DEGRADATION, SUSTAINABILITY, OR TRANSFORMATION? A CASE STUDY OF VILLAGERS' USE OF FOREST LANDS IN THE MALNAAD REGION OF UTTARA KANNADA DISTRICT, INDIA

By

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NOTE

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Abstract

Degradation, Sustainability, or Transformation?
A Case Study of Villagers' Use of Forest Lands in the Malnaad
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Sharachchandra Madhukar Lele

Degradation of tropical forest resources and the sustainability of biomass resource use in the rural tropics are overlapping issues that have attracted much attention in recent times. This dissertation proposes an approach that recognizes the socially constructed nature of "degradation", uses multiple assessment criteria to deal with the complexity of forest ecosystems under intensive human use, and focuses on the variation in needs, interests and constraints of the rural households using the resource. This approach is applied in a case study of villagers' use of forest lands in the hilly Malnaad region of Uttara Kannada district in southern India.

Villagers' in the Malnaad have historically used forest lands for various purposes. The resultant vegetative landscape is a mosaic of "disturbed" vegetation types. To understand

the rationales behind villagers' use, it is useful to define degradation as reduction in, or sub-maximal production of, each of the biomass resources desired by the rural user household.

The results of a woody biomass balance for the sampled villages show that production in the village forests is higher than previous estimates, and that woody biomass harvests do not in general exceed its production. Herblayer production shows substantial trade-offs with tree canopy, and significant intra-annual reductions under certain grazing regimes. The results of investigations of vegetative structure and soil characteristics are inconclusive.

In the rural Malnaad, forest use is not directly linked to the market. The outcome of biomass resource use is therefore governed by the balance between a number of variables operating at the household level: a household's domestic, agricultural and livestock-related needs, its access to uncultivated biomass resources to satisfy them, its capacity to control those resources and to invest in their management, and the regime of property rights that enables and allocates this access and control.

CONTENTS

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Chapter I. Introduction

The decline of India's "biomass economy" (Agarwal, 1985) and its consequences for the rural poor and the rural environment have concerned academics and activists for some time, and have gained legitimacy in policy circles over the past decade or so. The debate on what causes the degradation of village "commons" overlaps with the better publicized debate on the causes of forest degradation and loss because forests are also subject to human pressures. The two situations differ in the relatively direct role that state intervention has played in demarcating and reducing villagers' access to forest lands. They also differ in that there is a fairly widespread belief in the need for some state control of forests in order ensure the flow of the many benefits they provide to society at large, a belief that has been given a fresh impetus by the newly-discovered role of forests as a means of mitigating global warming. But the two debates share the belief that rapid degradation of forests or rural biomass resources in general is occurring, that rural populations are at least partly causing it, and that much of the villagers' contribution stems from a combination of increased requirements of a rapidly growing population and the open-access nature of the resource.[1] The question, it seems, is not whether forests or biomass resources are being degraded, but how to prevent their degradation and promote their "sustainability".

[1] The literature on rural use of biomass from forest lands is large. Much of it consists of case studies describing and quantifying the flow of uncultivated biomass resources through the rural economy (Singh *et al.*, 1984; Singh and Singh, 1989; Pandey and Singh, 1984; Moench, 1989; Gadgil and Sinha, 1986, are some examples). Most of these studies indicate some role for the increased demands of a growing population in causing resource degradation. More recently, attention has been focused on the role of institutions governing access to and control over village commons (Arnold and Stewart, 1989; Somanathan, 1991) and need for village-level institutions for resource management (Ravindranath and Gadgil, 1990).

A review of the literature on villager-induced forest/biomass resource degradation suggests, however, that it has often struggled with (or in some cases stumbled over) at least three difficulties: the first, common to any discussion on environmental issues, is the meaning of degradation; the second, most acutely felt in the general context of tropical rural biomass use, is the scarcity of scientific knowledge. The third, perhaps peculiar to the rural context, is the absence of attention to the relationships between social structure and resource use.

Sustainable resource use is generally understood as maintenance of an undiminished flow of benefits from the resource over time. But natural resources, whether physical (e.g., land) or biological (e.g., plants), are often used in different ways by different users, sometimes in conjunction but often in competition. Hence, any discussion of the sustainability of that resource use incorporates an implicit or explicit choice of *what* use is to be maintained undiminished.

Forests or forest lands are perhaps the archetype of this problem. As indicated in Table 1(a), the benefits obtained from forests are many, ranging from fuelwood to carbon sequestration. They flow differentially to different users, who are schematically indicated as local, regional and global. These differences in some cases result from the nature of the ecological process (e.g., downstream benefits of soil erosion control). In other cases, they result from the social distribution of rights to forest products (e.g., timber benefits to regional users rather than local ones). More important, as Table 1(b) shows, the vegetation types that maximize the flow of benefits to each beneficiary may be quite different. Timber production would be maximized under a plantation that may hardly yield any biodiversity benefits; fuelwood and grass production is likely to be maximized in tree savannahs that provide limited carbon sequestration or timber.[2]

Consequently, a forest that appears to be sustainably used from one person's point of view may appear to be degrading from another person's point of view not because they use different data or techniques to assess sustainability, but because their choices of "what is to be sustained" differ. In other words, degradation and sustainability are socially constructed (Blaikie and Brookfield, 1987, p.26; Lélé, 1993). This implies that one must make one's sustainability objectives clear before discussing forest degradation. More important, it suggests that if one is trying to understand why villagers might be using forests in ways that reduce the future flow of benefits to them, one must be careful to look at those benefits that the villagers care about. Such has not always been the case.[3]

The second difficulty is the lack of empirical data on many aspects of the

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[2] Note however, that substantial uncertainties exist in our knowledge about the tradeoffs, as denoted by the cells marked with "?" in the table. Note also that all the primarily "vegetative" uses listed in the table diverge from other uses of the land, such as for dam projects, buildings or roads.

[3] A classic illustration of how insensitivity to this fundamental issue can lead to unscientific and biased results is the "environmental sustainability ranking" of moist tropical forests presented by Goodland *et al.* (1990, Table II). They ranked different forms of forest utilization as follows:

Intact forests > Utilization of natural forest > Tree plantation > Agri-silviculture > Agriculture,

where " > " means "more environmentally sustainable". This ranking appears to be based on their definition of sustainable use as "the use of natural forest ..... [that] indefinitely maintain[s] ... biological quality [and environmental services] unimpaired".

Two points need to be made here. Firstly, the products of the system chosen as objectives to be sustained are biological quality and environmental services. Would not a rubber tapper or a peasant cultivating a small patch of paddy in these lands have different (and possibly conflicting) objectives? Secondly, the authors do not make a clear distinction between a productivity ranking, i.e., which land-use is more desirable in terms of the current magnitudes of the desired products, and a sustainability ranking, i.e., which land-use would be more likely to maintain these current magnitudes (whatever they may be) undiminished longer than others. That an intact forest will provide higher initial biological quality than any of the other forms of utilization follows by definition. On the other hand, that the biological quality of and environmental services provided by an intact forest will be maintained longer than those provided by a utilized natural forest or even agri-silvicultural system has not been demonstrated for moist tropical forests in general. The authors do not provide scientific justification for the ranking in any specific case either. Their approach is typical.

Table 1 (a): Schematic distribution of forest benefits across user groups

USERS or BENEFICIARIES		PRODUCT, SERVICE or other BENEFIT								
		Timber	Fuelwood	Leafy Matter	Fodder	"Minor" Produce	Hydro-logical benefit	Soil Con-servation	Bio-diver-sity	Carbon seques-tration
	Local	+	+++	+++	+++	+	++?	+	+	+
	Regional	+++	+	0	0	+++	++?	+++	+	+
	Global	+	0	0	0	+	+	+	+++	+++

(b): Magnitude of benefits provided by different vegetation types

Extent of benefit:
+++ : high; ++ : medium;
+ : low; 0: none; - : negative

VEGETATION TYPE		PRODUCT, SERVICE or other BENEFIT								
		Timber	Fuelwood	Leafy Matter	Fodder	"Minor" Produce	Hydrological benefit	Soil Con-servation	Bio-diversity	Carbon seques-tration
	Dense "Natural" Forest	0	++	++	0	+++	++?	+++	+++	+++
	Dense, Lopped Forest	++	+++	+++	+	++	++?	+++	+?	++
	Open Lopped Forest	+	++	++	+++	+?	++	++	+	+
	"Pure" grassland	0	0	0	+++	0	++?	++	+	+
	Monoculture Plantation	+++	+	+	+	0	++	+	0	++
	Paddy Cultivation	0	0	0	++	0	++?	++?	?	0
	Barren land	0	0	0	0	0	-	-	0	0

functioning of tropical ecosystems under human use. This often leads to the use of inappropriate assumptions and criteria in determining the existence of and impacts of forest resource degradation. Much of traditional forestry research in the tropics has focused on products and management systems that are of high commercial value, such as on stemwood increment in even-aged single-species plantations, to the neglect of those used by villagers, such as the production of leaves or minor produce in mixed "jungles" (Gadgil *et al.*, 1983; Robinson, 1985; Gadgil, 1993).[4] Conventional wisdoms in tropical ecology such as "the poor productivity of secondary forests", "the low nutrient status of tropical forest soils", and the innate "fragility" of tropical forest ecosystems are common substitutes for knowledge and analysis (Lugo and Brown, 1984). They often bias researchers against the possibility that any human use (such as grazing of animals or lopping of trees) could be sustained over time. Oversimplifications of criteria range from equating heavy use to degradation (Singh and Singh, 1989) to carrying capacity calculations (Martins and Nautiyal, 1988) or linear programming models (Parikh, 1988) that do not take into account the enormous complexity and variability of biomass production under human use.

Finally, the discussion on the causes of and remedies for the degradation of forests under village use has been hampered by an inadequate appreciation of the complex relationship between social structure and resource use. Villages in hilly forested regions are often assumed to be more homogeneous than those in the plains (e.g., Agarwal and Narain, 1989), the existence of an open-access resource is equated with a

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[4] This may the result of a divergence of interests, i.e., it might be related to the problem of who controls the social construction of the problem (e.g., Guha, 1985).

tragedy-of-the-commons, and "communal" institutions of forest management are suggested as both sufficient and necessary to ensure sustainable forest management. Conversely, stratification in access to forest lands is equated with degradation (Nadkarni *et al.*, 1989, p.153); such arguments are then often used to justify heavy-handed bureaucratic control. The inter-dependencies between household characteristics and its use and management of different biomass types, and the role of property rights governing forest access and control in mediating this use and management is rarely elaborated upon.

The research approach in this dissertation includes (a) explicit adoption of a definition of "resource degradation" that is likely to be related to the priorities of the most proximate users, (b) use of region-specific socio-ecological data and multiple methods to judge the extent of degradation in these terms, and (c) a focus on the variation of needs, interests and constraints characterizing rural households and villages that determines how they use, sustain, or degrade the biomass resources on which they depend.[5] This approach was applied to a case study of villagers' use of forest lands in the hilly (*Malnaad*) region of Uttara Kannada district in southern India.

Broadly speaking, I shall show that:

1) Where villagers use forest lands as sources of inputs to domestic, agricultural and livestock activities, the resultant landscape is bound to be a mosaic of "disturbed" tree and grass vegetation. Misplaced or imposed notions of "forest" land as "forested" land may confuse *changes in land-use* with *degradation*.

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[5] In this, the approach responds to the call made by Blaikie and Brookfield (1987, p.16-26) for sensitivity to the social constructed-ness of degradation, embracing the complexity of the ecological issues, and entering the system at the level where the final decisions about land use or resource management are made, viz., the level of the household.

2) The variety of biomass types used and the complexity of the tropical forest ecosystem requires the use of multiple criteria for assessing sustainability. Their application yields results suggesting that biomass resources *are* being used in a highly productive and sustainable manner in many cases. The results also yield important insights into the interaction between the productivity and sustainability of different biomass types.

3) In an economy where forest use is not directly linked to the market, the variation in resource degradation, and in the use of the forest land, is explained by the extent to which the forest rights regime balances access and control with needs and incentives.

In the remaining part of this chapter, I shall describe briefly the region of the case study, the methods used in the research, and the organization of the rest of the dissertation.

