. Passara	**2,400mm**	**Passara**	ultisol	steeply dissected	from 12th century
3. Kotmale	**3,600mm**	**Kotmale**	ultisol	steeply dissected	from 12th century
Between Ecosystems (within landscape)	local climate	**8 villages**	ultisol	steeply dissected	**village age** (10 - 400)
Ecosystem (forest gardens)	micro-climate	**Households** **members land garden size**	**slope (soil depth)**	**slope aspect**	**garden age**

* Time is measured here on a scale relevant to humans
**Wet Zone, Intermediate Zone, Dry Zone

At the landscape scale, three different rainfall regimes are distinguished as measures of climate. For human organisms, represented by organizational scale, two districts (Nuwara Eliya and Badulla) are represented, with Kotmale division in Nuwara Eliya

district, and two divisions (Welimada and Passara) drawn from Badulla district. The parent material in these areas has developed into the common great group of Ultisols Within each landscape (called 'between ecosystems' in Table 5.11) there are several villages of varying age.

At the most localized scale, that of individual forest gardens, the age of each garden is a variable, as are the slope and aspect of the land on which it is situated. The influence of parent material is estimated from soil depth an estimate based on slope. The size of the garden and the extent of land to which the household has access are further variables. Finally, household size, the number of members, is an indicator of available labor.

Aggregation Methods

Several alternative approaches can be applied to aggregate information in this model. Earlier work has shown that the mode of aggregation across scales affects the outcomes achieved (Govil, 1990). The most obvious method with clear ecological content is to aggregate by spatial scale, from individual gardens, to patches of gardens, to gardens within one landscape, and then to compare aggregations of gardens between several landscapes[4]. This approach, though clearly important and with many implications for links to the spatial analysis from Chapter 4, cannot be applied here. The gardens were sampled at random in each village. In only very few cases were neighboring gardens sampled. The data are not sufficient to group households spatially for the within landscape scales. For the between landscape scale, the aggregation by landscape corresponds with the aggregation along human organization lines.

Another approach of relevance to a human managed pattern of vegetation is to aggregate data by levels of human organization from household, to neighborhood, to village, to division, to district and province. Perhaps administrative and political decisions at these levels influence conditions for vegetation.

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[4]At the scale of the landscape, all ecosystems within the landscape (all vegetation types) would be the logical next level of aggregation for vegetation.

A third mode of aggregation with ecological meaning is aggregation through time. Gardens of different age represent different potentials in successional stages and can be aggregated in groups of early, mid and late succession potential gardens (a 15 year old garden cannot have 100 year-old vegetation, but a 100 year-old garden may or may not have 100 year-old vegetation).

Finally, the data are aggregated randomly to test whether aggregation categories lead to higher correlations with values for vegetation or not.

Data gathered at the household level are aggregated and tested for fit in the state factor model using stepwise regression. The three aggregation approaches are aggregation by human organization; by succession potential; and at random. Certain special circumstances apply in each case. The results from each approach are discussed for the degree to which the state factor variables fit the model and the degree to which the results vary between scales. Finally the results from each approach to aggregation are compared with those from the other aggregation methods.

Aggregation by Human Organization: Village, Division, District and Province

Several nested scales of human organization are represented in the forest garden data. At the most localized level, every forest garden belongs to a household. At the next level in scale, each household belongs to a village. There are several villages in each administrative division. There are two districts and two provinces represented in the study.

First, stepwise regression is applied to test for state factors which may influence conditions for forest gardens within each village. The variables are garden age, slope, aspect, land, garden size and members. Then gardens within each administrative division (landscape) are aggregated. At this level of aggregation, a new variable, village age, is added to the model. Next, data from gardens in Badulla District from Welimada and Passara divisions are grouped, adding the variable rainfall to the model. Finally, Badulla District (Uva Province) and Nuwara Eliya District, Central Province (represented by Kotmale division) are grouped, which adds the Wet Zone rainfall value to the model.

VILLAGE SCALE

At the village level the variables slope,aspect, household land, garden size, garden age and number of household members were entered into the step-wise regression analysis. Variables entered the model if their 'F to remove' was at least equal to 4 indicating significance at the 95% level and (Table 5.12). Significant variables are highlighted. The first variable to enter the model is the most significant for each analysis.

Table 5.12 State Factor Aggregation by Village for Canopy Closure
(variables: slope, aspect, land, garden size, # members, garden age)

village	factor	R	adj R2*	F to enter
Wijebahukande	**1. garden age**	.498	.206	-
(n = 20)				-
Ravanagoda	**1. slope**	.461	.168	-
(n = 20)				
Rogers.	(aspect)	-	-	3.93
(n = 10)	(garden age)	-	-	2.5
Maussagolla	**1. slope**	.488	.193	-
(n = 19)	(aspect)	-	-	2.28
Maussagolla	**1. slope**	.745	.51	-
Colony[5]	(aspect)	-	-	2.58
(n = 12)	(members)	-	-	2.36
Mirahawatte	(slope)	-	-	3.17
(n = 61)	(member)	-	-	2.24)
Balathotelle	**1. garden age**	.573	.261	-
(n = 12)				
Matatila	(land)	-	-	2.97
(n = 19)	(garden age)	-	-	2.8
	(garden size)	-	-	2.48

*adjR2 refers to the adjusted R square value

Additionalvariables contribute a smaller (cumulative) proportion of the fit (the columns of increasing value under R and adj. R2 in the tables). For cases in which no variable enters

[5] In Maussagolla-Colony, all gardens are .125 acres in size. The variable garden size is therefore excluded from the model.

the model or where variables have F values over 2.0, the variables are listed in parentheses. These variables are not statistically significant but their relative ranking is still of interest for this analysis. The results for these analyses are summarized in the text. More complete results are appended (Appendix 3).

Table 5.12 State Factor Aggregation by Village for Species Richness
(variables: slope, aspect, land, garden size, # members, garden age)

village	factor	R	adj R2*	F to enter
Wijebahukande (n = 20)	land	-	-	3.54
	garden size	-	-	2.75
Ravanagoda (n = 20)	**1. garden size**	.565	.281	-
	land	-	-	2.78
	garden age	-	-	2.11
Rogersongama (n = 10)	**1. garden size**	.758	.521	
	2. garden age	.864	.675	
Maussagolla (n = 19)	none	-	-	-
Maussagolla Colony[6] (n = 12)	garden age			3.3
	slope			2.66
Mirahawatte (n = 61)	**1. land**	.393	.140	-
	aspect			2.6
Balathotelle (n = 12)	none	-	-	-
Matatila (n = 19)	garden age			2.95

The results by village are variable. At least one variable entered the model for either canopy closure or species richness in all villages except Matatila. High correlations between vegetation and garden size and age were reached for Rogersongama. However, the number of cases (only 10) makes these results somewhat suspect. In several cases there was no significant fit at all, such as for the measure of species richness in

[6] In Maussagolla-Colony, all gardens are .125 acres in size. The variable garden size is therefore excluded from the model.

Wijebahukande. The limitations are likely due to small sample sizes. However, in all but two cases, there were variables close to entering the model. When the significant and nearly entering variables are considered as a group, garden age and slope are the most important variables associated with canopy closure at this scale, indicating the importance of time and site quality (topography and parent material) for vegetation development. For species richness, land and garden size were the most frequent variables, suggesting that access to area on which to plant is the key condition for diverse vegetation.

This may in part, have to do with small sample sizes, however this would not explain the lack of any fit for canopy closure in Mirahawatte where there are 61 cases. The lack of fit may also be due to inappropriate measures selected for the state factors. Further, at this level of scale, human organization into villages may be an arbitrary measure with little meaning for vegetation patterns.

ADMINISTRATIVE DIVISION / LANDSCAPE

In the next step villages are aggregated by their administrative division - in effect an aggregation at the landscape scale. An additional variable, village age, is added to the model (Table 5.14).

These results show variables entering the model with significantly higher correlations. With an adjusted R square of .663, the variables village age and slope in Welimada division have the best fit with vegetation values at this scale. In Welimada and Passara, village age is the dominant variable. Clearly the variable representing time has shifted scale from the garden to the village level (garden age drops out). In Kotmale this effect did not occur. This may be a problem related to the sample sizes. Both Wijebahukande and Ravanagoda are 400 year old villages represented by a total of 40 cases, while Rogersongama provides the contrast in villages age with only 10 cases (In the other landscapes the groups of cases are more balanced).

Again as at the village scale, site quality (slope) enters for canopy closure and land availability enters the model for species richness. In the Welimada villages, slope is

negatively correlated with canopy closure. This result corresponds with the results of the spatial analysis for the Mirahawatte landscape, in which the more gently sloped areas were settled first. These areas are more likely to have mature forest gardens (although with the fragmentation process now occurring, this does not always mean full canopy closure). The

Table 5.14 Aggregation at the Division and Landscape Level
(variables: slope, aspect, land, garden size, # members, garden age, village age)

1. Kotmale: Wijebahukande-Ravanagoda-Rogersongama (n=50)

canopy				species richness			
factor	R	adj R2	F	factor	R	adj R2	F
1. garden age	.373	.121		**1. garden size**	.511	.246	-
slope			2.77	land	-	-	3.12

2. Passara: Maussagolla and Maussagolla-Colony (n = 31)

factor	R	adj R2	F	factor	R	adj R2	F
1.village age	.765	.571	-	**1. village age**	.838	.691	-
2.slope	.834	.674					
aspect	-	-	3.16				

3. Welimada: Mirahawatte-Balathotelle-Matatila (n=96)

factor	R	adj R2	F	factor	R	adj R2	F
1.village age	.808	.65	-	**1. village age**	.597	.349	-
2. slope	.819	.663	-	**2. land**	.63	.384	-
				members	-	-	2.01

newer gardens on steeper slopes demonstrate a strong tendency toward hedgerow planting around vegetable plots which leads to lower canopy closure. Matatila especially, is situated on steep slopes with very little tree cover. The low degree of canopy closure may also be an indication of the relative difficulty of establishing vegetation on steep slopes with little top soil remaining. These sites are especially dry during the June to August drought.