1. The case study : The Malnaad region of Uttara Kannada district

Uttara Kannada district (formerly known as North Canara/Kanara or Karwar district) is the northern of the two coastal districts of Karnataka state in peninsular India (see Figure 1). The district straddles the range of mountains known as the Sahyadris or the Western Ghats that runs down the western coast of the sub-continent. East of the crestline of the Western Ghats, which is at its shortest (<600m) here, is a region of rolling hills of old rocks and red sandy-loam soils. Rainfall is heavy but decreases rapidly from west to east.[6] The natural humid tropical forest vegetation generally follows this rainfall gradient, changing from evergreen to semi-evergreen and moist-deciduous types,

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[6] Rainfall decreases from 5000mm or more annually at the crestline of the Ghats to 1700mm at a point just 40 km to the east. Details of the spatial and temporal distribution of rainfall, geology and soils are given in Appendix A.

and covers more than half of the land in Uttara Kannada district even today.[7] Throughout the Western Ghats of Karnataka, this hilly forested region east of the crestline is known as the Malènaad or Malnaad (in Kannada, the language of Karnataka state, *malé*=hill, *naadu*=region). In Uttara Kannada district, the southern and central part of this region (i.e, most of Siddapur, Sirsi, and Yellapur *talukas*, i.e., sub-divisions, see ?) constituting about 3000 km² is characterized by the dominance of centuries-old areca-spice cultivation, and the evolution of forest use, vegetative condition and forest tenure reflecting this dominance. This part of the hilly region of Uttara Kannada is the focus of my study of village-forest interactions, and will be referred to hereinafter as "the Malnaad".[8] In this section, I shall briefly describe the region's rural society, its agriculture, its relationship with forest lands, and the institutions that mediate this relationship.

1.1 Brief history of human settlement

The Malnaad region of Uttara Kannada is believed to have been settled by hunter-

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[7] Existing data on the extent of forests are quite confusing. Official land-use statistics (e.g., Census of India, 1981; District Statistical Officer, 1988) suggest that 80.9% of Uttara Kannada district is "forest", but this corresponds only to the legal classification of the land, not its physical condition. In fact, it does not even reflect the fact that by 1985 nearly 10.3% (1,052 km²) of the total land had been converted to various other uses, including cultivation, hydro-power projects, and mining (Reddy *et al.*, 1986). Much of this conversion is officially approved, yet is not reflected in the equally official land-use statistics, due to some arcane bureaucratic and legal complications. Gadgil *et al.* (1987) used Landsat imagery to estimate that 65% of the total land area is under some kind of tree cover (not counting orchards). Reddy *et al.* (1986) suggest a somewhat lower figure. Clearly though, the portion of land with some tree cover is more than 50%, a percentage far beyond that in most other districts in peninsular India.

[8] With apologies to the districts of Shimoga, Chikamagalur, Hāsan and Kodagu, which span similar hilly regions and are therefore part of the Malnaad region of Karnataka. Also, since land-use and other statistics are maintained not according to eco-climatic boundaries, but administrative ones, I will therefore often use the three talukas of Siddapur, Sirsi, and Yellapur as proxy for the areca-cultivating Malnaad region, and call them "the Malnaad talukas".

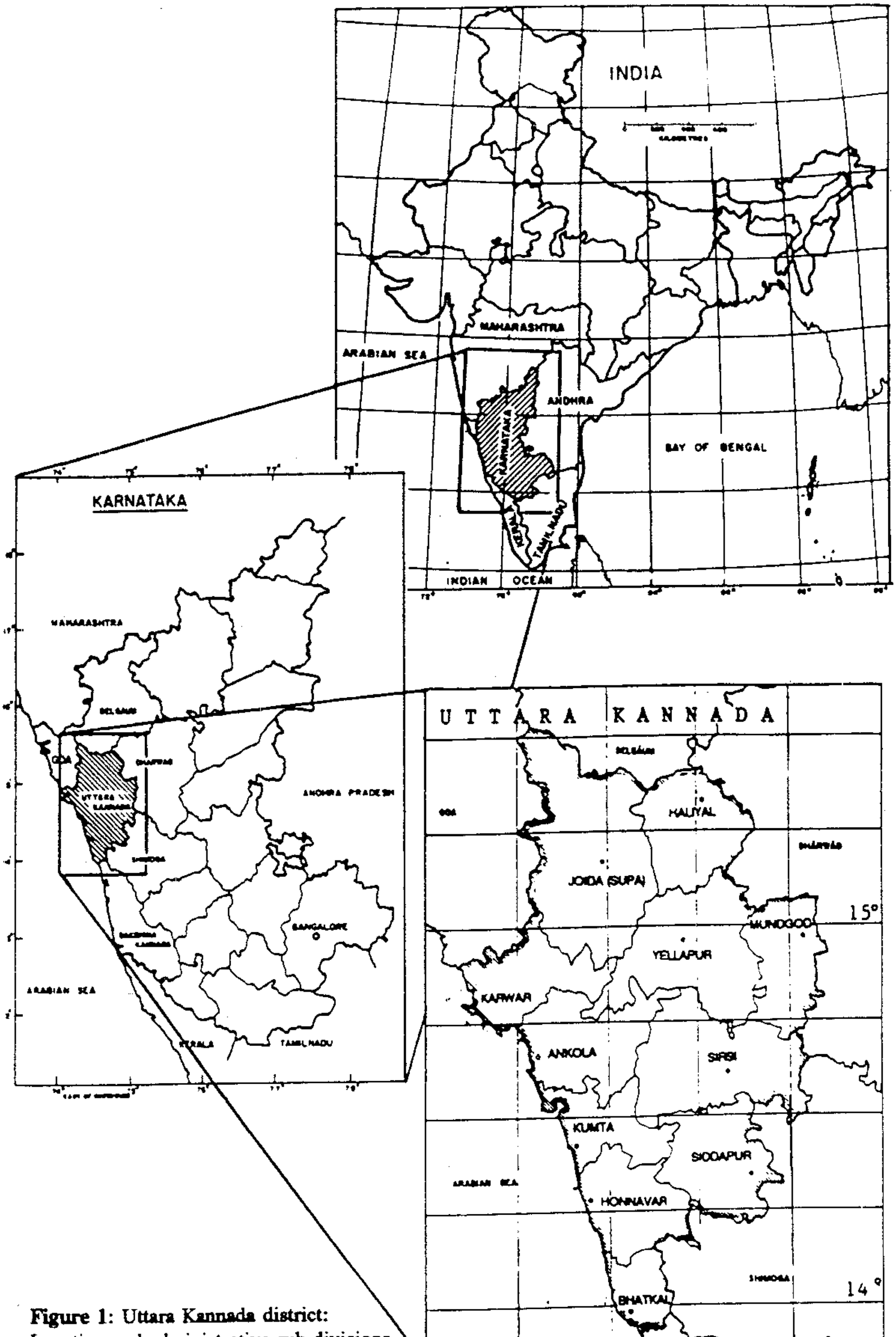

Figure 1: Uttara Kannada district:
Location and administrative sub-divisions

gatherer tribes before 1000 B.C. Agriculturalists and pastoralists are likely to have colonized the region between 1000 B.C. and 300 B.C., possibly beginning in the coastal areas and moving inland and into the Malnaad, practicing shifting cultivation. Wild pepper and cardamom cultivation is likely to have begun around this time, and exports of these spices from the west coast ports appears to have flourished.[9]

Subsequently, the region was settled by many other communities, prominent among these being the Havyak Brahman community that is credited with having developed the modern cultivation system of multi-tiered areca-spice orchards. This system relied upon the systematic import of nutrients and organic matter from forests to enhance and maintain the fertility of the cultivation under conditions of heavy rainfall and leached soils. Many other endogamous communities ("castes" in the biological sense) occupied other occupational niches as paddy cultivators, graziers, artisans and hunters. But the Malnaad region, because of its malarial climate, dense forests and sloping lands, was always sparsely populated compared to the coastal zone. A system of seasonal immigration of labourers from the southern coastal zone to work in the areca orchards evolved, and continues to this day.

The British colonialists gained control over this area around 1799, after their defeat of Tipu Sultan. After an initial period of uncontrolled exploitation of the region's (and India's) forest resources (Cleghorn, 1861,p.viii), the British established a forest department in 1864 and systematically appropriated these resources (Guha and Gadgil, 1989). Consequently, the condition of the communities dependent directly upon the

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[9] See Gadgil and Chandran (1988).

forests for subsistence took a significant turn for the worse. Shifting cultivation was completely suppressed, and the displaced communities were used as labour in the extraction activities initiated by the state (Pouchepadass, 1990). Other activities, such as *kath*-making (from the pith of *Acacia catechu*) were subjected to heavy taxation, or suffered from the heavy exploitation and conversion of large tracts of forests to timber plantations. Access to forests was curtailed for those involved in settled agriculture as well. But the importance of the cultivators (*ryots*) as sources of land revenue to the state gained them the support of the Revenue Department (see, e.g., Davidson, 1891). Thus, after a protracted struggle, the areca cultivators were able to obtain the *soppinabetta* privileges that gave them exclusive access to the forest lands around their orchards that they had traditionally used.[10] Other cultivators, less important as sources of revenue and less powerful in making these demands heard, were granted lesser privileges in more randomly assigned areas (see below).

During much of the British rule, the Malnaad region's population was decreasing or stagnant. While the rulers attributed this to malaria and influenza, local leaders claimed that the state's severe restrictions on people's rights to obtain inputs from the forest and to protect themselves against wildlife and malaria through periodic burning of vegetation around human habitat were also an aggravating factor (Masur, 1918).

The region was rapidly repopulated after Indian independence (i.e., post-1947), as malaria was eradicated and family sizes expanded. Thus, during the period 1941 to 1991, the total population of the three Malnaad talukas more than tripled. Although the

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[10] See Nadkarni *et al.* (1989, pp. 50-63) and Kamath (1987).

urban fraction increased from 11% to 26% in the same period, the absolute rural population in the Malnaad talukas increased from 82,200 to 231,900. With limited capacities to absorb this growth in industrial or other activities, demand for cultivable land mounted, prompting the Karnataka state government to release to cultivation significant tracts of land designated as forest land in a "Grow-more-Food" campaign in the 1960s. These tracts may amount to an (as yet unofficial) increase in the cultivated area of 15-25% in the Malnaad; most of these land grants appear to have occurred in the flatter eastern periphery of the hilly region.

1.2 Agriculture

Although forests are the dominant feature of the landscape, agriculture is still the major occupation in the Malnaad, as it has been for many centuries.[11] While paddy is the most extensive crop, it is the exports from the areca-spice orchards for more than ten centuries (and earlier from forest-based spice cultivation) have been the dominant feature of the rural economy.

The label "areca-spice orchards" applies to a complex system of horticulture that has evolved in this region over centuries. The structure of a fully-developed orchard is multi-tiered. The areca palm (*Areca catechu*, also known as betel-nut) forms the top canopy; Banana (*Musa sapientum*), which initially provides the shade for the arecanut seedlings, later forms the understorey, along with young areca plants. Vines of black

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[11] The forestry sector accounted for only 6% of the total workforce of the district in 1981 (Nadkarni, 1989,,, p.86). This low level of employment is partly a consequence of the extensive nature of modern forestry, but it may be aggravated by the exhaustion of important forest resources (e.g., bamboo and softwood) due to unsustainable harvests (Gadgil and Chandran, 1989) leading to idle capacity in the forest-based industries (Nadkarni, *et al.*, 1989).

pepper (*Piper nigrum*) or betel-leaf (*Piper betle*) are trained on adult areca palms, while cardamom (*Elettaria cardamom*) shrubs form the bottom layer. For the sake of convenience, and as the devastating impact of fungal diseases on cardamom and pepper over the past few decades has made areca the most important crop, I shall hereinafter refer to these orchards as "arecanut orchards".[12]

The orchards typically nestle in the narrow parts of the shallow valleys created by streams flowing off the hills. A pond at the upstream end stores water for the dry season, and drainage channels above it help prevent excess inflow from the hills during the torrential rains. Valuable evergreen trees such as mango (*Mangifera indica*), jack fruit (*Artocarpus heterophyllus*) and *néralu* (*Syzigium cumini*) are grown as shade trees and windbreaks around the orchard.

Downstream of the orchards, as the valleys broaden into flatter land, paddy cultivation dominates the landscape. In the Malnaad region, most of the paddy land is rain-fed, and the crop is grown during June-November, using the transplanting technique. Ploughing of most of these lands is carried out with bullocks, or sometimes with male buffaloes. A second crop may be grown during the dry season of January-April in the few fields that can be irrigated from the ponds or streams; this crop may be of legumes or, moisture availability permitting, of paddy or vegetables. In a small fraction of the wet

[12] Pepper and cardamom have been used as spices for millennia. Arecanut is chewed all over India and parts of south-east Asia, often along with betel-leaf and lime. In the past two decades, cocoa, ginger, turmeric and pineapple are being tried as inter-crops in these orchards. For more details on these cultivation systems, see HGVSCS, 1981 and Bavappa *et al.*, 1982. It is interesting to note that at least pepper, jack fruit and mango are indigenous to this region. The system of wild pepper cultivation, where the pepper was harvested from wild vines trained on forest trees (Buchanan, 1870 vol.II, para.1801, p.347) was prevalent till the 1890s, when restrictions by the British government on forest access appear to have forced its abandonment.

lands (typically 2-5%), sugarcane is cultivated. All the produce of the wet lands is for local consumption, with rice being the staple food, and sugarcane being crushed and boiled into *jaggery*, a form of unrefined sugar. Table 2 provides some idea of the area under the main crops and approximate estimates of that under forests (see footnote in table).

Table 2: Land-use in the Malnaad talukas

Land-use	Siddapur	Sirsi	Yellapur
Paddy	7000	10600	6300
Sugarcane	160	330	100
Areca	2400	2900	1100
Coconut	40	290	290
Forest	68200	103600	117700

[All values are in hectares. Agricultural area values are for 1988-89, obtained from the Statistical Assistant, Tahsildar Office, Sirsi. They have been rounded off to reflect my estimates of their accuracy, based upon my mapping of land-use in the sample villages. Forest areas are official statistics for legally designated forest lands. They do not exclude, and therefore the cropping areas do not include, land officially released for or illegally encroached for cultivation since the 1960s.]

Historically, in addition to areca-spice and paddy cultivation, *rāgi* (finger-millet: *Eleusine coracana*) or *jola* (*Sorghum vulgare*) were often cultivated in broadcast fashion on slopes adjoining paddy fields (Campbell, 1883, vol.II, p.5). Today, with the easy import of the millets from the extensively cropped regions to the east, their cultivation in the drylands of the Malnaad has virtually ceased. Significant parts of the erstwhile dry lands have been brought under coconut cultivation; mulberry (for silkworm rearing) and pineapple cultivation are also being tried out. The remaining dry lands are usually maintained as grasslands, and constitute an important source of fodder in the villages.

1.3 Communities and social relations

The Havyak (or Haviks) community[13] is a rare example of farming *brahmans* (who are otherwise engaged mainly in clerical, priestly or scholarly activities). Having developed the technique for orchard-based areca and spice cultivation in the Malnaad, they own most of the areca orchards (except in pockets of Siddapur taluka) and significant portions of paddy lands in the Malnaad. Simultaneously, their strong tradition of interest in formal intellectual activities, and the income from areca, has given them access to modern education and white-collar jobs.

The Kare-Vokkaligas and Kumri Marathas are primarily paddy cultivators, with the latter originally being shifting cultivators (*Kumri* = shifting cultivation) who settled in the northern parts of Sirsi taluka after the British administration suppressed their traditional occupation. Poorer Vokkaligas and Marāthās, as well as individuals from a sprinkling of other communities (Halepaiks, Gam Vokkaligas, Chaluvadis, Ambigas, Devadigas, Upparas, etc.) work as agricultural labourers in areca orchards, which are a major source of employment. Many of them were originally seasonal migrants from the coastal region who carried out the heavy work of soil addition, manuring and mulching, and the skilled work of areca harvesting and fungicide spraying in the areca orchards, and who have now settled in the Malnaad. The labourer households are invariably very poor, forming the bottom stratum of society.

The series of land reforms that occurred between 1951 and 1974 was successful at breaking the absentee-landlord tenancy systems that prevailed in the coastal areas, but

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[13] I use the word "community" to denote an endogamous group. The more conventional term "caste" may denote an endogamous group or a broad category within the hierarchical social structure known as the Hindu caste system.

not in redistributing access to cultivated lands. The land reforms therefore had limited impact in the Malnaaad, where tenancy was not very common to begin with (Joshi, 1985).

1.4 Forest dependence, use and impact

The historical relationship between villagers and the forest vegetation has always been somewhat schizophrenic. While forests were invaluable as inputs to the rural economy, they were also a barrier to expansion of cultivation, and even a hazard to existing cultivation as they harboured malaria and provided habitat to wildlife that caused much damage to crops.[14] While I shall focus on the nature of the dependence, the manner of its expression, and the general implications for vegetation condition, it is important to keep this duality in mind.

Uncultivated lands (which, in the Malnaad are mainly forest lands)[15] play a crucial supporting role in the rural economy of the Malnaad in many ways. Firstly, virtually all households (cultivators or otherwise) depend upon forest (tree) vegetation for meeting their requirements of fuel and structural materials. Secondly, cultivation in this region of high rainfall and leached soils requires continuous additions of organic matter

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[14] This tension was evident in the debate around forest rights and grievances in the early part of this century, when cultivators not only agitated for forest usufruct, but also for the right to burn strips of land around cultivation and habitation in order to protect themselves against wildlife and malaria (Masur, 1927).

[15] The term "forests" is apt to be confusing, as it may denote the physical vegetation condition on the land or its legal status. I shall use the term "uncultivated" lands or resources to denote all vegetation that is not directly planted, irrigated and manured. Thus, uncultivated lands include all lands with tree, shrub or grass vegetation in the legally designated forest areas (i.e., area lost to other purposes such as cultivation, roads, quarries), as well as in legally designated cultivable lands that are lying fallow (typically dry lands with grass, or some fallow paddy terraces). I shall use the term "forest lands" to denote the uncultivated lands legally classified as forest. As we shall see below, the vegetation on these lands may not conform to conventional notions of "forest" vegetation.

and nutrients to maintain soil fertility. This is achieved through the heavy application of manure to the fields and orchards. This manure consists of the dung, urine and bedding of animals, the latter being mainly leafy matter. Thirdly, areca cultivators use large quantities of tree leaves and twigs as mulch in order to (i) protect the soil from erosion during the monsoon, (ii) provide additional nutrients, (iii) control weed growth, and (iv) control soil moisture loss during the dry season. Finally, in order to obtain dung, draught power and milk, most households (especially cultivators) keep livestock (cattle or buffaloes). While some fodder for the livestock may be obtained from cultivated lands (e.g., paddy straw) or private uncultivated lands (green or dry grass), varying but substantial fractions of the fodder requirements are met from forest lands, mostly by grazing the animals for some or all of the year.

A qualitative picture of the complex pattern of extraction and use of biomass from uncultivated lands is provided in calendar form in Table II. A number of features may be noted. Firstly, the biomass inputs may be broadly categorized as tree woody biomass (for fuelwood and construction/fencing), tree leafy biomass (mulch and manure), shrub biomass (manure), and grass (mainly fodder/forage). Secondly, only fuelwood and timber might be directly used by the household; all other biomass goes as inputs into some productive asset: areca orchard, paddy field or livestock. This implies that households or communities with different productive assets within a village would have different needs for uncultivated biomass. Thirdly, the use takes place through substantial disturbance of the vegetation, through lopping, felling, cutting, and grazing. Further, in order to promote certain biomass type or species, villagers manipulate the vegetation further through fire and seasonal protection or care of natural regeneration.

Table 3: Calendar of biomass extraction from forest and other uncultivated lands.

Period	Biomass harvested (method)	Use of biomass
Monsoon	Shrubs, & sometimes tree leaves (cut/lopped)	Bedding for livestock and then to manure pit, or green manure for paddy fields
	Grass (cut or grazed)	Fodder, with dung going to manure pit
	Saplings & bamboos (cut)	Fencing material for paddy fields, orchards & grasslands
Early winter	Dry grass (cut)	Mainly as fodder, sometimes as mulch in areca orchard
Winter	Trees: leaves and tender shoots (lopped)	Mulch covering the manure applied to areca palms
	Trees: Twigs and branches (lopped)	Fuelwood for household consumption
Spring-Summer	Tree leaflitter (swept up)	Mulch in areca orchard; cattle bedding, or direct addition to manure pit
All dry season	Dead trees, logs (gathered)	Fuelwood, especially for arecanut & sugarcane boiling
Inter-mittent	Live trees/branches	Building construction/repair, agricultural implements

Note: Other products such as honey, fruit, nuts, herbs and bamboo/cane are also extracted to a small extent.

A quantitative description of the forest dependence of Malnaad agriculture has been provided elsewhere (CES and KSCST, 1990, see also Nadkarni et al., 1989) and will not be repeated here. Briefly, it shows that rates of biomass use are generally high, such as ~600-1000 t/capita/yr of woody matter, and up to 20 t/ha/yr inputs of leafy matter to the areca orchards and 5-8 t/ha/yr to paddy lands.

This manner of extraction and use of biomass from uncultivated lands has been the norm in the Malnaad region for centuries. Consequently, the vegetation around the cultivated lands or inhabitation in the villages is substantially different from that in "pristine" natural forests. The landscape is a mosaic of tree and grass-dominated vegetation types, varying in morphologies (e.g., lopped/unlopped), densities (e.g., high density trees with no grass, or completely treeless grasslands), and species composition (e.g., evergreen or deciduous).[16] Pockets of relatively undisturbed dense evergreen stands dot the landscape, especially in Siddapur taluka. This mosaic reflects the historical expression of people's use modified by the system of forest rights and the partitioning of usufruct between the local villagers and the state.

1.5 Institutions governing forest use and management

The structure of tenurial arrangements regulating and mediating the social use of forest resources in Uttara Kannada district is complex, and indeed in some ways unique. The "settlement" and "re-settlement" of forest rights carried out by the British colonialists during 1890-1930 is a watershed in the history of these institutions, and the resultant allocation of forest rights and privileges, embodied in the form of the Kanara Forest Privilege Rules (Anonymous, 1944), has remained essentially unchanged since then.[17] All forest lands are nominally owned by the state, but the extent of its control varies significantly by the legal category.

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[16] For details see Appendix D.

[17] What form these institutions took before British intervention, what motives dominated British actions, what their social and ecological consequences were, why the institutions have been largely untouched since India's independence in 1947, and what the consequences of such inaction in a rapidly changing socio-political environment might be are matters of substantial debate (Gadgil and Chandran, 1988; Nadkarni *et al.*, 1989; Buchy, 1990). Here I confine the description to how these institutions directly influence forest use today.

In the Malnaad, there are three forest land categories: Reserve Forest, Minor Forest and *soppinabetta*. Reserve Forest (RF), the category containing most forest land in the Malnaad and in the district (see Table 2), is the forest over which the government, in the form of the Karnataka state Forest Department (KFD), exerts maximum control. Local populations may be allowed to collect deadwood or sometimes graze animals, but these "privileges" can be withdrawn at any time, and indeed *are* withdrawn when, for instance, KFD starts a timber plantation in the land or declares it to be a wildlife sanctuary. Lands classified as RFs include most forests in sparsely populated areas, many forests in large villages, and pockets of climax evergreen forests (*Kaans*) that appear all over the region and have often been preserved through religious sanctions.

Minor Forests (MF) are forest lands assigned for the use of residents of a village or group of villages to meet their needs of fuelwood, fodder, leaf manure and other forest products. MFs are said to have been assigned in the proportion of 2 acres for every head of livestock in the village at the time of the forest settlement, but proportions were neither strict nor meaningful (Masur, 1918), since the villagers have neither exclusive use, nor any formal role in their management.