DISTRICT AND PROVINCIAL SCALE / BETWEEN LANDSCAPES

Next, district level and provincial boundaries are used to determine the scale of aggregation. Passara and Welimada divisions belong to Badulla district in the Uva

Province. As the rainfall regimes in the landscapes represented by the divisions vary considerably, climate is added as a state factor variable (Table 5.15)[7].

Table 5.15. Badulla District, Uva Province: Welimada and Passara (n=117)

canopy				number of species			
factor	R	adj R2	F	factor	R	adj R2	F
1. village age	.656	.447	-	**1. village age**	.603	.359	-
2. slope	.722	.513	-	**2. members**	.676	.448	-
3. members	.734	.528	-	**3. climate**	.693	.467	-
				land	-	-	3.05

The overall fit of the model is fairly good with the adj.R2 of .528 for canopy and .467 for species richness. The importance of village age is further underlined as it appears as the primary variable for both canopy closure and for species richness. Slope continues to be an important condition for canopy closure. Household composition is significant for the first time for both vegetation variables. Climate enters the model for the first time for species richness. Land, a variable of major significance for species richness at the landscape and village scales does not quite enter the model.

BETWEEN PROVINCES / BETWEEN REGIONS

Finally, all variables were tested together for all cases to see whether regional differences (expressed in terms of Provinces in human organizational terms) emerged (Table 5.16). The fit for the model is further improved for canopy closure and slightly lower for species richness. Several variables are close to entering the model.

Again, village age is the primary variable for both vegetation measures. The importance of time for canopy development is further underlined as garden age enters immediately after villages age. Land is again a key variable for species richness.

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[7] As noted earlier, Maussagolla is situated on the slopes below Namununkula Peak, a very wet location by comparison with the rest of Passara division, some of which goes into the Dry Zone.

Table 5.16 Regional Level Between Uva and Central Provinces (Kotmale Division In Nuwara Eliya District)

(variables: slope, aspect, land, garden size, # members, garden age, village age, climate)

canopy				number of species			
factor	R	adj R2	F	factor	R	adj R2	F
1: village age	.7	.487	-	**1: village age**	.577	.329	-
2: garden age	.721	.515	-	**2: land**	.625	.383	-
3: members	.732	.527	-	**3: members**	.651	.413	-
4: climate	.746	.546	-	garden age	-	-	3.52
slope	-	-	3.37)	garden size	-	-	3.33
				slope	-	-	3.22
				climate	-	-	2.84

INTERPRETATION

The model's fit was better at the landscape level for the Welimada and Passara cases (Table 5.14), than when garden data were aggregated at district and provincial scales (though the fit is still reasonable there as well). It may be that data gathered at the scale of individual gardens is not ideal for comparisons across scales as large as the between district / provincial level (across a more significant climatic range as well). It would, in future, be of interest to gather data spatially, so as to have average values for blocks of gardens covering a scale of tens of ha as well as of fractions of ha. The larger scaled samples might lead to higher correlations in the model at large scales of aggregation. An alternative approach would be to have samples of all landuse or vegetation types to compare at the broad spatial scales.

At the very localized village scale, the results were not so conclusive, perhaps due to lack of sufficient data. However, it is also likely that villages, with boundaries artificially created for administrative purposes, are not very relevant for ecological variables such as vegetation. The hamlets within the official village of Mirahawatte, for example, are of several ages and may have closer associations with other nearby hamlets officially belonging to other villages. At the larger scales, where the results of the analysis become

more meaningful, the aggregation scale can be interpreted as administrative divisions of human organization or as landscapes, with landscape having clear ecological connotations with likely relevance for vegetation.

Aggregation By Successional Status:

In another approach to aggregation, gardens are grouped according to garden age, which is a hierarchically nested measure indicative of potential successional state in garden vegetation. Gardens less than 20 years old may be well established and are likely to have abundant fruit trees, hedges and short rotation perennials such as bananas, but will not have large trees of late successional stages[8]. The latter trees, such as the kitul palm (Caryota urens), germinate and grow in the shade of other vegetation. Seedlings of these species may be present after two decades, but large, mature specimens would not be expected. The mid range of age for gardens surveyed, defined as 21 - 99 years, represents mature garden potential. By this time, a well managed garden could have a wide range of species of many age classes though the later successional stage trees that can produce timber would still be of pole size. In 100 year old gardens, mixtures of all age classes are common. In some cases there will be very large up to 48" diameter timber producing trees in these old gardens. In most cases however, trees are cut not long after they reach merchantable size. Old gardens often have one or several old jak fruit trees, which are retained for their fruit, shade and symbolic values, despite their high timber value. Of course it is possible for a very old garden to have little old vegetation, depending on the management practices of the owners. This is why the older gardens are presented as having greater potential for species rich mature vegetation of high canopy closure.

Gardens from all villages were grouped into three age classes, less than 21 years old; 21 - 99 years old, and 100 years and older (Table 5.17). Of course, garden age is a continuous variable and as the cut off points are arbitrary, an effort was made to have

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[8]For a more detailed discussion of succession in forest gardens see Everett, 1987.

groups of gardens of comparable size to avoid variation resulting from sample size (n roughly = 60).

Table 5.17 Dominant State Factor Variables for Gardens Aggregated by Garden Age

	canopy				species richness			
group	factor	R	adj R2	F	factor	R	adj R2	F
0-20 years (n= 68)	1. village age	.713	.499		1 village age	.588	.333	-
	2. members	.782	.597		2 members	.713	.49	-
	3. climate	.829	.67		slope	-	-	2.73
	4. garden size	.848	.697					
	slope	-	-	2.99				
21-99 years (n = 60)	1. village age	.41	.154	-	1 climate	.418	.161	-
	2. garden size	.507	.232	-	2 members	.522	.248	-
	land	-	-	3.27	3 garden size	.583	.305	-
	slope	-	-	3.24	4 slope	.637	.363	-
					aspect	-	-	3.65
					village age	-	-	2.03
100+ years (n=56)	1. village age	.579	.323	-	1 village age	.486	.222	-
	2. slope	.629	.373	-	2 land	.606	.344	-
	3. aspect	.67	.418	-	garden size	-	-	2.22
	climate	-	-	2.72				

The general fit of the model is highest for the youngest gardens (.697 for canopy and .49 for species richness). The fit is not quite so conclusive for the older gardens. Perhaps at later stages in the gardens' development other variables not included here become more important. As in the tests of the model in for aggregation by human organization, village age is the leading variable for all but one case. As this analysis is already an aggregation in time, this may be seen as further support for the significance of this state factor. The secondary variables are very different in this analysis. Members are significant for both vegetation variables in young gardens. This would be expected,

because the majority of labor input into gardens occurs when the garden is first planted. Access to land (including garden land) enters the model frequently. In this mode of aggregation, the importance of site quality (slope and aspect), which was very prevalent for canopy closure in the previous, human organization / spatial scale aggregation, only enters the model for gardens of 100 years or more.

Aggregating gardens by garden age has mixed results. While the overall levels of fit are not as high as for the aggregation by human organization (and spatial scale), the fit for canopy closure in the most recently established gardens is higher. The information gained from the two approaches differs as well. While village age is the dominant variable for both approaches to aggregation, the secondary variables are not the same, thus supporting the hypothesis that the mode of aggregation influences the analysis results.

To test the degree to which these two examples of aggregation rules have underlying meaning, the results of the hierarchical analysis for organizational and time scales is next compared with random aggregation.

Aggregation at Random

Gardens are aggregated at random to see to what degree the choice of aggregation method and sample size may influence the outcome of analysis. This approach serves as an alternative (a control) for the previous hierarchical aggregation methods.

A random number table was used to assign each garden a number. The gardens were then sorted by random number and ranked. The first group included the first 30 gardens. The second group included the first 30 with an additional 30 gardens (n=60); the third group included 100 gardens. The group sizes reflect samples sizes for analyses carried out above. A group of thirty cases is a comparable size to the size of groups in which cases were aggregated by village. Sixty cases are a group similar in size to those analyzed for the scale of divisions/landscapes, and for garden age classes. The analysis by district had over 100 cases. Independent variables tested included slope, aspect, rainfall,

land, garden size, village age, garden age, and number of members per household (Table 5.18).