Soppinabetta (or betta for short) literally means "hill of leaves or leafy matter" (*soppu*= leaves or leafy matter, *betta*=hill). Physically, it referred to the strips or patches of treeland on the hill slopes adjoining the areca orchards that were traditionally lopped by the areca cultivators for mulch, animal bedding, manure, and fuelwood. Legally, it refers to the specific piece of forest land "attached" or assigned to a specific orchard plot(s), conferring *exclusive* privileges to the owner of that orchard plot.[18] These privileges include lopping of trees for mulch, manure and fuelwood, and livestock grazing and fodder collection, and even obtaining timber from these lands for personal use upon obtaining the sanction of and making a (till recently nominal) payment.

Thus, the current allocation of forest rights is such that direct commercial exploitation of the forest lands is the state's domain, but villagers have varying access to and control over biomass that can be used largely as inputs to their agriculture or livestock systems, or for domestic use.

1.6 Summary: What is forest degradation?

The rural areca-cultivating Malnaad region has had a long history of settlement and cultivation that has developed complex relationships between people and the uncultivated lands surrounding them. Villagers use various biomass inputs for various purposes. These inputs are harvested or gathered from the vegetation on forest and other uncultivated lands, disturbing the vegetation quite heavily in the process. Villagers may also actively try to manipulate this vegetation to change the product mix. The historical outcome of this use has been a mosaic of vegetation types that is far from "natural forest".

What constitutes forest "degradation" in this context? Historically, forest degradation has tended to be defined as a situation in which the forest vegetation is declining or absent, where "forest" gets variously interpreted as natural vegetation or

[18] I shall hereinafter use the term *soppinabetta* or betta land to denote the legal category, not physical status or use of the land.

simply as trees. Any manipulation of this vegetation is seen as degrading. With this definition, and given the tradition of heavy village use in the Malnaad, it is not surprising that "villager-induced forest degradation" as an issue dates back almost a century. For instance:

> "The kind of *bet* [betta] that meets one at every turn in the garden tracts consists of open forest of mutilated stems from which the branches have been lopped close to the trunk, ... This distressing landscape, ever present to the traveller in the garden tracts of Sirsi, Siddapur, and Yellapur, has forced me to the conclusion that the garden business is being overdone, and that ruin and desolation will be the outcome of a continuance of the present state of things (MacGregor, 1894, para. 10-11).[19]

More recent judgements about the state of affairs in the Malnaad have been even more obvious about their value stance:

> Nearly 70% of Betta lands [which are mainly in the Malnaad] are in degraded condition, and have become grass lands instead of being covered by useful trees (Reddy *et al.*, 1986).

Clearly, grass lands are not considered "useful", and hence represent degradation. However, the description of the rural biomass use system presented above suggests that this value stance may not coincide with that of the villagers', who use grass biomass in substantial quantities. To apply a "tree-based" value system to assess a piece of land that has historically been granted for villagers' use is to impose a model that may "see" degradation where another value system may produce very different conclusions. If the purpose is to understand why villagers use vegetation in ways that reduces the current or future flows of benefits from their forest lands to them, the external value system would not be analytically useful because it is likely to miss the motivations of the

[19] MacGregor was Conservator of Forests for Kanara at that time.

primary users and modifiers of the resource.

I therefore adopt the following definition of degradation and sustainable use for this investigation. Degradation is either (a) reduction in the future productivity or (b) sub-maximal production of the useful biomass obtained by the primary users of a piece of land, i.e., the village community or household using it. Sustainable resource use *maintains undiminished the useful flow of future production* to that community or household.[20] This definition assumes that the villagers are interested in maximizing and maintaining undiminished the production of the biomass they use.

2. Methods

This research was inspired by and carried out in full collaboration with Professor Madhav Gadgil and his team of researchers at the Centre for Ecological Sciences (CES), Bangalore. CES began its research into the natural and social ecology of the forests and villages of Uttara Kannada in 1983. Their work included an initial survey of three clusters of villages, and the subsequent initiation of an "eco-development" program in them. I was fortunate to be given access not only to large quantities of unpublished data but also to the knowledge and help of CES' field staff. I was introduced by them to the villagers, who had become quite familiar with CES' activities. My field work spanned the period between August 1989 and February 1991. I shall briefly describe the sites chosen and field methods used for the research.

[20] Further, given that villagers' use of uncultivated biomass is non-commercial, i.e., the biomass is not directly sold in the market, and that the marginal benefit from the product to the household is not likely to change rapidly over time, I chose to look at the physical production, not its economic value.

2.1 Sites and units of analysis

My choices of village sites for the study was largely governed CES's earlier work in three "micro-catchments", which I have denoted as the Tattikai (TK), Sirsimakki (SM) and Malenalli (MH) and indicated in Figure 1. These sites, all in the arecanut belt, provided good coverage of (a) much of the rainfall gradient within the Malnaad region: 4300 mm at Tattikai, 2600 mm at Sirsimakki, and 2000 mm at Malenalli; (b) different mixes of cultivation and forest categories; and (c) varying distances from the main urban centre of Sirsi.

In choosing the households and land to be surveyed in the study, I used the "revenue village" or "hamlet"[21] as the boundary, since it appeared that the pattern of agricultural and forest-related activities better corresponds with these units than with the hydrological boundary of the micro-catchment. That is, households within a revenue village tend to have agricultural land in and only in that village, and, particularly in the case of *soppinabettas*, tend to use forests in and only in that village.[22] At the same time, I took care to ascertain the "trans-boundary" population, landholdings, and forest-use activities of each household. My sample therefore consists of three "village-clusters",

[21] Under the British land survey and settlement system followed today, Any spot on the map lies within one and only one "revenue village" (*graama*), the smallest administrative unit that, however, may vary in size from 50 hectares to 1000 hectares and 20 households to 4000 households. Geographically, it may consist of one or more clusters houses, denoted as hamlets (*majare*). The surveyed plots of land within a revenue village will include private (usually cultivable or residential) lands, as well as "public" lands (forest, pasture, riverine or barren land, and on rare occasions even unoccupied fallow lands.)

[22] In some cases, however, the size of the revenue village was too big for me to include fully in the surveys. In these cases, viz., Keregadde and Sarakuli villages in the TK cluster, I chose hamlets that were similarly separable from those of the rest of the village. Two other hamlets, Vadageri and Mulakinakoppa hamlets of 3 and 6 households respectively, had been included in CES' surveys because they were within the hydrological boundary. I used the household information from them in my analysis, but tested the results with and without these households. Finally, a set of 40-odd households in Malenalli micro-catchment that lay within Belale revenue village was dropped due to logistical limitations.

Table 4: Salient features of sampled units

Unit Name (Other hamlets included)	Revenue Village (part or full)	Cluster Code & Taluka	Total Area [ha]	# of Households	Main Crop(s)	Forests	Distance from Sirsi town
Kelagina Sarakuli	K. Sarakuli (full)	TK, Siddapur	69.1	17	Areca & Paddy	Betta	16 km South-West
Tattikai (Bilekal, Baddemane)	Sarakuli (part)		175.7	33	Areca, Paddy	Betta, RF	
Keregadde (Bitgod, Mélina Sarakuli)	Keregadde (part)		not mapped	36	Areca	Betta, MF	
Mundagesara (Bellekeri, Abrimane)	Mundagesara (full)	SM, Sirsi	259.9	52	Areca	Betta	0-2 km South-West
Sirsimakki	Sirsimakki (part)		159.1	34	Areca, Paddy	Betta, RF	
Vadagéri	Heepanalli (small part)		not mapped	3	Areca, Paddy	Betta, MF	
Golikoppa	Golikoppa (full)	MH, Sirsi	80.2	24*	Areca, Paddy	Betta, RF	12-14 km North
Arasāpura	Arasapura (full)		158.1	20	Areca, Paddy	Betta, MF	
Malenalli (Bhoorkantha, Hélanasara)	Malenalli (full)		270.3	34+	Paddy	MF,RF	
Mulakina-koppa	Bhairumbe (small part)		not mapped	6	Areca	Betta	

* : Some households may be within the legal boundary of Mulakinakoppa (Bhairumbe).
+ : Excluding the two households that own very large tracts of land in MH, but live in the neighbouring village of Hulgol, and 3 "households" of migrant labour teams that work for them, staying in Malenalli for 9 months in a year.

including 5 complete revenue villages, 3 contiguous hamlet-clusters, plus 2 small hamlets. The main characteristics of this sample are summarized in Table 3 below.

By the time I began my field work in 1989, various eco-development programs,

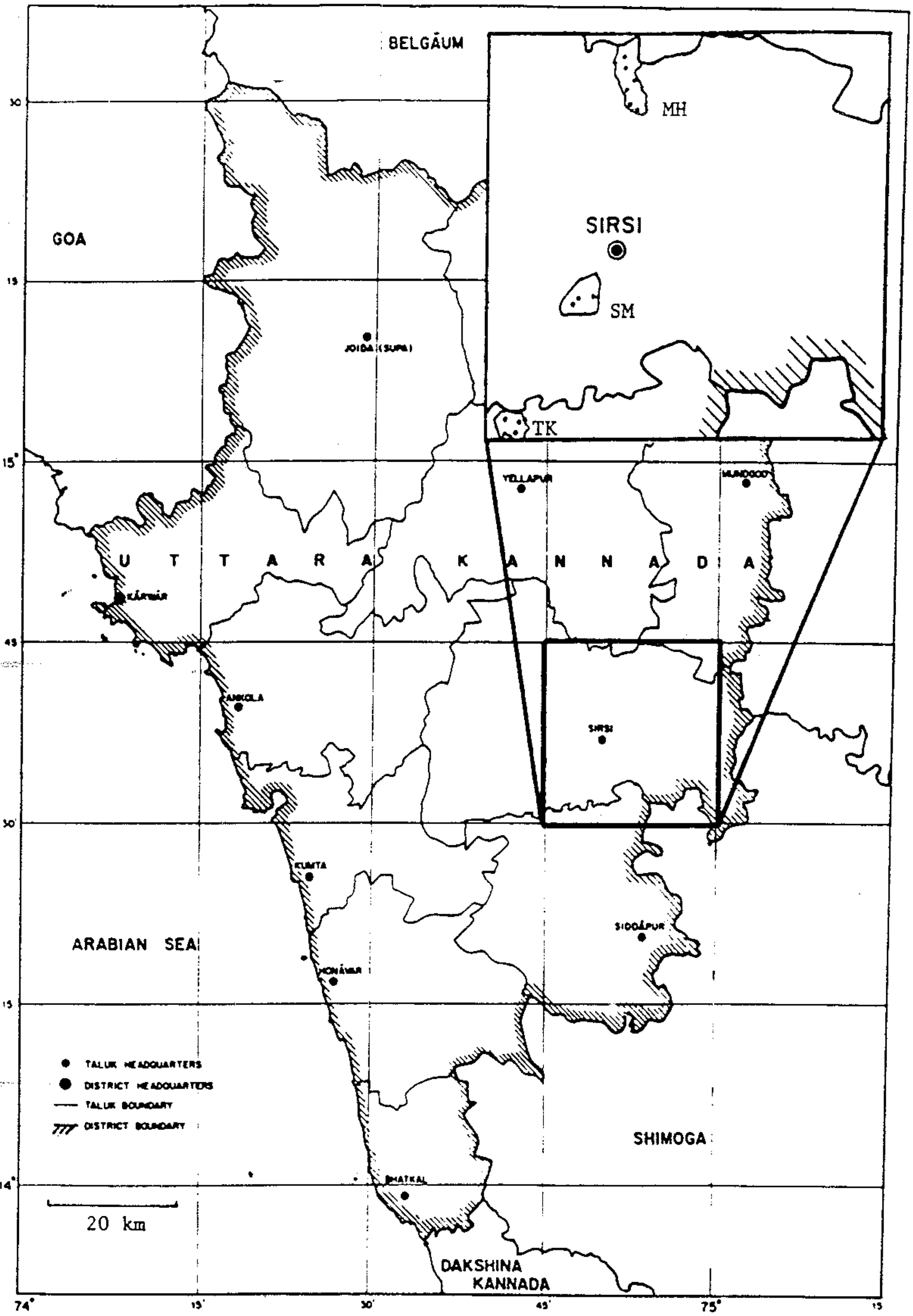

Figure 2: The location of the sampled village clusters in the Malnaad region.

including tree planting, bio-gas and improved cookstoves, exotic fodder and leaf manure species trials, sunhemp as a second crop, had been implemented in these villages to varying degrees (CES and KSCST, 1990). In order to assess the situation free of such intervention, I avoided in my vegetation assessment those locations where vegetation had been modified as a part of these programmes. I used information from the farmers and CES staff to build a picture of the situation that is likely to have existed earlier. In my resurvey of the households, I standardized all the information collected in various earlier surveys by CES staff to a single reference date corresponding to the period before programme implementation. However, I also used the information on the adoption of bio-gas, improved cookstoves and modern animal husbandry technologies by some of the households to examine their implications for forest use.[23]

2.2 Field Methods

The details of the field methods used are given at the appropriate points in the text. Broadly speaking, the data collected consisted of two components:

1) Data on resource productivity and condition: These were obtained through the monitoring of tree growth rates and the effects of lopping on productivity in forests in the region (CES data), sampling of tree vegetation and soils in the sample villages, mapping of vegetation and land-use in the villages, and grass clipping experiments in exclosures set up at five sites across the village clusters.