Table 5.18 Dominant State Factors for Gardens Aggregated at Random
(slope, aspect, rainfall, land, garden size, village age, garden age, members)

group	canopy factor	R	adj R2	F	species richness factor	R	adj R2	F
1-30	**1. village age**	.81	.639	-	**1.village age**	.647	.398	-
gardens	**2. members**	.847	.696	-	**2.slope**	.723	.488	-
	climate	-	-	2.9	land	-	-	2.27
					aspect	-	-	2.05
60	**1. village age**	.731	.526	-	**1.garden age**	.63	.386	-
gardens	climate	-	-	3.98	**2.slope**	.724	.508	-
	slope	-	-	3.05	**3.land**	.771	.572	-
	members	-	-	2.17	climate	-	-	3.67
					village age	-	-	2.09
100	**1. village age**	.735	.535		**1.village age**	.599	.353	
gardens	climate	-	-	2.94	**2.land**	.674	.443	
	slope	-	-	2.74	**3.slope**	.696	.468	
	garden age	-	-	2.5	**4.garden age**	.713	.487	
All*	**1: village age**	.7	.487	-	**1.village age**	.577	.329	
gardens	**2: garden age**	.721	.515	-	**2.land**	.625	.383	
	3: members	.732	.527	-	**3.members**	.651	.413	
	4: climate	.746	.546	-	garden age	-	-	3.52
	slope	-	-	3.37	garden size	-	-	3.33
					slope	-	-	3.22
					climate	-	-	2.84

*(The results for all 173 gardens are the same as for Table 5.16)

The high degree of fit from this random aggregation is interesting. Yet for some groups, the fit not as good as or only matches the results for parts of the hierarchically scaled analyses with similar groups size, especially for canopy closure in the Welimada landscape (n = 96) and the Uva province (n=117 Tables 5.14 and 5.15)), and in the early

successional state gardens (n = 68, Table 5.17). It is notable that for two groups in the test for fit with canopy closure, only one variable, village age, entered the model. A closer look at the variables which enter the model with random aggregation, shows that once again, village age is dominant. The results for canopy closure are not consistent. Members enter once and climate nearly enters the models at the next larger groupings.

For species richness, the importance of land is evident, as it was for the human organization aggregation approach. In the random approach, slope appears as significant when it never entered the model for species under the human organization mode and only once, for the middle-aged gardens in the successional potential aggregation.

The high correlations achieved when aggregating data at random and the inability of the models applied to explain the results within the limits of their assumptions, suggest that there is much room for exploration of relations among these variables beyond the analyses carried out with the human organization and garden succession approaches to aggregating the data.

5.5 Summary of General State Factor Model Results

In summary, the independent state factor model variables selected here do apply to the dependent variables selected for vegetation, though the fit does not always represent a high correlation. The results from the analyses are summarized in Tables 5.19 and 5.20.

In general, variables representative of time (garden age and village age) and site quality (slope, aspect) entered the model for canopy closure, while land area (including 'land' and 'garden size') was a prevalent variable associated with species richness for spatial aggregation at the village and division levels (e.g. Table 5.12- 5.14). Members are significant at the district level for both vegetation variables. In addition, climate is significantly associated with canopy closure when gardens from all regions are compared.

After village age, members are the most significant variable associated with gardens grouped by age, particularly for species richness. The importance of labor availability is an explanation for the entrance of household size in the model for young and mid- aged

gardens (Table 5.17). As in the results from aggregation by human organization, land is associated with species richness after the intial, establishment phase (0 - 20 years).

The state factors appear to provide a useful approach to modelling influences on vegetation. More complete data would be expected to be more conclusive. Further, to the degree measurable within the limitations of the available variables, state factors show different expression at different scales.

Table 5.19
Significant State Factors for Canopy Closure by Aggregation Rule

Human Organization	Garden Age	Random
Village	**0 - 20 years**	**30 cases**
1. slope 2. garden age (averaged for eight villages)	1. village age 2. members 3. climate 4. garden size	1. village age 2. members
Division	**21 - 99 years**	**60 cases**
Kotmale 1. garden age	1. village age 2. garden size	1. village age
Passara 1. village age 2. slope		
Welimada 1. village age 2. slope		
Badulla District	**100 + years**	**100 cases**
1. village age 2. slope 3. members	1. village age 2. slope 3. aspect	1. village age

All Cases

1. village age
2. garden age
3. members
4. climate

Garden age was immediately replaced by village age when this more aggregated measure of the state factor 'time' entered the model. Certainly with the exception of the overriding importance of village age, different variables took precedence at different levels of scale in

Table 5.20
Significant State Factors for Species Richness by Aggregation Rule

Human Organization	Garden Age	Random
Village*	**0-20 years**	**30 cases**
1. garden size 2. land and garden age	1. village age 2. members	1. village age 2. slope
Division	**21-99 years**	**60 cases**
Kotmale 1. garden size (land) Passara 1. village age Welimada 1. village age 2. land (members)	1. climate 2. members 3. land 4. slope	1. garden age 2. slope
Badulla District	**100 + years**	**100 cases**
1. village age 2. members 3. climate	1. village age 2. land	1. village age 2. land 3. slope 4. garden age

All Cases
1. village age
2. land
3. members

(* Village factors averaged for 8 villages)

all three sets of analyses. Very specific measures of site quality for topography and parent material (slope and aspect) are significant at the village and landscape scale, but fell

away as the broader scaled variable rainfall (for the state factor climate) entered at the supra-landscape scale.

Finally, the results from the three different modes of aggregation varied considerably. Some of the results from the human organization and garden succession approaches to aggregation were meaningful. The two different modes of hierarchical aggregation achieved high correlations for different factors at different levels of scale. The best results were achieved for the scale of division (landscape) and district (between proximate landscapes). This result confirms the value of the hierarchical approach for identifying inital conditions for vegetation and landuse by seeking constraints for the ecosystem scale at the next higher scale. Just as the theory suggests, the explanatory power of the model is reduced as one moves away from the focal level. Here, for example, the data based on randomly selected households and forest gardens are meaningful in the analysis for village, division and district levels of scale, but less so for analysis between landscapes in very different regions. This indicates that in order to achieve meaningful results, the questions asked of a hierarchical state factor analysis will need to be asked for a particular mode of aggregation with the focal level (s) clearly held in mind. The data employed should be within the range of scale of the focal level (s). In this case the data were gathered at one level of scale with a randomized approach, not very conducive to aggregation across many scales. An alternative approach would be to gather data using a mode of spatial aggregation for vegetation for the larger scaled analysis. With such an approach, it is possible that the explanatory power of model could range beyond two or three levels of scale. In addition, the variable results from the alternate aggreation rules suggest that it may be useful to explore several modes of aggregation across several scales.

Finally, the results from the completely random aggregation mode fit the model vary well. It is possible that a state factor analysis based on a more complete data set, for example, including variable measures for all factors at all scales would be more conclusive. The difficulty in interpreting the random aggregation results is also an indication of the

limits of the state factor approach as defined here. Alternative modes of explanation from other theoretical bases, such as economic or demographic analyses might provide insight. They could be incorporated to strengthen the state factor model through further development of the discussion of the role of people in the system. Alternatively they might develop entirely different interpretations but still benefit from the hierarchical aggregation approach.

5.6 Application to the Problem of Forest Garden Fragmentation in the Welimada Landscape

Despite the variation in some aspects of garden structure and composition, the basic pattern of forest gardening in and around Mirahawatte has, in the past, been similar to the pattern found throughout the highlands. In Chapter 4, a trend away from this pattern was noted for Mirahawatte - both in newly settled areas and in old, well established gardens.

The state factor approach demonstrates fairly high degrees of correlation between measures of initial conditions and vegetation for several modes of aggregation of garden data, including for the Welimada (Mirahawatte, Matatila, Balathotelle) landscape and for Uva province as a whole (Table 5.14 and 5.15).

To what degree can this approach contribute to the analysis of forest garden fragmentation in the case study landscape? Analysis of variance for several of the state factor variables between households with vegetable cash cropping in their gardens (called 'fragmented') and households which have maintained the traditional tree dominated structure (called 'non-fragmented') showed several significant differences (Table 5.21).

Conversion of existing forest gardens toward vegetable cultivation or predominantly hedgerow planting in recent gardens was noted in 52 of 92 gardens surveyed. All gardens in Matatila fit this pattern; the gardens in Mirahawatte and Balathotelle are mixed[9]. The gardens with vegetable cropping tend to be larger, though

[9]Only data for Mirahawatte are used here to avoid the confounding influences of village age and site quality.

their households do not have access to significantly more or less land overall. These fragmented gardens tend to be on significantly steeper slopes. The families of vegetable growers have fewer members and though the difference is not significant, their gardens are more recently established. This result supports my impression from interviewing people, that the farmers growing vegetables are often young couples just setting up a household.

The long term trend in Matatila, based on continued border planting patterns after 20 years does not suggest that the traditional block planting pattern is likely to emerge there. The people cultivating vegetables are most likely to be farmers gaining all of their income from their land. The break down of occupations (Table 5.22) is interesting, though not conclusive as it is based on responses from only 61 (66%) of the 92 households. The existing survey data show that farmers, laborers and traders are most likely to use homestead land for cash cropping, while none of the professionals in the survey are. Under conditions of land scarcity, for example, a farmer or an agricultural laborer (the smallest landowners) might attempt to glean as much income as possible from all land and be induced to grow vegetables instead of trees, while someone employed in town could have the luxury of a non-cash producing homestead garden. This hypothesis, is supported by the result that professionals do not grow vegetables for cash and thus do not convert their gardens.

Another variable which would be expected to be of significance is labor. Vegetable cash cropping is a labor intensive production process. One would expect families with less adult labor available to be less likely to grow vegetables, and thus be less inclined to convert gardens from tree cover to vegetable cover. However, this interpretation is not justified as there were significantly more members in families with no garden fragmentation.

Forest garden fragmentation is really a categorical measure for the pattern of canopy closure in gardens. Gardens with vegetable cash cropping require sunlight and thus will

have low canopy closure, at least for part of the garden. In gardens which are not used to grow vegetables, there is no general incentive to keep large areas clear, and they are likely

Table 5.21 Comparison of Key Variables for Gardens with Vegetable Cropping and Non-Fragmented Gardens in Mirahawatte, Balathotelle and Matatila

Variable	Vegetables (n=52)	Non-Fragmented (n=40)	sig 95%
Garden Size (ha)	.36	.27	yes
Slope (%)	30.5	25	yes
HH members (no)	5.87	7.29	yes
On Farm Income	58%	54%	yes
Land (ha)	.53	.61	no
Age of Garden (years)	36.6	42.5	no
Children (no)	2.19	2.15	no

Table 5.22 Fragmentation Related to Occupation

by Occupation	n	% with veg	n	% of occup*	% no fragm	n	% occup
Farmers	32	42%	22	69	25%	10	31
Laborers	6	10%	5	83	2.5%	1	17
Trader	8	10%	5	63	7.5%	3	37
Craft	4	6%	3	75	2.5%	1	25
Worker	5	6%	3	55	5%	2	45
Professional	4	0	0	0	10%	4	100
Home	2	1%	1	50	2.5%	1	50
missing	32	25%	13	41	45%	18	59

*% of occup refers to the proportion of all people in the occupation who grow or do not grow vegetables in their gardens.

to exhibit higher canopy closure. Therefore it is justified to test the state factor approach using the categorical variable of fragmentation ('fragmented' 'non-fragmented') as the

dependent measure for vegetation (Table 5.22). Again in this analysis stepwise regression was applied with an F to remove of 4.0. Variables entering the model are significant at 95%.

Table 5.23 Dominant State Factors linked to Fragmentation in Gardens
(slope, aspect, land, garden size, village age, garden age, members, income)

factor	R	adj R2
1. village age	.383	.137
2. slope	.441	.177

(garden age - F to enter 2.05)

In parallel with the results for canopy closure for Welimada division in the earlier state factor analysis, the primary variables entering the model are village age and slope. The independent variables do not fit the model for fragmentation as well as they did for canopy closure (adj R2 only .177). Thus, 'time' and 'topography' / 'parent material' seem to be the dominant state factors determining initial conditions for forest garden management pattern. The older village, Mirahawatte, was established on the gentler slopes and better soils in the landscape, while the newer settlements of Matatila/Belipola and Balathotelle are on converted *patana* and marginally productive tea estate land respectively. Planting trees on steep slopes with thin soils under the seasonally dry and windy conditions in the upper Uva is difficult. This does not mean that establishment is not possible, as there are many forest gardens on steep slopes in Mirahawatte and Balathotelle, but it may take longer and require more skill or effort. Under the prevailing conditions in the 1980's and 1990's in which often newly established households on marginal sites must earn a living, it is to be expected that farmers will choose to grow known crops which bring quick and relatively reliable yields that can be marketed easily.

CHAPTER 6

Conclusions

This study began by raising the problem of influencing human impacts on global ecological functions when these impacts are the aggregated result of the individual, uncoordinated actions of billions of people. One approach to addressing the problem is to increase our understanding of the process through which human impacts on ecological processes are aggregated in space and time. Many environmental problems with global implications, including deforestation and species loss, occur as a result of human land use and resource extraction. I suggested that landscapes are a significant level of focus for analyzing these issues because at this scale the actions of individual land users first coalesce and have aggregated impacts. In practical terms, this is a threshold at which a change in human impacts can not be effected by individuals acting alone, but requires cooperation and coordination among people.

I studied an agricultural landscape in highland Sri Lanka, analyzing patterns of aggregation in vegetation and land use types over time, from which landscape functions and ecological impacts of human action could be inferred. Further I sought to identify contributing factors which determine vegetation patterns. These results could contribute to efforts at a coordinated response by land users. I posed two questions:

1) How can the aggregated landscape level role of a given ecosystem or land use be assessed?

2) How can the possible landscape factors (boundary conditions) that create initial conditions for the ecosystem be isolated?

I addressed the first question using a Geographic Information System to analyze spatial changes in vegetation patterns, especially for forest garden agroforestry systems, over a thirty year period in an agricultural landscape in Welimada division of the Uva

province, Sri Lanka. For the second question I used a model based on the state factor approach (Jenny, 1941, 1980, Jenny and Amundson, 1991). The state factors of climate, organisms, parent material, relief and time, were hypothesized to determine initial conditions for forest garden vegetation in three regions studied in the Sri Lanka highlands, including the Welimada landscape. The results of the analyses and some of their theoretical and practical implications are summarized here for each question in turn. The results are then applied to suggest one example of an alternative spatial model of land use for the landscape studied, based on existing land use practices but incorporating vegetation management alternatives to mitigate negative impacts of land use practices on water flows and native flora and fauna.

6.1 Vegetation Change and Land Use Aggregation Patterns for the Mirahawatte Landscape

Results

The GIS based analysis of vegetation and land use in and around Mirahawatte, Balathotelle and Matatila settlements shows that major shifts in land use occurred over the 30 year period between 1956 and 1988. The nucleus of settlement in the Mirahawatte hamlets on relatively gentle slopes close to roads and sources of water has expanded into increasingly marginal land and remote areas as population increased. As a result, unmanaged wildlands, particularly *patana* grassland and natural forest, have decreased in extent. Surprisingly, the greatest increase in absolute area for a single vegetation type during this time was in tree planting on private land, primarily in forest gardens. In addition, forest plantations on government land expanded considerably. Thus, various forms of tree management are to some degree countering the long trend of deforestation in the landscape. Vegetable cash cropping has emerged as a new land use since the early 1960's and now extends across 10% of the landscape. Much of the vegetable growing

occurs on land recently converted from *patana* along the Matatila river. Other major land uses, such as estate tea cultivation and paddy cultivation, remained fairly constant.

The overall increase in fragmentation is an important aspect of change in the landscape. Excluding the estate tea and paddy fields, the individual patches of land use in 1988 are far more numerous and, on average, only one third of their previous size. The changes in perimeter to area ratio and fractal dimension indicate that patches have more complex shapes and more edge than in the past. The change in forest gardens' fractal dimension and the results from the grid-based pattern analysis indicate that the previous planting pattern of dense stands of trees is being replaced by a new pattern in which trees are planted primarily on the boundaries between homesteads, leaving the interior open for vegetable cultivation. In aggregation at the landscape scale, the pattern of patches of interlocking closed canopy gardens is being replaced by a lattice-like pattern of trees planted in hedgerows.

Implications

The land use conversion and fragmentation processes occurring on individually managed private land aggregate and have implications for ecological functions at the landscape level. The two major changes have been the increase in vegetable cultivation and the increase in tree planting, which is combined with a shift in forest garden planting pattern. I focus on general implications for native flora and fauna, and for flows of water in the landscape.

Vegetable Cropping

Cultivation of temperate climate vegetables involves a repetitive cycle of land clearing and soil cultivation which can lead to soil erosion problems on steep slopes, unless mitigation techniques, such as terracing or contour planting of perennials, are employed. If this cultivation occurs in proximity to riparian areas, soil protection measures are particularly important to reduce flows of soil into the stream channel. Silt loads are in general detrimental for stream biota (especially fish). In addition, accumulations of silt and

sand scour out water courses while in suspension and eventually are deposited downstream, a particularly undesirable factor in the upper watershed of a reservoir system.

Spatial analysis shows that much of the emerging vegetable cultivation in the Mirahawatte landscape occurs in close proximity to the Matatila river. Field surveys indicate very little visible mitigation occurring on the ground. It is very common for cultivation to extend to just a few feet from a stream. While there are a few patches of perennial vegetation left along the river, for much of its course there is no such buffer between the stream and cultivation. A further issue of concern with regard to vegetable cultivation, particularly in proximity to surface water flows, is the need for chemical inputs in order to grow these crops. Buffers of perennial vegetation could help to filter and dilute the impacts of fertilizers and biocides and reduce their probable effects on sensitive stream flora and fauna.

Perennial Vegetation

The changes in the landscape's perennial vegetation also have likely ecological implications. The loss of natural forest is a loss of habitat for native forest flora and fauna. It is not compensated for by forest plantations. Surveys of species distribution in this landscape show very few birds and little soil invertebrate diversity in the plantations when compared with natural forests (Senanayake, 1987). Forest gardens, though not as valuable in this regard as natural forest, provide much better habitat for fauna and have high species richness for woody perennials. Thirty seven percent of the woody perennial species (35% of the 38,618 individually counted trees) found in gardens are native forest species from the area (Everett, 1991). Thus, the increase in gardens may to some degree make up for forest loss for these species[1]. However, the combined loss of natural forest patches and

[1]It would be interesting to study the species level selection process occurring as the block planting with many self seeding volunteers shifts to restriction of the area under tree cover to homestead borders. Some species may be 'weeded out'.

the shift toward boundary planting in forest gardens indicate a reduction in forest interior type habitat which could lead to extinctions for specialized flora and fauna.