[23] It may be argued that the choice of sites is somewhat biased, since CES' interest in eco-development work may have led them to choose villages with farmers enthusiastic about forest conservation and regeneration. However, both the responses elicited from individual farmers, and my observations in other villages indicated that the chosen villages were not particularly unrepresentative of the region.

2) Data on household socio-economic characteristics and biomass resource use: These were obtained using existing questionnaire survey data from CES archives, re-surveys of all the households for additional information and cross-checks during my field work, monitoring of forest biomass extraction and its use in a small sample of households, monitoring of fuelwood consumption and livestock management (CES data), unstructured interviews with key informants in different communities, local activists, and government officials, information from village and taluka-level government offices, and personal observations.

When in the field, I had as my base CES' field station in Sirsi town, the hub of the Malnaad region, with frequent visits to and periodic stays in the sample villages. I also spent time in Bangalore, the capital of Karnataka state, where I obtained archival materials and governmental statistics, conducted a test-run on the usefulness of satellite imagery for the mapping of vegetation condition, arranged for the analysis of my soil samples, and participated in official meetings of rural development activists and forest department officials on various issues pertaining to the management of forests in Uttara Kannada district and Karnataka that were being debated at that time.

3. Organization of dissertation

Chapters II through V focus on the question of assessing the sustainability of the uncultivated land-uses. Chapter II presents an overview of the possible methods for assessing sustainability of uncultivated land resource use, a brief discussion of their limitations, and a description of the choice and manner of implementation of those used here. Chapters III, IV and V present the results thus obtained.

In Chapter VI, I demonstrate the manner in which household characteristics affect the use and management of uncultivated biomass. I discuss the complex implications of these characteristics and contextual variables for household needs for, access to, and capacity to manage biomass resources. I highlight the pivotal role played by the peculiar regime of forest access and control in the Malnaad. Attention is also drawn to the importance of household land assets, and the role of contextual factors, in determining the distribution of uncultivated vegetation types within "forest" lands under household control.

I conclude with a discussion of the implications of long-term changes in agriculture and demography of the region for the observed outcomes, the implications of such outcomes for alternative perceptions of forest degradation, and for rural eco-development policy.

Chapter II. Sustainable use of biomass resources: Criteria and application

"The biomass extracted is broadly indicative of the quality of *bettas*."
— Nadkarni *et al.* (1989, p.126)

In chapter I, I described the manner in which villagers in the Malnaad use uncultivated biomass resources. I argued the stance that sustainability and degradation of these resources should be defined in terms of the useful production that the villagers obtain from them. I defined sustainable use as that which enables undiminishing physical production of the particular biomass resource utilized. In the Malnaad, the broad categories of biomass resources used by the villagers are tree and grass biomass. The question that will now be explored in this and the next three chapters is essentially the following: To what extent are the tree and grass biomass resources being used sustainably, in terms of the above definition and perspective? In this chapter, I shall provide a general overview of the possible approaches to answering this question, their applicability and limitations, and the manner in which I have implemented those chosen for this study. The results of the sustainability analyses will be presented in Chapters III-V.

1. Approaches to testing the sustainability of biomass resource use

Even after choosing a fairly narrow definition for sustainability,[1] its assessment in a particular case is no easy task. The typical criteria for sustainability of uncultivated

[1] See Lélé (1992) for a more dynamic definition of sustainability.

biomass use fall into two approximate categories that I label "empirical" and "structural", depending upon the degree to which they focus on the production itself, as against the capacity to produce in the future. I list the more common ones; many others are possible.

Empirical criteria:

1) Is production non-diminishing or declining over time?

2) Is production equal to or lower than what it could be?

3) Is the rate of harvest of the resource greater or less than its production?

Structural criteria:

4) Is the current condition of vegetational factors that determine future production likely to ensure undiminished production?

5) Is current soil condition likely to maintain or diminish future production?

6) Is there a "nutrient input-output balance"? Or is there net nutrient depletion that will eventually reduce future production?

I shall discuss each of these criteria in terms of their assumptions, applicability, and ease of implementation. I shall devote most space to criterion (3), as it has been most commonly used in the literature on rural biomass use and deforestation.

1.1 Production trends: temporal and spatial

Criterion (1) follows rather obviously from the definition of sustainable use. Its application requires longitudinal data on production for sites like those under consideration; unfortunately, such data are rarely available. Note also that in most cases estimating production requires some model of the production process, exogenous variables affecting it, and endogenous variables such as the harvesting regime (see below).

Criterion (2) is essentially an attempt to obviate the need for longitudinal data, by using cross-sectional data. It requires the determination of a "benchmark" production level or levels, i.e., the maximum level(s) of production that may be expected from the site(s) under best management conditions. This in turn requires some information on the relationship between exogenous factors (i.e., non-anthropogenic conditions such as climate, topography and, to some extent, soils that characterize the site) and vegetative production. An important limitation of this criterion is that it cannot really tell us whether an observed difference between production at the particular site and the benchmark value (after controlling the exogenous factors) indicates a trend of diminishing production, i.e., *unsustainable use*, or a situation of sub-maximal but undiminishing production.

In terms of implementing either of these criteria, there are a number of difficulties in estimating production. The first set of difficulties pertains to the practical ones:

(a) the longer growth cycles (on the order of decades) and larger physical size of tree biomass, as compared to (say) grass biomass, means that longer monitoring and larger sample areas are in general necessary for estimating the former;

(b) estimation of production in the living parts of the vegetation usually requires harvesting and weighing these parts at various points during their growth cycles, a process that is again easier and less socially disruptive for grasses and shrubs than for trees, especially where data on relationships between volumetric measures and biomass are scarce and cutting of trees is socially and personally unjustifiable;

(c) estimating production in uncultivated vegetation that is simultaneously growing and being harvested (as against a cultivated crop, whether in a paddy field or a timber plantation, which grows and is then harvested at a specific point(s) in time) requires protection against such extraction from the sample sites in order to ensure full counting of the production; again, it is easier to protect small plots of grassland rather than ask villagers not to extract from an acre of tree vegetation.

Thus, production estimation is probably easiest for seasonal and small-sized vegetation such as grasses, where (a) the growth cycle is short enough to be covered during a typical field study period, (b) the growth form is such as to allow destructive sampling if necessary, and (c) it is possible to protect sampled sites from human extraction (in order to measure all the production) with relative ease and little cost to the users themselves. Conversely, it is hardest to implement in the case of tree production, where production is on varied time-scales (leaves grow fast, stems grow slow), destructive measurements are unacceptable and volumetric measurements very laborious, and protection against human extraction difficult since larger plots need to be closed off for longer periods.

The second set of difficulties in measuring production consists of the more analytical ones, pertaining to

(d) eco-climatic and site effects,

(e) interactions, and

(f) extraction effects.

The composition and production of forest vegetation is determined by climatic, edaphic and topographic variables. Furthermore, the different elements of the vegetation interact ecologically with each other, such as trees competing with each other and with the shrubs and herb layer for light , or physiologically within themselves, as different parts of a tree have source-sink relationships (Cannell, 1985).

Finally, the process of extraction (and in general of management or disturbance) can have profound effects on the partitioning of productivity among the biomass components and on their interactions. For instance, lopping of trees removes leaves and twigs, which affects the partitioning of future assimilate between foliage and stemwood within a tree. Lopping also modifies the canopy and hence affects grass production as well as other trees. Tree felling changes the age-class distribution and canopy structure in ways quite different from lopping. In other words, extraction is not simply a matter of "skimming off" the annual increment, but an active intervention in and modification of ecological processes. Estimating production under protected conditions will therefore not give a correct estimate of the production levels in locations where extraction or other disturbance is going on. Capturing this effect will typically requires conducting controlled experiments that simulate the manner and magnitude of extraction while allowing for the measurement of the extracted material. For instance, grazing effects on grass production may have to be simulated by clipping, and tree lopping conducted in a controlled manner on a protected plot of trees.

Given these difficulties, it is not surprising that production estimates in the literature on rural biomass use are often somewhat sketchy, or even flawed. For instance, total production from trees may be equated to only net annual increment (Reddy *et al.*, 1986, p.6; Prasad *et al.*, 1987a), effect of lopping on twig production in trees may be ignored (Singh *et al.*, 1984), grass production may be estimated without controlling for amount grazed away by livestock (Bhat and Gadgil, 1987). In extreme cases, production may simply be equated to harvest (Nadkarni *et al.*, 1989, p.125)! Attempts to take into account extraction effects may not always be successful. For example, Moench's method of using twig residence times to estimate twig production (Moench, 1985; Moench, 1989) turns out to be flawed, because, by virtue of the assumptions made, it in fact yields just another estimate of harvest.[2]

1.2 Comparing production and extraction

Criterion (3) is perhaps the most widely used in the literature on forest use and degradation. It criterion is based upon a simple input-output model with stock-dependent input (production):

$$\frac{dB}{dt} = G(B) - H \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where t is time, B is biomass resource stock, G is its natural growth rate that is determined by the level of the stock, and H is the rate of harvest or extraction. Now, regardless of the shape of the function G, or the dependence of H on B, one is justified in saying that production G will be constant (not just undiminishing) when B is constant, i.e., when $dB/dt = 0$, i.e., when $G = H$. Thus, an "input-output balance" of vegetative

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[2] Moench used a stock-flow model for estimating twig production in lopped oak forests. He assumed that "on a short-term basis, the stock of branches [to be at] a steady state", and therefore used the rate of harvest to estimate production (Moench, 1985, p.154). But precisely because a steady-state requires that harvest be equal to production, one cannot use this assumption to *test* whether in fact harvest *is* less than or greater than production. Not surprisingly, his estimate of twig production was remarkably similar to his estimate of twig-fuel consumption.

flows is a sufficient condition for sustainable use. "Biomass budgeting" (Gadgil and Sinha, 1986) is yet another term used to refer to the application of this criterion.

Furthermore, production can never increase indefinitely with resource stock: G may either be initially increasing and then decreasing with B, as in the case of a logistic growth function, or monotonically increasing with B up to some maximum. Therefore, the G=H condition would also be a necessary one in most cases (always in the latter case of a monotonically increasing growth function, and at values of B below the inflection point in the former case of logistic growth). Any excess of harvest over production will thus ultimately "eat into" the resource stock (the "capital"), leading to a reduction in future production. The idea of carrying capacity is thus an obvious extension of this criterion, the idea being that there is a maximum limit on resource production, which therefore sets the limit for the maximum level of extraction (and, given a minimum level of use per capita, on the number of users) that can be sustained.

The major advantages of this criterion are that it has predictive value, that it incorporates the harvesting regime and does not insist that production be at its maximum possible. It has been extensively used and developed in the conventional literature on renewable resource management, i.e., in the context of timber forestry and fisheries. It has also been the favorite criterion of researchers assessing the sustainability of rural biomass resource use. In doing so, however, a number of issues appear to have been overlooked. I shall briefly review the situations under which this criterion may not be applicable, and give a few examples of such mis-application.