As far as hydrologic conditions are concerned, the primary measure for fluxes of water linked to vegetation pattern in a landscape is the overall area of cover (Forman and Godron, 1986). In the Mirahawatte landscape, the increase in tree cover is likely to be very significant and will outweigh effects of the change in tree planting patterns. The larger area covered by trees in 1988 indicates a higher capture of water and greater infiltration into the ground-water in this landscape than was likely in 1956. The degree to which this effect is balanced by increased evapotranspiration from the vegetation would be interesting to ascertain. In addition to these overriding results, there may be localized variation in run-off patterns within the landscape depending upon vegetation configuration. If the pattern of forest garden conversion toward border planting of perennials is maintained (and strengthened in the most recent homesteads), soil erosion from vegetable cropping in gardens will be contained. However, should this be the beginning of a larger trend of loss of perennial vegetation, as observed for the landscapes between Welimada and Nuwara Eliya and suggested by the evolving planting patterns above the Matatila river, then water capture may be reduced in future and problems with rapid run-off and soil erosion could emerge.

6.2 Analysis of State Factor Contributions to Initial Conditions Determining Forest Garden Vegetation

While the phenomenon of vegetation fragmentation in individual landholdings and patterns of land use aggregation in the larger landscape were revealed by spatial analysis, efforts to explain what determines conditions for vegetation, in particular for forest gardening, and why some Mirahawatte gardens are being converted to vegetable cultivation and why others are not, required an alternative approach to analysis. Using a state factor approach, in Chapter 5 I sought to identify variables which are or seem to be correlated

with forest garden vegetation and in particular, to define factors related to the fragmentation process in the Mirahawatte landscape.

Forest Garden Structure and Composition

First, I described vegetation structure and composition for forest gardens in several regions of the highlands. I compared woody perennial species richness, frequency and abundance, density , height class structure and crown closure, as well as ground cover in gardens. I found that while the traditional pattern of forest gardens as dense blocks of diverse species of trees around a home was common to all regions, the structure and composition of gardens varied. Gardens in the Mirahawatte landscape were less dense and less species diverse than gardens in the two other regions surveyed. While a range of species is shared among all gardens, many trees and shrubs are confined to certain regions, with implications, among other things, for the gardens' economic productivity.

Variables for the State Factor Model

In order to better understand the process of garden management and the conditions which may influence garden vegetation, I used a state factor model to identify variables which can be linked to measures of vegetation in forest gardens. I asked first what variables might be appropriate measures of vegetation and of state factors in the model. It was desirable to find several variables for each state factor, and in particular, to have variables operating at different levels of spatial and time scale. The data available to test the model were very limited, and as a result, this analysis is suggestive of the potential of a hierarchical state factor approach rather than being a full test of the model.

Vegetation is the dependent variable in the model and was represented by canopy closure as a variable measure of vegetation quantity, and by species richness as a measure of vegetation quality. The independent variables analyzed as expressions of state factor influence were:

* for topography: slope position, relief, aspect and slope

* for parent material: soil pH and slope

* for climate: rainfall
* for time: garden age and village age
* for organisms: garden size, available land, household members and children, gender roles in vegetation management, use of chemical inputs in gardens, education, source of income, and occupation

On the basis of analyses of variance and correlation the following variables from the pool were selected to be tested in the state factor model: aspect, slope, rainfall, garden age, village age, garden size, available land, and number of household members.

The Aggregation Approach and Implications of its Results

I applied several rules for aggregating data hierarchically in the state factor model. It was likely that key variables determining conditions for vegetation might vary spatially, between gardens or landscapes. Further, there might be variables which are relevant for all gardens at a particular scale of aggregation, while others become more significant at higher or lower levels of scale. In addition, the mode of aggregation itself was likely to reveal different degrees of significance among factors (Govil, 1991).

The first aggregation rule used here was for human organization, from the household through the village, division, district and provincial levels of administrative boundaries. The division and district level scales in human organization, also correspond with the landscape and regional scales described by a spatial aggregation rule (e.g. garden, neighborhood patch[2], landscape, region). In this case, not only did the relative importance of state factor variables change with scale (e.g., slope was a significant variable in some villages but did not enter the model at all at the division (landscape) level), but the overall fit of the model, indicated by the value for the adjusted R square, was variable across scale. The variables did not fit the model very well at the village scale, yet at least for the Welimada division and for the Badulla district level, the fit was over 60%. The explanatory value of the model declined at the provincial level where districts were combined.

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[2]The spatial aggregation hierarchy would have been tested, but I have no field data for the neighborhood patch scale of garden aggregation.

In a second approach, the aggregation rule for the analysis was to compare gardens in groups of increasing age, thus using a nested time scale instead of a spatial hierarchy. Results again varied for different scales. Very good results were achieved in correlations between vegetation in relatively new gardens and state factor variables. For example the correlation between canopy closure and species richness in gardens and the number of family members (an indicator of available labor) is clear for young gardens, but no longer appears for gardens over 20 years of age. In general, the results for middle aged and old gardens were less conclusive, perhaps because there is an exponentially increasing potential in vegetation variation as a garden gets older[3].

To test the difference between a hierarchical aggregation rule with some implied meaning and a random form of aggregation, the data were randomly aggregated into three groups of increasing numbers of cases to test for a difference in the variables' fit. Overall, the results from the random aggregation approach showed that the variables had a high degree of fit with the model, but they were difficult to interpret within the theoretical framework defined for the state factor model. The results, in terms of R and adjusted R square surpassed those of the hierarchical aggregations for several levels of scale, yet did not match the best fit of the hierarchical groupings for others. These results both confirm the value of the hierarchical state factor approach and demonstrate its limitations. In the cases of the scales at which the hierarchical aggregation approach surpassed the random approach, interpretation of the results leads to clarification of the role and relative importance of state factors in influencing vegetation and land use. The model employed data collected at the ecosystem level. As predicted by hierarchy theorists (Salthe, 1984) the model thus had the best explanatory power at the levels of scale directly above, the landscape and between landscape levels, and lost value with increasing distance from the

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[3] A middle aged garden could exhibit characteristics of middle aged vegetation in terms of canopy closure and species richness, or if parts or all of the garden had been cleared at one time, its vegetation would have a less developed character. The potential for variation is increased, the older the garden gets.

focal level. It is possible that better fit could be achieved at more removed levels if data were collected using a method applicable to several focal levels to extend the range of the model. Further the results demonstrate the limitations of the state factor approach as defined here. It is possible that incorporation of theoretical insights from other disciplines such as economics or demographics might provide expanded bases for understanding the role of the human state factor in the model which would strengthen the state factor approach.. Finally other theory may provide insights to interpreting the random aggregations' results in ways beyond the limits of state factor theory.

The results from these three approaches to aggregating data for testing in the state factor model indicate the importance of the choice of aggregation rule. Not only do the approaches lead to different overall values of fit, the quality of results, such as which variables are more correlated with vegetation measures under which circumstances, varied with the specified aggregation rule as well. This result supports earlier work on data aggregation in econometrics by Govil (1991) and is very logical once it is considered, yet in statistical analyses, the implications of such choices have often been overlooked (Ibid). In this case, the ability to analyze the data with two different hierarchical approaches led to valuable additional information which would have been missed had only one or the other rule been applied.

Results from the State Factor Model

Despite the limitations of the data, the results from the hierarchical state factor analysis are very interesting and suggest that the approach has some utility in determining key variables which influence vegetation pattern at different levels of scale.

When data from all gardens in the survey are entered in the model, the overall adjusted R square for canopy closure is .548, and for species richness it is .409. Thus, half or close to half of the variability in these vegetation parameters is correlated with variations in the state factor variables. When the aggregation rules were applied to analyze the data at different levels of scale, better results were achieved for some levels.

TIME

Overall, the importance of the variable 'village age' for vegetation quantity and quality (canopy closure and species richness) overrides. Village age enters the model for all three modes of aggregation at nearly every scale, and it enters first. For the case of individual villages, where village age is constant, garden age enters the model as frequently as any other variable. Thus, the model indicates that time is the most important state factor for garden vegetation. No other variable is nearly as significant.

VEGETATION QUANTITY AND QUALITY

When data were aggregated using a hierarchy of human organization, the results for canopy closure (i.e. vegetation quantity) were quite conclusive. In addition to time, the state factors representing site quality enter the model most often. In particular, slope, which is a measure of both topography and parent material (soil depth) appears in or nearly enters the model in most cases, playing a predominant role at the more localized scale and decreasing in significance at the regional level. In the relatively xeric Welimada division, slope is an indication of lower canopy closure and poor vegetation establishment. In the wetter regions, where vegetation grows easily, the high canopy closure indicates land too steep to support other cropping patterns such as paddy cultivation or even tea growing.

Further variables associated with canopy closure at large spatial scales of aggregation, and also for young gardens, indicating importance for vegetation establishment, are climate and household size. Gardens with high canopy closure tend to be associated with wet climates. Labor is required to achieve a dense and species rich garden in a short period of time.

Land and garden size are the major variables associated with species richness (vegetation quality) besides village age. People with access to more land have more species rich gardens. Labor is also important for species richness in young and middle aged gardens, and appears as a significant variable at the larger scales of spatial aggregation as well. This indicates perhaps that a larger household is more likely to have someone

interested in and ready to plant and maintain a greater variety of species. Climate is also a significant factor at the between landscape and regional scales as well as influencing richness in middle aged gardens.

Interpretation of Results

The results suggest that gardens with dense and species rich vegetation are most likely to occur in old settlements in wet climates on comparatively large plots of moderately sloped land belonging to large families. Initial conditions for species richness and canopy closure in gardens not fitting the description are less favorable, suggesting that they will require more effort to establish. The gardens in the Mirahawatte landscape belong in the latter category, at least as far as climate is concerned, and for the case of gardens established since the 1950's, several other variables representing conditions for vegetation are marginal.

Beside the effects of climate, access to sufficient land of good quality is a constraint. In the old villages, including Mirahawatte, homesteads were established on moderate slopes, near water, close to land that could be converted to paddy fields. Some of the larger landowners have land claims dating back to land grants from the Kandyan kings. The next generation of settlers made do with the second best sites, and smaller holdings. The influence of population pressure is clear in the comparison of settlement in the GIS coverages for 1956 and 1988 in Mirahawatte (Fig.3.3, 3.4).

In addition there are other factors which make garden establishment more difficult in new colonies. First, there are fewer mature trees nearby. This means less planting material is available close by from neighbors or from natural seed sources[4]. There are greater cultural and socio-economic difficulties in colonies (Perera, 1985). Often people from different backgrounds are thrown together and make community cooperation and

[4] A tree planting campaign by village youth from Mirahawatte for farmers in Matatila demonstrated this principle. There ware few trees and no sources of seed and seedlings in Matatila, a key reason, according to the farmers why they did not have more trees. But in Mirahawatte, every child lived in a forest garden and easily collected 50 or more surplus seedlings to contribute to the program. Over 2,000 seedlings were collected in a few days.

development difficult (GTZ; Gunasinghe, 1990). These results have particular implications for changes in land use in the upper Uva Basin.

The fundamental settlement patterns and farming systems are similar throughout the highlands, yet in relative proportions of farming systems components and land use, they vary. The spatial analysis indicates that the Mirahawatte landscape is changing rapidly. The pattern of conversion in agriculture from traditional paddy and chena crops for subsistence toward vegetable cash cropping found in the Mirahawatte area has been documented for other parts of the Intermediate Zone in Sri Lanka, but is not widespread in the Wet Zone (Marby, 1974; Wickramasinghe, 1990).

A significant conversion toward annual cropping in the Mahaweli watershed may have aggregated effects beyond the highland region and is therefore of national concern. The state factor analysis suggests key factors which may identify households, villages, landscapes and regions likely to have good degrees of perennial cover and species richness as well as areas likely to be converting toward vegetable cultivation. These latter areas deserve particular attention from agricultural extension efforts at promoting soil conserving cultivation techniques and research and development of perennial crops.

For the case of fragmentation of gardens and hedgerow planting in Mirahawatte, the state factor model suggests that village age and site quality are major factors influencing the conversion process. It suggests that in the newer settlements of Matatila and Balathotelle, poor quality land on steep slopes and with thin soils is being used for vegetable cropping. This finding is substantiated by the GIS spatial analysis correlating vegetable cultivation with steep slopes. Two way analysis of variance further indicates that farmers are the most likely land owners to be growing vegetables for cash on their homesteads.

This study has used spatial analysis to study changes in land use patterns and their landscape aggregation around Mirahawatte, Sri Lanka. It has confirmed that vegetation and land use patterns are correlated to initial conditions which can be represented by state factors (Jenny, 1941, 1980). State factors have different expression at different levels of

scale. As suggested for previous econometric analyses in which hierarchical aggregation was applied (Govil, 1991), state factors in landscape ecology have varying degrees of significance depending on scale and the mode of hierarchical aggregation.

For a given place or scale of analysis at a given point in time, key state factors which influence vegetation patterns can be elicited with this approach. In Welimada division, Sri Lanka, village age, topography and parent material are key factors influencing forest garden vegetation. Gardens in more recent settlements, and homesteads located on steep slopes are less likely to have dense and species rich woody perennial vegetation.

These findings, along with the large literature in social forestry and agricultural and community development , indicate that policies directed at watershed protection and maintenance of biodiversity on the Uva Basin side of the Upper Mahaweli Watershed should focus on working with the small farmers in each landscape on planning and implementing economically attractive and ecologically sophisticated land use.

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Appendix 1

Implications for the Mirahawatte Landscape - An Ecologically Focused Landscape Model

Land use patterns aggregate and have cumulative effects on landscapes. Landscape level effects and their feedbacks to influencing initial conditions for land use and life in the landscape can be inferred. In the case of Mirahawatte, the changes occurring in homestead gardening as a result of uncoordinated actions of individual land owners have likely negative ecological implications for the future of the larger landscape, and as part of the Mahaweli watershed, for the region and the nation as a whole. Perhaps landscape level planning and coordination could provide approaches to mitigating ecological impacts of human land use.

Effective land use planning that incorporates ecological values would require both an understanding of present land use and likely future needs of the people, and a vision of spatial configurations for human land uses which sustain the ecological resilience of the landscape as a whole. In Mirahawatte, forest gardens and the recently emerging hedgerows are forms of land use which have emerged from the local culture, have withstood the test of time, have demonstrated ecological value, and may yet have more than subsistence level economic value, if explored in earnest. One approach to coordination in the landscape could be based on the strengths which this system provides in the existing context. A model for a modified spatial distribution of land use to meet ecological goals and social needs is presented.

A GIS coverage was built to provide examples of some approaches which might be considered under a landscape management plan. Three vegetation management possibilities, the changes in vegetation and land use area implied and the expected ecological implications for the landscape are discussed. Potentials for implementing these or other types of coordinated management are evaluated for

cooperation between local people, local non governmental organizations and local and regional government. The three mitigation measures suggested are, a riparian buffer zone, vegetable plot hedgerows, and removal of monoculture forest plantations.

RIPARIAN BUFFER ZONE

The ecological importance of riparian zones is well documented (e.g., Jeffries 1990; BLM, 1990). Protection of riparian zones can include a range of measures, one of which, that is largely agreed upon is to maintain buffer zones of perennial vegetation along stream channels (Yates, 1988, BLM, 1990).

The lack of perennial vegetation along the banks of the Matatila river has been demonstrated and a few of the likely ecological implications have been discussed. The existing legislation requiring stream protection is difficult to enforce. A cooperatively planned stream protection zone of perennial vegetation could mitigate many ecological problems here.

The specific issues including, what width the buffer should have; what types of vegetation should be planted or encouraged (would perennial cash crops such as fruit trees be advisable?); who should pay for the cost of taking land out of its present use and converting it to a landscape-wide and regionally beneficial use; how would the protection zone be maintained and monitored (given the exiting patterns of private land use, this could mean making individuals responsible for strips adjoining their land) are issues to be addressed in Sri Lanka, along the river, with the people concerned.

VEGETABLE PLOT HEDGEROWS

Vegetable cultivation is an important source of income for small farmers in the Mirahawatte landscape. The environmental impact of this form of cultivation, based on the tendency for plots to be located on steep slopes and often in close proximity to the river, is expected to be severe.

One approach to mitigating problems from soil erosion and possible build up of chemicals in the landscape is to use perennial vegetation for contour terracing. Sloping Agricultural Land Technology (SALT) a cultivation method introduced from the Philippines (e.g. GTZ, 1992) is now being tested by the Department for Export Agriculture in Kandy District and by the NeoSynthesis Research Centre in Mirahawatte. Two parallel rows of small, fast growing, nitrogen fixing trees (Gliricidia sepium works well in NSRC trials) are planted close together along the contour at intervals of several meters depending on the slope. The trees soon form a hedgerow to trap soil and in time create bench terraces. The trees provide fodder and mulch and can be used to support vines such as pepper. Other crop bearing trees or shrubs can be planted at intervals along the contour. The width of such hedgerows might vary, but is likely to be kept narrow to maximize land available for field crops.

In order to roughly simulated a SALT approach, a one meter buffer around each vegetable plot was entered into the landscape model. The scale of Fig. 6.1 does not allow many of these hedgerows to be visible, however, the data in Table 6.1 do include their effect.

FOREST PLANTATIONS

The ecological value for biodiversity of the pine and eucalyptus plantations on the mountainsides above the village is questionable (Senanayake, 1987), while the species richness in the *patana* can be very high (Mueller-Dombois and Perera, 1971). The hydrologic value of grassland, in terms of run off for stream flow is high (Maduma-Bandara, 1985, NARESA, 1991). The economic yield from the forest plantations - too distant from the factory to make resin tapping economical from the pines, and often quite far from transport roads for logging - are not likely to be very high, if indeed, they can cover the cost of their establishment. The value of the *patana* by these criteria is higher than

the value of forest plantations, and thus the forest plantations were removed and reconverted to *patana* in the model.

A LANDSCAPE MODEL

In this model, I have arbitrarily chosen a buffer width of 20 meters on either side of the river, and a one meter strip around each vegetable land use patch[1] as a test case[2].

The land under forest plantation was simply reconverted to *patana*. The change in land use resulting from this conversion (i.e. the cost of these buffer zones in terms of land subtracted from other uses) is indicated in Table 6.1. The individual impacts of the stream buffer and the vegetable cultivation can not be distinguished from the present data.

The costs of the conversion for this scenario are not as high as one might expect (Table 6.1). A total of 1,719,037 square meters (16%) fall into the buffer category. The 18% loss in forest gardens indicates a shift in significance attached to these garden areas, rather than a conversion to other uses. Managing these lands as buffers would likely not entail major changes, though there could be preferred species compositions to fulfill ecological goals. The 8% 'loss' in natural forest is really only a conversion in name, that would not entail changes on the ground. The loss in bare ground (18%) and land presently under vegetable cultivation (6%) would mean conversion of private land from other uses with likely economic costs. The loss of some *patana* to buffers is made up for in part by the return of forest plantation land to *patana*.