(a) Issues in the applicability of the model

The above model is based upon two key assumptions: (a) that the resource stock can be treated as homogeneous (or "well-mixed") so that one unit of harvest (production) simply reduces (increases) the resource stock by one unit and (b) that this effect on growing stock and hence on future growth takes place immediately (instantaneously in the case of the continuous-time model of equation 1 above, or in the next time period in the case of a difference model). Both of these assumptions may appear to be reasonable in the case of timber forestry or fisheries, where a single resource is being harvested in a fairly gross fashion. This may, however, not be the case in other situations typical of village use of uncultivated biomass resources.

Consider the case of grass biomass. Grass production takes place seasonally, both above and below ground level. At the end of the growing season, almost all the standing stock dies, leaving behind roots and dispersed seeds. Grazing or grass harvesting can remove at most all of the production above ground. But, such removal does not *directly* affect, i.e., "eat into" any resource stock, since the "stock" that enables above-ground production is primarily seed and/or root stock. Thus, the resource is *not homogenous*, but in fact better represented as consisting of at least two compartments (say, below-ground and above-ground), with extraction taking place in only the latter, and production being added to both, but controlled by both. Another way of looking at this situation is to say that since what is harvested is only part of what is produced, harvest can never exceed production, and hence application of the criterion will not yield the desired insight.[3]

A similar situation may also exist in the case of tree biomass, when its different components are being used by rural people. Even though much of the "capital" stock (the stem and branchwood) is in fact available for extraction, extraction may take place only from certain compartments that contain only production. For instance, if only litterfall (dead leaves, twigs, branches or even whole dead trees) is harvested by the users, as is indeed the case in the Malnaad and elsewhere, then there is no way that the harvest can "eat into" the capital stock, since litter production is determined *not* by the stock of dead litter biomass, but by the stock of living tree biomass. In other words, the homogeneity assumption is again not reasonable.

In general, since dead biomass does not contribute directly to vegetative production, it can be removed without affecting future production. Litter removal can affect future tree growth through its effect on soil nutrients and structure (see, e.g., Bossel and Schafer, 1989), but the effect will be long-term and complicated. Comparing gross production (including litterfall) with gross extraction (including dead material) may give misleading results.

Even if live biomass is being harvested, it is not clear that an input-output comparison is always useful. In particular, consider the case of green leaves on trees. The most that the harvester can remove is *all* the leafy biomass on the tree. In this case, if B is taken to be the stock of leafy biomass only, then the model in equation 1 indicates that future production of leafy biomass will be zero. In fact, however, complete removal

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[3] This not to deny that harvest can affect future grass production, but to point out that a simple input-output model is not applicable.

of foliage may still result in the production of new leaves on the tree.[4]

Finally, even in the case of woody tree biomass, where its stock may relate approximately to its production as in equation 1, one has to be careful either to include both litterfall and above-ground increment in one's estimate of total production for comparison with total extraction, or compare only the woody biomass that has been *cut* from the live tree with the *net* increment in above-ground woody biomass during that period.

(b) Dynamic aspects: degradation or new equilibrium?

If the G-B relationship is indeed not monotonically increasing but something like a logistic, then one cannot conclude that an excess of harvest over production will necessarily lead to an continuous decline in stock and therefore in production. In the particular case of a simple logistic function (Clark, 1976), where

$$G(B) = r \cdot B\left(1 - \frac{B}{K}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

with r and K being constants that are interpreted as the "natural growth rate" and the carrying capacity respectively, the net growth rate initially increases directly with B, but then peaks at K/2 and drops to zero at B=K. In this case, as long as $B > K/2$ and $H \leq r.B/2$, a situation with $H > G(B)$ may not lead to degradation, but instead to a new equilibrium, as the decrease in resource stock resulting from the "imbalance" will result in *increased* production. Thus, a static of current production with current harvest is not

[4] If B is taken to be total tree biomass, then one has to split total production G into production of leafy biomass, G_L, and woody biomass, G_W. Steady-state in this model then requires simultaneous constraints on H_L and H_W, the leafy and woody harvests.

enough; one needs information on the dynamics of both resource production (and of extraction) in order to predict whether a new equilibrium will be reached or whether production will show a secular decline.

(c) Quantitative imbalance versus qualitative issues

While the simplicity of this criterion makes it an attractive one to use, focusing on "quantitative imbalance" has distracted researchers of rural biomass use away from the more "qualitative" aspects of resource use and management. Not only does the amount of extraction affect growth (i.e., $G \equiv G(B,H)$), but so do many qualitative aspects of resource management that are not manifested in the amount extracted. In other words, the problem may not be the amount that is extracted, but the manner in which it is extracted. For instance, while total woody biomass extracted may be less than its total production, the extracted material may all be in the form of young saplings, leading to a deficit in the future crop of adult trees. The need for other criteria that focus on such aspects is therefore quite clear.

(d) Difficulties in implementation

The difficulties in proper estimation of production have already been described in section 1.1. The estimation of the harvest can be equally difficult, especially in situations of use by villagers, as it requires the monitoring of a multiplicity of products extracted in different ways at different times from different locations by different communities.

Not surprisingly, much of the literature on biomass resource use suffers from methodological problems in estimating production, extraction or both.[5] More importantly, the fundamental issue of model applicability and the aggregation of biomass components has largely been ignored in the literature on rural biomass resource use[6]. In the context of the Malnaad, Gadgil (1987a) compared the gross total of woody, leafy and grassy biomass extraction to gross biomass production. Bhat and Huffaker (1991) used a logistic growth function to relate leafy biomass production in trees with the standing stock of leafy biomass in their bio-economic model of *soppinabetta* management; however, leafy biomass production is not so simply related to leafy biomass stock. Only on rare occasions have researchers managed to combine detailed estimates with consistent application of the criterion; Bajracharya (1983), for example, carefully disaggregated fuelwood consumption and production by live/dead wood, by geographical location, and by tree vegetation structure before making production-consumption comparisons for only live wood.

1.3 Structural criteria

Criterion (4) is a broad one covering different aspects of vegetation structure for different vegetation types. For instance, one may look at age-class distribution and regeneration rates of trees, at seed formation and dispersal rates for grasses, or at underground root stock for shrubs and perennial grasses. At another level, one might

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[5] In some cases, claims about excess extraction being the cause of degradation are made even without providing any estimates of production (Singh and Singh, 1989).

[6] Some researchers apply the harvest-production comparison to herblayer or tree leafy biomass by imposing some kind of a sustainability *threshold*, i.e., by insisting that only a certain fraction (say 0.5) of the total production can be "on a sustainable basis" (Singh *et al.*, 198?, p.30). The basis of this threshold model is, however, not explicated.

attempt to predict the ecological dynamics (competition, succession, etc.) between different vegetative elements of the resource, and their effect on useful production. In all cases, the basic idea is to see whether the future productive stock is being provided for in the selectivity, as contrasted with the quantity, of extraction.

Two approaches to implementing this criterion may be considered: a time-series approach or a cross-sectional approach. In the latter approach, the benchmarks may be determined either from some empirical observations or from theoretical models about resource population dynamics. To the extent that the effects of changes in vegetative structure are likely to affect production levels somewhat later than those of a direct reduction in stock size (if the model in equation (1) is applicable), this criterion may be said to predict "medium-term" sustainability.

Criterion (5) focusses on the main "non-vegetative" basis of vegetative production, viz., soil. Again, many variables can be used to describe soil condition, and changes in them can be compared either across time or space. The question of which benchmarks to use in the latter case are not easily answered: if the rate of soil erosion is chosen as an indicator, is any level of soil erosion "unsustainable", or is there some "threshold" and if so, how is this threshold to be determined? Since changes in soil condition typically affect vegetative production even more slowly than changes in vegetative condition itself, this criterion can be thought of as predicting "long-term" sustainability.

Criterion (6) is an application of the input-output balance criterion to the basis of biomass production, rather than to the biomass stock itself. It obviates the need for benchmarks; balance between total inflow and total outflow of nutrients into the system is the criterion for sustainability. The complete measurement of nutrient inflows into and outflows from any village-sized area would require a major research effort of the kind invested in the Hubbard-Brooke study (Likens *et al.*, 1977); such an effort was not possible in this study.

2. Choice of criteria, methods and locations for this study

The above discussion points to the need for adopting a methodologically plural and analytically careful approach to assessing the sustainability of different land-use patterns in the forest lands used by villagers in the Malnaad. In light of the data already available and the logistical constraints faced in this research, I applied the criteria as follows:[7]

(a) a comparison of production and extraction for tree woody biomass in the village-clusters of interest (Chapter III);

(b) a comparison of the age-class distribution and regeneration of trees in locations in the clusters under different "use regimes" with each other and (in the case of age-class distribution) with respect to some theoretical benchmark (Chapter IV);

(c) a comparison of soil physical and chemical conditions under different use regimes and different intensities of biomass extraction (Chapter IV); and

(d) an estimation of the "benchmark" level of grass production, the likely effect of tree canopy on it, and the effect of different intensities of grazing on within-season production

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[7] As will be seen, the estimation of tree woody biomass production and its comparison with extraction estimates required most of the research time; consequently, the other analyses are somewhat limited in their coverage.

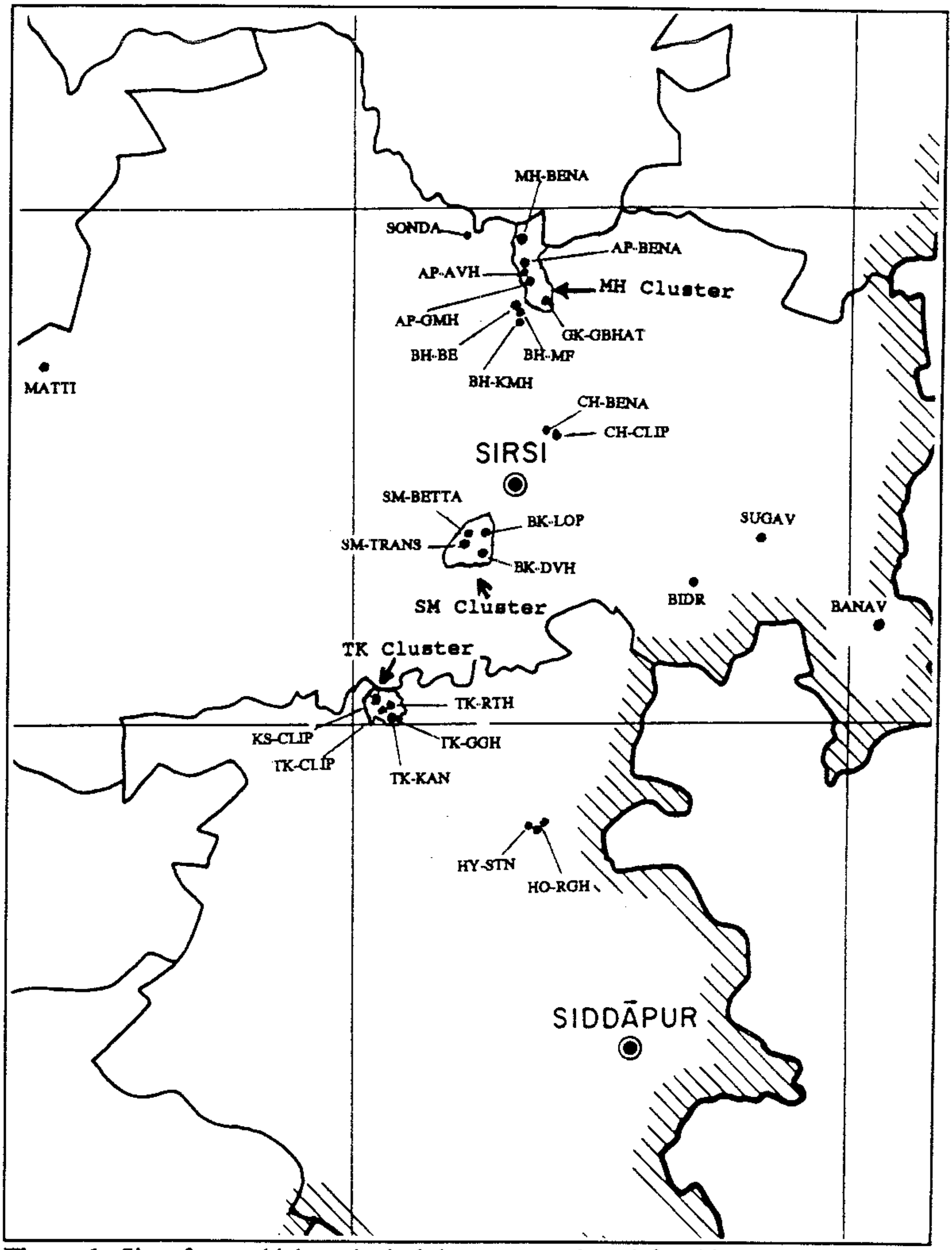

Figure 1. Sites from which ecological data were gathered for this study

using an experimental approach instead of spatial sampling (Chapter V)[8].