Many other vegetation management approaches could be included, such as landscape level design of habitat corridors for local and migratory fauna. The suggestion here is that such planning is possible. The degree to which it occurs and

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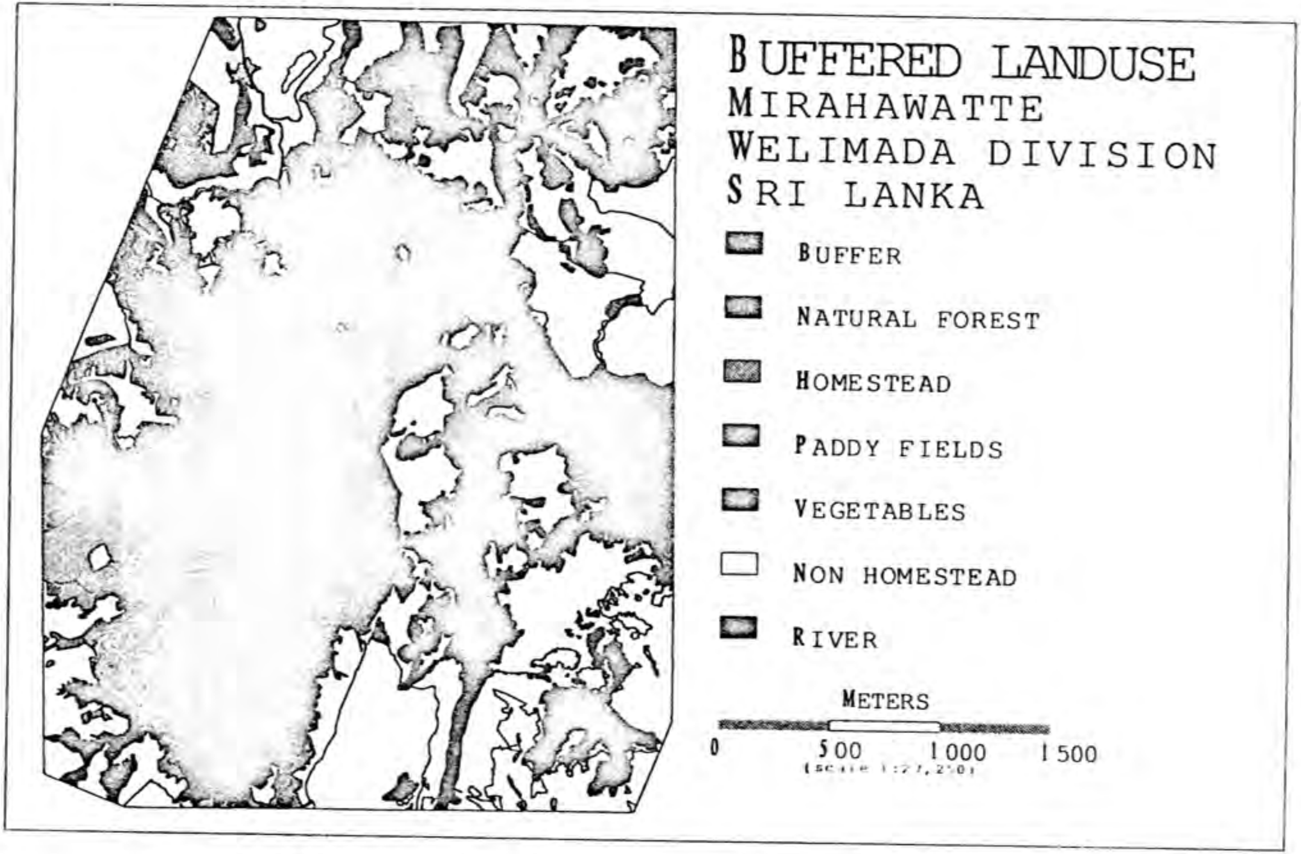
[1]Note that the one meter buffer surrounds each identified patch of vegetables in the landscape, not the individual holding size, which in many cases could be smaller.

[2]There is a great deal of discussion about the necessary width and the degree of exclusion of various land uses required for such protection zones to fulfill their purpose under a variety of circumstances.


BUFFERED LANDUSE
MIRAHAWATTE
WELIMADA DIVISION
SRI LANKA
BUFFER
NATURAL FOREST
HOMESTEAD
PADDY FIELDS
VEGETABLES
NON HOMESTEAD
RIVER
METERS
0
500
1000
1500

then is actually implemented will depend in large part upon local people, their interest and involvement in the process. Their interest is likely to be determined by the costs and benefits they would incur from participation.

Table 6.1. Area Changes with River and Vegetable Plot Buffers

Land Use	m2 in 1988	% of total	m2 if buffered	%change
Grassland	2,516,074	22	2,313,291	-8
Natural Forest	305,345	3	278,263	-8
Forest Plant*	847,754	8	none	-100
Estate Tea	905,733	8	895,488	-1
Paddy fields	1,245,357	11	1,205,078	-3
Trees**	2,596,941	23	2,140,743	-18
Private Tea	1,445,899	13	1,389,186	-4
Vegetables[3]	1,072,272	10	1,009,606	-6
Bare Ground	81,934	.7	66,617	-19
Buffer	na	na	1,719,037	
TOTAL[4]	11,017,309			

*Forest plant are pine and eucalyptus plantations on government land

** 'Trees' are forest gardens

Implications for the Mirahawatte Landscape - the Potential for Local Landscape Planning

Three tiers of cooperation can be envisaged here. First and foremost are the farmers, the land users in the landscape. If information can be provided them about long term changes and effects of change in their landscape, it is fundamentally up to them to decide whether cooperation to achieve an alternative future is desirable and what it would cost each of them to participate in a joint planning and maintenance effort. If people wish to work on the problem, then it would be the role of local and national government to support the people's effort as much as possible. Some elements of government

[3]I was not able to distinguish vegetable cultivation from bare ground on the 1956 photographs, and therefore called all cleared land with no cover bare ground (paddy fields are more easily distinguishable). As the major vegetable boom did not begin until at least five years later, it is not likely that there were many plots under vegetable cultivation at the time. On the 1988 photos by contrast, rows of cultivated vegetables can be seen and, in addition, I had recent ground truthing experience in the village (1986; 1989-1991) to help in defining cover types.

[4]Roads and the Matatila River were also digitized as polygons (visible on the maps figs. 4.1-4.8) which later proved problematic as errors in digitizing these linear features grew disproportionately.

involvement already exist, (e.g. agricultural extension; legislation for riparian zone protection; land alienation for village expansion programs). These and many others might be coordinated in conjunction with landscape and regional planning efforts.

In addition, NGO's might contribute to the process for example in supporting research ranging from ecological surveys and environmental monitoring and education to the search for marketable perennial cash crops (e.g., the NeoSynthesis Research Centre, Mirahawatte which supported this research).

GARDEN SPECIES LIST[1]

	species name	family	english	sinhala	use
1.	Achronychia pedunculata	Rutatceae		ankenda	fuel, med.
2.	Aegle marmelos	Rutaceae	bael fruit	beli	fruit, med
3.	Agave vera-cruz	Agavaceae	agave	hanna	fibre, fences
4.	Albizzia lebbek	Leguminosae		mara	shade
5.	Albizzia odoratissima	Leguminosae		huriye	shade
6.	Allophyllus cobbe	Sapindaceae		kobbe	tools, fuel
7.	Alstonia macrophylla	Apocynaceae		avarinuge	
8.	Anacardium occidentale	Anacardiaceae	cashew	cadju	nut
9.	Ananas sativus	Bromeliaceae	pineapple	anasi	fruit, med
10.	Anona muricata	Annonaceae	soursop	katu-anoda	fruit, med
11.	Anona squamosa	Annonaceae	custard apple	anoda	fruit, med.
12.	Areca catechu	Palmae	areca, betel nut	puwak	masticant, med
13.	Artocarpus incisa	Moraceae	breadfruit	del	food
14.	Artocarpus heterophyllus	Moraceae	jak fruit	kos	fd, fr, med, timb
15.	Azadiracta indica	Meliaceae	neem	kohombe	med, pesticide
16.	Bambusa sp.	Bambusoideae	bamboo	una	construction
17.	Callophyllum cuneifolium	Guttiferae		kina	
18.	Callophyllum tomentosum	Guttiferae		kina	
19.	Callophyllum trapezifolium	Guttiferae		kina	
20.	Camelia sinensis	Theaceae	tea	te	beverage
21.	Carica papaya	Caricaceae	papaya	papol, gas labu	fruit, latex
22.	Caryota urens	Palmae	fishtail palm	kitul	sugar, toddy,
23.	Cassia divericata	Leguminosae		ranawara	fences, shade
24.	Cassia spectabilis	Leguminosae		kaha-kona, mai	fences, shade
25.	Casuarina equisetifolia	Casuarinaceae			
26.	Canthium dicoccum	Rubiaceae	Cey. box wood	panduru	woodcarving
27.	Cedrela toona	Meliaceae	white toon	toona	timber, furnit.
28.	Chrysophilum roxburghii[2]	Sapotaceae		lawulu	fruit
29.	Cinnamomum verum	Lauraceae	cinnamon	kurundu	spice, essent. oil

[1]References: 1959 Abeywickrama. B.A. A Provisional Check List of the Flowering Plants of Ceylon Ceylon Journal of Biol. Sciences Vol2 No2:119-240.; 1959 Worthington, T.B. Ceylon Trees Colombo Apothecaries Co. Ltd.; Purseglove Tropical Crops Vol 2 Dicotelydons.