Table 1. Methods and data used for the application of sustainability criteria in the next three chapters

Sustainability criterion	Biomass type to which applied	Variable or Effect	Manner of estimation	Data used	Location codes used
(1) Production-Harvest balance	Tree woody biomass	Increment in live WAGB	Girth monitoring, & allometric equations	Five 1-ha plots (6-yrs) & one 2.5-ha plot (3-yrs girth)*	BH-BE, BH-MF, SONDA, BIDR, SUGAV, & BK-LOP
		Deadwood production	Mortality	as above	as above
			Litterfall	Bhat, 1990	BH-BE & 4 more
		Effect of lopping	Harvest & girth	Lopping experiment (3-yrs)*	BK-LOP
		Production in village clusters of interest	Above results applied to sampled tree vegetation	Quadrats in betta lands in villages of interest	AP-AVH, AP-GMH, GK-GBHAT, BH-KMH, BK-DVH, SM-BETTA, SM-TRANS, TK-GGH, TK-RTH
(2) Trend in production	Tree leafy biomass	Effect of annual lopping	Leaf harvest and litterfall	Lopping experiment*	BK-LOP
	Grass biomass	Benchmark production	Peak biomass	Harvests from protected grasslands	MATTI, CH-BENA, AP-BENA, MH-BENA, BANAV
		Canopy effect	Peak biomass	Bhat & Gadgil, 1987	9 sites, including 5 in (1) above
		Grazing effect	Cumulative biomass	Cumulative harvests from clipping	CH-CLIP, AP-CLIP, MH-CLIP, TK-CLIP, KS-CLIP
(3) Vegetation structure	Tree vegetation	Regeneration & Age-class distribution	Seedling, sapling & tree-girth distributions	Quadrats in betta lands in villages of interest	AP-AVH, ... (as above)
(4) Soil condition	Tree vegetation	Effect of management regime	Soil physical & chemical composition	Samples from different bettas	AP-AVH, ... (as above) plus TK-KAN, TK-CLIP§, KS-CLIP§, HO-RGH, HY-STN, CH-CLIP§

* : Raw data provided by Centre for Ecological Sciences (CES)
§ : Herblayer clipping sites were located in tree land
WAGB : Woody above-ground biomass (trees)

[8] Shrubs have thus been excluded from this study. Shrubs are intermediate between perennial grasses and trees, in that their future production is likely to depend upon root stock as well as above-ground stumps. In the villages studied, shrubs, which are used mainly as animal bedding (and manure), are dominant in certain parts of the forest. In the remaining forest lands, however, they appear to have been systematically removed or burnt to facilitate grass growth. They were therefore considered less important than trees and grasses, and the analysis the sustainability of their use had to sacrificed on the altar of logistical limitations.

The data and methods used in each case are summarized very briefly in Table 1. The locations from which the data were gathered are a mixture of regionally distributed sites (such as those where CES had initiated its monitoring of tree growth rates, or those I sampled for peak grass production) and sites within the village-clusters of interest (used to estimate the structure of tree vegetation and soil condition for (a), (b) and (c) above, as well as some of the clipping studies in (d) above). These locations are shown in the map in Figure 1, and the particular information collected there is indicated in the last column in Table 1.

The sustainability criteria were applied only to *soppinabetta* lands for tree-related assessments and to privately owned or controlled grasslands. The reasons were that, firstly, betta lands constitute nearly half of the forest lands that are legally accessible to the villagers in the Malnaad talukas (i.e., betta and MF lands; see Table 3 in Chapter II), and 73% of all the forest land in the village clusters studied. Secondly, in order to relate production and sustainability to modes of extraction and protection, one needs reliable estimates of the latter variables. Such estimates are difficult to obtain for Minor Forest lands, which are open-access, but easier in the privately controlled *soppinabetta* lands, that are subjected to fairly consistent traditional systems of use.

Chapter III. Sustainability of tree biomass use in the Malnaad villages:

Comparisons of woody production and harvest

Taking into account the annual increment at one cum per hectare, we get ... 2.90 lakh tonnes of fuelwood annually from [all RF, MF and betta] areas. ... Thus, we have been eating away the capital itself to the tune of 6.30 lakh tonnes. This explains the loss of total forest cover in 50% forest area of the District.

-- Reddy *et al.* (1986, p.6)

A quantitative comparison of vegetative production and harvest has often been the first, if not the only criterion applied to assessing the sustainability of biomass resource use. As explained in the previous chapter, such a "biomass budget" criterion applies only to woody tree biomass, and its application is complicated by various factors governing production and the effects of extraction on it. Within these constraints, however, the criterion could provide valuable insights into the question of the sustainability of resource use, in particular, whether *villagers' use of woody biomass* is likely to be causing a decline in the Malnaad forests and thus contributing to the apparently rampant over-extraction of woody biomass that Reddy *et al.* (1986) suggest is occurring in the district as a whole. In this chapter, I present such a "woody biomass balance" for the sampled villages.

In constructing estimates of woody biomass production in the village forest lands, I have used raw data on tree biomass production gathered by the Centre for Ecological Sciences (CES) from forest sites spread across the Malnaad region to derive relationships between tree size and production. I have then applied these relationships to sampled plots of tree vegetation in sample plots of lopped forests (*soppinabettas*) in the villages to estimate typical production levels per unit area. These plot estimates are then extended to the village as a whole. Extraction estimates are also presented for the sampled plots and for the villages as a whole. Comparisons between plot and village scales then provide means for assessing the extent of "unsustainable" use and its location.

1. Estimating tree productivity in "disturbed" forests

Estimating the production of woody tree biomass in forests used by villagers requires, first, a clear understanding of the components or biomass types that constitute tree production. Second, it requires the development of relationships between production rates and the structure of the tree vegetation in ways that account for anthropogenic and non-anthropogenic effects. Finally, it requires the application of these relationships to estimate the production in the tree lands of interest.

1.1 Overview

If one ignores below-ground biomass and its production[1], one may disaggregate the components of "tree woody above-ground biomass" (TWAGB) in a forest as follows:

TWAGB production = Net increment in TWAGB of the tree stand + woody litterfall (including dead tree fall) + Harvest . . . . (1).

Now,

[1] Below-ground parts, mainly roots, are of course a crucial component of the functioning of the tree as a whole, and are affected by the manner in which the vegetation is managed, including possibly the periodic pruning or lopping of above-ground parts that characterizes much of the forest tree use in the Malnaad (see footnote 3). The feedback effects of the manner and quantity of extraction on future production through "root-shoot interactions" appear to be poorly understood (Cannell, 1985), but are likely to be long-term ones for grown trees, and are likely to be captured in parameters that are measured above-ground, such as rate of tree girth increment.

Net increment in stand TWAGB ≈ *survivor growth* + *recruitment* - *mortality (i.e., dead fall)* - *harvest*, ... (2),

where "survivor growth" is the increase in TWAGB of trees that were alive throughout the monitored period, "recruitment" (or ingrowth) is the TWAGB of new trees that crossed into the smallest measurable class due to their growth after the first measurement, and "mortality" and "harvest" are the TWAGB values for trees that died or were harvested during that period. The approximations involved in this expression are (a) that harvest occurs only in the form of whole trees, (b) that the amount of dead material remaining on the trees also does not change significantly during that period, and (c) that the trees that were lost to mortality or harvest did not grow significantly between the time they were measured and their death/harvest.[2] Hence,

TWAGB production ≈ *survivor growth* + *recruitment* + *woody litterfall (excluding dead fall)*, ... (3),

the third term is the amount of woody matter that grows and falls off the trees before the second measurement. This expression corresponds to the total woody (lignaceous) component of what ecologists call "net production" (Satoo and Madgwick, 1982, p.33).[3]

In the case of tree vegetation in the Malnaad, however, much of the removal of

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[2] The last assumption implies that if measurements are taken (say) every five years, and if x trees die or get cut (say) three years after the first measurement, then the *increase* in the TWAGB of these x trees in those three years (just before they died or were cut) is taken to be insignificant compared to the increase in the TWAGB of all the other trees that survived through the five years.

[3] On the other hand, if one were interested only in timber production, one would equate production to net *increment* (= survivor growth + recruitment − loss due to mortality) of AGB (usually restricted to "commercial timber"). This is the definition of production most commonly used by foresters, including by Reddy *et al.* in the quote at the beginning of this chapter. However, in the context of villagers' use of tree woody biomass, where deadwood can be (and is) almost fully utilized as fuelwood, using the foresters' definition would lead to a serious underestimation of useful production, as TWAGB loss due to tree mortality is of the same order of magnitude as survivor growth + recruitment, and woody litterfall is significant as well.

woody biomass takes place in the form of the regular lopping[4] of trees, i.e., the heavy pruning of adult trees (typically > 40 cm girth at breast height) to obtain green leaves, twigs and small branches (typically less than 5 cm in diameter) in addition to the removal of deadwood. Between two loppings, a tree would produce woody AGB not only by adding girth and height to the unlopped portions of its main stem and branches, but also by producing twigs that regenerate its photosynthesizing canopy, some of which may die and be shed before the next harvest. It might therefore be more useful to estimate TWAGB production for lopped trees using the expression

Tree WAGB production = *increment in stemwood & branchwood of survivor trees + increment in TWAGB through recruitment + amount of woody biomass regrowth after lopping + amount of woody biomass in the litter from lopped trees* . . . . (4),

where stemwood is the woody biomass of the main stem, and branchwood is the biomass of the branches, which for our purposes may be defined as all the woody matter down to 5 cm diameter. since all trees are not lopped, one would also have to estimate the growth in the twig biomass (<5 cm diameter) of unlopped trees.

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[4] The debate on the meaning, legality and effects of "lopping" versus "pollarding" in the context of arecanut cultivators' use of the Malnaad forests dates back to the 1890s (Davidson, 1894; MacGregor, 1894; Nugent, 1894). Lopping generally means the removal of foliage, twigs and small branches, leaving a small portion of the tree crown (what tree physiologists might call the "apical meristem") or at least most of the main stem intact. Pollarding includes the cutting of the main stem by a substantial amount. Both practices are followed by arecanut cultivators. The differences between the effect of one against the other are not well understood. I shall use the term "lopping" hereinafter, with the reminder that it includes the cutting of the top of the main stem.

Arecanut cultivators follow a fairly systematic schedule, lopping trees on a two, three or four year rotation, with the lopping occurring in the early part of the dry season (December-February) before the deciduous trees shed most of their leaves. Households of non-arecanut cultivators are less systematic and aperiodic, but do obtain a significant fraction of their fuelwood by lopping trees, rather than by felling them.

I used various data gathered by CES to estimate each term on the right-hand side of equation (4). These data consisted of time series data on tree girth increment at different sites and under different management, tree height data, twig harvest data, and previously published litterfall data that I re-analyzed for my purpose. Volumes were estimated from tree dimensions using an expression derived from the literature. The results are presented here in brief. The details are given in Appendices B and C.