[2]in survey not distinguished from Lucuma palmerii

30.	Citrus aurantifolia	Rutaceae	lime	dehi	fruit, med
31.	Citrus grandis	Rutaceae	grapefruit	jambole	fruit
32.	Citrus nobilis	Rutaceae	mandarine	naran	fruit
33.	Citrus sinensis	Rutaceae	orange	pani-dodan	fruit
34.	Citrus vulgaris	Rutaceae	bitter orange	ambul-dodan	fruit
35.	Cocos nucifera	Palmaceae	coconut	pol	nut, fibre,copra,
36.	Coffea arabica	Rubiaceae	coffee	kopi	beverage, med
37.	Coffea robusta	Rubiaceae	coffee	kopi	beverage, med
38.	Corypha umbraculifera	Palmae	talipot	tal	ornamental
39.	Cucurma domestica	Zingiberaceae	turmeric	kaha	spice, condiment
40.	Cupressus sp.	Cupressaceae	cypress		coffins
41.	Cyphomandra betacea	Solanaceae	tree tomato	gass takgali	food
42.	Datura fastuosa	Solanaceae	datura	attane	med.
43.	Dendrocalamus giganteus	Bambusoideae	bamboo	una	
44.	Durio zibethanus	Malvaceae	durian		fruit
45.	Elaeocarpus glandifuler	Elaeocarpaceae	Ceylon olive	weralu	fruit, condiment
46.	Elaeocarpus serratus	Elaeocarpaceae	nil weralu		timber
47.	Elettaria cardamomum	Zingiberaceae	cardamom	enesal	spice, essent. oil
48.	Eriobotria japonica	Rosaceae	loquat	lokat	fruit
49.	Eriodendron anfractuosum	Bombacaceae	kapok	kottepulum	pillow stuffing
50.	Erythrina lithosperma	Leguminosae	dadap	eramudu	shade, mulch,
51.	Eucalyptus camaldulensis	Myrtaceae	river red gum	(k)tarpentine	timber, fuel
52.	Eucalyptus grandis	Myrtaceae	rose gum	(k)tarpentine	timber, fuel
53.	Eucalyptus robusta	Myrtaceae	red gum	(k)tarpentine	timber, fuel
54.	Eugenia caryophyllus	Myrtaceae	clove	karambu	spice, essent. oil
55.	Eugenia javanica	Myrtaceae	rose apple	jambu	fruit
56.	Eugenia michelii	Myrtaceae	Brazil cherry	cherries	fruit
57.	Ficus asperrima	Moraceae		buthediya	
58.	Ficus fergusonii	Moraceae		nuga	sacred
59.	Ficus hispida	Moraceae		kota dimbula	
60.	Ficus religiosa	Moraceae		bo	sacred
61.	Flacourtia ramontchi	Flacourtiaceae		ugurasse	fruit, med
62.	Garcinia cambogia	Guttiferae		goraka	
63.	Garcinia echinocarpa	Guttiferae		kokatiya	oil; hedges
64.	Garcinia mangostana	Guttiferae	mangosteen		fruit
65.	Gliricidia sepium	Leguminosae			
66.	Gmelina asiatica	Verbenaceae		demata	
67.	Grevillea robusta	Protaceae	silver oak	sabuku	shade, fuel
68.	Hibiscus spp.	Malvaceae	shoeflower	sapatumal	hedges, ornam.

69.	Jacaranda mimosaefolia	Leguminosae			
70.	Languas galanga	Zingiberaceae	aratta	condiment	
71.	Leucaena leucocephala	Leguminosae		ipil ipil	shade, mulch, fodder
72.	Ligustrum walkerii	Oleaceae		bora	tools, fuel
73.	Limonia acidissima	Rutaceae	woodapple	divul	fruit, bev., med.
74.	Litsea ovalifolia	Lauraceae		beeriya	timber, fuel
75.	Litsea spp.	Lauraceae		wal jambu	fuel,
76.	Macaranga peltata	Euphorbiaceae		kenda	
77.	Macaranga tomentosa	Euphorbiaceae		bu-kenda	
78.	Madhuca longifolia	Sapotaceae		mi	oil
79.	Mangifera indica	Anacardiaceae	mango	ambe	fruit
80.	Manihot ultissima	Euphorbiaceae	manioc	maioca	food, med.
82.	Melaleuca leucodendron	Myrtaceae	cajeput	lothsombul	
83.	Mesua ferra	Guttiferae	ironwood	na	
84.	Michelia champaca	Magnoliaceae		sapu	timber, fuel
85.	Moringa pterygosperma	Leguminosae	horseradish tree	morunga	food,
86.	Morus nigra	Moraceae	mulberry		fruit
87.	Muntingia calabura	Tiliaceae	jam fruit	jam	fruit
88.	Murrayana koenigii	Rutaceae	curry leaf	karapincha	culinary leaf
89.	Musa sp.	Musaceae	banana	kessel	fruit, fibre
90.	Myristica dactyloides	Myristicaceae	malabode		
91.	Myristica fragrans	Myristicaceae	nutmeg, mace	sadica	spice, essent. oil
92.	Neolitsea involucrata	Lauraceae		kududawule	fuel
93.	Nephelium lappaceum	Sapindaceae	rambutan		fruit
94.	Nephelium litchee	Sapindaceae	lytchee		fruit
95.	Nerium odorum	Apocynaceae	oleander		ornamental
96.	Nothopegia beddomei	Anacardiaceae		balle	
97.	Opuntia dilenii	Cactaceae	prickly pear	katupatuk	ornamental
98.	Oroxylum indicum	Bignoniaceae		totilla	
99.	Pandanus ceylanicus	Pandanaceae		pan	fibre
100.	Passiflora edulis	Passifloraceae	passion fruit	passiona	fruit, bev.
101.	Pavetta indica	Rubiaceae		pawatta	med.
102.	Persea americana	Lauraceae	avocado	aligata peere	fruit
103.	Phoenix sp.	Palmae			
104.	Phyllanthus emblica	Euphoribaceae		nelli	fruit, med, bev.
105.	Phyllanthus sp.	Euphorbiaceae		dikirile	fuel
106.	Pinus caribaea	Pinaceae	Caribbean pine		
107.	Piper betel	Piperaceae	betel leaf	bulath	masticant
108.	Piper nigrum	Piperaceae	pepper	gamiris	spice, condiment

109.	Pithecolobium saman	Leguminosae	rain tree	mara	shade
110.	Plumeria acuminata	Apocynaceae	temple flower	aralia	puja
111.	Pongamia pinnata	Leguminosae		karanda	
112.	Prunus persica	Rosaceae	peach	peaches	fruit
113.	Psidium cattleianum	Myrtaceae	strawb. guava	jam-peere	fruit
114.	Psidium guajava	Myrtaceae	guava	peere	fruit
115.	Punica granatum	Punicaceae	pomegranite	delum	fruit, med.
116.	Pyrus communis	Rosaceae	pear	pears	fruit
117.	Malus spp.	Rosaceae	apple		fruit
118.	Ricinus communis	Euphorbiaceae	castor	endaru	oil, med.
119.	Saccharum officinarum	Graminaea	sugar cane	uk	sugar
120.	Sambucus nigra	Sambucaceae	elderberry	ornament.	
121.	Santalum alba	Santalaceae	sandalwood	suduhandung	
122.	Saraca indica	Leguminosae	asoka	asoka	ornament
123.	Schefflera racemosa	Araliaceae			
124.	Schefflera walliciana	Araliaceae		ite	
125.	Semecarpus spp.	Anacardiaceae		badulla	
126.	Shorea robusta	Dipterocarpaceae		sal	timber
127.	Solanum spp.	Solanaceae		gass-battu	food
128.	Spathodea campanulata	Bignoniaceae	flame of forest	jus mal	ornamental
129.	Swietenia macrophylla	Meliaceae	mahogany	mahogany	timber
130.	Symplococs spicata	Symplocaceae		alu-bombu	med.
131.	Taddalia aculeata			kudumiris	
132.	Tamarindus indicus	Leguminosae	tamarind	siambala	condiment, med.
133.	Tectona grandis	Verbenaceae	teak	teke	timber
135.	Tephrosia sp.	Leguminosae			
136.	Theobroma cacao	Sterculiaceae	cocoa		condiment
137.	Thespesia populnea	Malvaceae		gansuriye	
138.	Tithonia diversifolia	Compositae	Mex. sunflower	titamal	mulch, bean poles
139.	Trema orientales	Tiliaceae		gedumbe	
140.	Turpinea malabarica	Staphylaceae			
141.	Vanilla moonii	Orchidaceae	vanilla		essential oil
142.	Vitex negundo	Verbenaceae		nikke	med.
143.	Vitis vinifera	Ampelidae	grape		fruit
144.	Wendlandia bicuspidata	Rubiaceae		sawanidele	fuel
145.	Zingiber officinale	Zingiberaceae	ginger	inguru	spice, cond, med