1.2 Annual increment in stemwood and branchwood of survivor trees

Rates of annual increment in TWAGB of trees depend critically on the age or size of the tree, on species type, on climate, soil and other site factors, on vegetation structure (such as stand density and canopy cover), and on the anthropogenic modifications in the tree's vegetation. Estimation of the rate of AGB increment is typically done in two steps, (a) determining the rate of change in some measurable dimensions such as girth and height, and (b) characterizing the relationship between these dimensions and woody biomass. The implementation of these steps for a particular plot of natural forest is difficult and tedious. This is not the least because of the slow rate of growth trees as compared to, say, grasses and the added difficulty in estimating AGB through destructive sampling. Further, very little information is available for the manner in which the rate of growth and the dimensional relationships depend upon all the above-mentioned factors in the Malnaad or in most other natural tropical forests. In cases where data are not available I use approximations.

1.2.1 Rate of girth increment

The only sources of information on girth increment rates of trees in the Malnaad forests are "increment plots" set up by the Forest Department in the 1930s, for which preliminary results were published by Mathauda (1953) and 36-year results were published by Rai (1980a; 1981; 1982a; 1982b; 1983). Neither the species composition nor the level and manner of anthropogenic "disturbance" in these state-protected evergreen forests resembles the lopped semi-evergreen or moist-deciduous vegetation prevailing in most of the villager-used forests. I preferred to use time-series data provided by CES, in spite of their much shorter time span of 3-6 years (effectively only one period of increment), because they included plots in *soppinabettas* and Minor Forests in or near two of the three village clusters of interest (see Figure 1 in Chapter II).

Using data from five 1-hectare plots (BH-BE, BH-MF, SONDA, BIDR and SUGAV) monitored between 1984-1990 and one 2.5-ha plot (BK-LOP) monitored between 1987-1990 (see map in Figure 1 in Chapter II), the rates of increase in basal area (cross-sectional area of the tree at breast height) were calculated. The details of the method of measurement and calculation are given in Appendix A. The annual percentage rates of increase in basal area (%BAI), averaged for all trees in each 20 cm girth-class for each plot, are presented along with the associated standard errors in Table 1.

The systematic decline in percentage growth rates across girth-classes[5] is almost exclusively an artifact of the increasing denominator. Absolute BAI values generally show an initially increasing and then decreasing trend similar to Rai's results. In the

[5] The decline is systematic only till about 200 cm girth, beyond which the values vary dramatically. But these values are not very reliable, because the number of trees in each girth class beyond 200 cm is less than 5, and often 1 or 2.

Table 1. Average percentage annual increment in tree basal area for five plots in the Malnaad forests: Means and standard errors (SE).

Tree girth-class (Girth at breast height, cm)†	BK-LOP (Annually lopped *soppina-betta*)		BH-BE (Intermittently lopped *soppinabetta*)		BH-MF (MF: limited felling, some lopping)		BIDR (Reserve Forest: significant felling)		SONDA (RF: little tree felling or lopping)		SUGAV (MF: little felling, some lopping)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
0-20cm‡	NA	NA	6.7%	0.8%	9.1%	0.6%	9.4%	1.1%	4.6%	0.6%	9.6%	0.8%
20-40cm	9.1%	0.8%	5.5%	0.5%	6.4%	0.7%	8.4%	1.3%	7.0%	0.6%	7.9%	0.7%
40-60cm	4.0%	0.6%	1.6%	0.4%	3.3%	0.6%	5.0%	2.0%	3.3%	0.7%	3.1%	0.8%
60-80cm	2.6%	0.5%	0.6%	0.3%	2.3%	0.6%	2.1%	1.1%	0.9%	0.5%	1.2%	0.2%
80-100cm	2.1%	0.5%	0.3%	0.3%	1.1%	0.9%	1.8%	0.3%	1.2%	0.4%	1.8%	0.3%
100-120cm	1.8%	0.6%	0.4%	0.1%	2.9%	1.1%	1.7%	0.6%	0.5%	0.3%	2.0%	0.3%
120-140cm	2.0%	0.6%	0.3%	0.2%	1.3%	0.7%	0.9%	0.5%	0.8%	0.2%	1.4%	0.2%
140-160cm	1.0%	2.0%	0.1%	0.2%	0.6%	0.2%	1.9%	0.5%	1.4%	0.3%	1.4%	0.5%
160-180cm	2.8%	0.9%	0.5%	0.1%	0.8%	0.3%	1.2%	0.3%	1.7%	0.6%	0.9%	0.6%
180-200cm	NA	NA	NA	NA	1.9%	0.6%	1.0%	0.4%	1.3%	0.3%	1.4%	0.3%
200-220cm	NA	NA	0.7%	1.0%	2.4%	0.4%	1.6%	0.6%	1.9%	0.5%	0.0%	0.9%
220-240cm	NA	NA	NA	NA	2.7%	NA	-0.1%	2.2%	1.3%	0.6%	1.6%	0.7%
240-260cm	NA	NA	1.1%	NA	0.8%	0.3%	1.1%	0.4%	1.5%	NA	NA	NA

†: 0-20cm is all trees with $0 \leq GBH < 20$ in year 1, and so on
‡: Since the cutoff used by CES was 10cm, this girth-class is actually only 10-20cm
NA: No trees in this girth-class in this plot, or standard error cannot be estimated because there is only 1 tree.

absence of clear tree ring formation in these tropical evergreen and semi-evergreen forests (Mathauda, 1953), it was not possible to develop age-specific BAI rates.

The values in Table 1 suggest that trees in different sites might be growing at different rates. Given that the purpose here is to develop BAI relationships that can be reliably applied to other sites in the region, it is important to attempt to separate the effects of different factors, including species composition, vegetation structure (density and canopy cover), soils and topography, as well as lopping.[6] I focused in particular on three sites, viz., BK-LOP, BH-BE and BH-MF, that were geographically and ecologically closest to my sample villages, and that also covered the full range of variation in %BAI, with BK-LOP appearing to be one of the fastest growing sites, and BH-BE the slowest.

I tested for differences in girth-class-specific %BAI between species for unlopped trees within each site, then for a "lopping effect" in a few species that contained enough samples of lopped and unlopped individuals by girth-class, and finally for a "site effect" by comparing girth-class specific %BAI for unlopped individuals of a few species that occurred in sufficient numbers across the sites. The statistical tests were constrained by the unbalanced and often quite inadequate sample sizes in each cell in a "girth-class x species x site x lopping" design. Information on the tests conducted and the detailed results of these tests are given in Appendix C. While there are systematic differences in growth rates between some species, the total number of tree species in the village forests of interest were far greater (between 25 and 45) than those for which girth-specific %BAI rates could be meaningfully calculated. On the other hand, reduction in %BAI appeared to be correlated with tree lopping only for small trees (girth-class 20-40cm)[7]. Thus, the

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[6] That girth increment rates differ by age, species, stand density, site index, etc. is well-known (Satoo and Madgwick, 1982, among many others), although, as mentioned earlier, little data are available for the Western Ghats forests. There is also reason to believe that lopping or pollarding of grown trees may reduce stemwood and branchwood increment (Cannell, 1983) due to a shift in the partitioning of new assimilate towards leaf and twig production. For instance, it has been reported that lopping of 80% of the crown reduced diameter increment by as much as 80% in 12-year old trees of *Schima wallichii* (Mohns, 1984 reported in Robinson, 1985).

[7] It is technically incorrect to conclude that "lopping resulted in reduced %BAI" for even this girth-class, because the choice of trees to be lopped was made by the farmers owning the *soppinabetta* land and hence may not have been completely random.

difference in average %BAI values between BH-BE and BH-MF apparent in Table 1 is largely a consequence of differences in species composition and girth-class distribution. If, however, %BAI rates for only *Terminalia paniculata* (of which all sites had sufficient individuals) are compared, the difference between BK-LOP and BH-BE is significant in at least four girth-classes (20-40cm, 80-100cm, 100-120cm and 120-140cm). This difference might largely be a result of differences in tree vegetation structure, with the smaller (basal area $13m^2$/ha as against $24m^2$), shorter (average height 7m as against 12m) and more intensively lopped trees in BK-LOP compared to BH-BE result in a much more open canopy structure, which promotes more rapid growth due to lesser competition for light.

In light of these results, I adopted a heuristic procedure in the choice of %BAI rates to be applied to the vegetation sampled in the villages of interest. The sampled tree vegetation plots in the Sirsimakki cluster resembled the BK-LOP plot which is also located in that cluster, in their species composition, and lopped morphology. The average %BAI rates for BK-LOP were therefore used for these plots. For the plots in the Malenalli village cluster, which neighboured the BH-MF and BH-BE sites and contained species that were frequent in either one of these sites, girth-class specific average %BAI rates for the pooled sample of all trees from these two sites were used. No plot with time-series data was located in or near the TK cluster. The species composition and lopped morphology in the TK cluster better resembled BK-LOP than any other site;

hence the rates for BK-LOP were used.[8]

1.2.2 Estimating change in TWAGB from basal area increment data

Having estimated the rates of change in basal area due to survivor growth, recruitment and mortality, one is then faced with the problem of converting them to estimates of changes in stemwood and branchwood biomass. This is usually done by using relations between woody volume and tree girth and height developed in similar forests. Ideally, one would like to develop fresh estimates of these relationships for the forests of interest, especially since the intense use of the trees in the village lands is likely to modify reported relationships that are invariably derived for unlopped trees. Destructive sampling of trees was impossible (for social and moral reasons), and non-destructive volumetric measurements of the number of trees required to cover the main species and diameter-classes of interest were not attainable for logistical reasons. I therefore adopted a simple relationship between basal area, height and volume:

$$\textit{Stemwood+Branchwood Volume} = 0.025 + 0.50*(BA)*(H) \quad \ldots\ldots\ldots \quad (5),$$

where basal area (BA) is in m^2, height (H) in m, and volume in m^3. The rationale behind

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[8] The absence of any girth-monitoring site in or near the Iattikai cluster is a matter of some concern, since the two most important species in this region (in terms of their frequency per hectare and basal area contribution per hectare in the sampled plots), viz., *Hopea wightiana* and *Lophopetalum wightianum*, are completely absent from all the 6 sites listed in Table 1. Average girth increment rates for *Hopea wightiana* in this region were published by Rai (1981) without associated standard errors. A graphical comparison of his values with the average BK-LOP values suggests that my values may result in significant overestimates only for the 20-40cm girth class. On the other hand, Rai's data are for a dense (unlopped) closed canopy forest where the growth of smaller trees is likely to be severely light-limited. Compared to the uncertainties in BAI in general that are already incorporated in the standard error values used to calculate high and low estimates, the additional error in using BK-LOP values for the Iattikai forests therefore are unlikely to be significant.

While the species combination in the pooled sample of BH-BE and BH-MF resembles the sampled plots in the Malenalli cluster, there are some variations in the tree density and canopy structure which are likely to make these rates slight underestimates for certain plots. As it turns out, however, an increase in these rates can only strengthen the conclusions drawn later.

the choice of this relationship is discussed at length in Appendix B. Suffice to say here that this relationship allows for variation in the Tree Form Factor (ratio of actual tree volume to the product of basal area and height) with tree size. The use of this relationship results in Stand Form Factor values (ratio of stand volume to the product of stand basal area and average tree height) of between 0.65 and 0.70, which is at the lower (and what turns out to be conservative) end of the range of 0.68 to 0.90 reported by Rai and Proctor (1986a) from the only study based upon destructive sampling reported for the Karnataka Western Ghats.

A sufficient number of tree height data obtained using a clinometer, were available for one plot in the Sirsimakki cluster (SM-TRANS) and one plot near the Malenalli cluster (BH-BE). Separate log-log relationships[9] were derived for each data set, as shown in Figure 1. These plots were fairly representative of the typical heights of trees in the village clusters of interest (SM-TRANS for the Sirsimakki and Tattikai clusters, and BH-BE for the Malenalli cluster), and so the derived curves were used to estimate the heights of sample plots in these clusters.

Volume estimates were converted to biomass estimates using wood specific gravity values for some species from KFD (no date), with the remaining species being assigned the value of 0.6 gm/cc (which is lower than the unweighted average of 0.7 reported by Rai and Proctor, 1986a).

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[9] Regressing expressions of the form $\ln(H) = a + b \ln(G)$ gave r^2 values similar to those for a regression of the form $H = a + bG$, but the homogeneity of the variances was higher in the former case. In using the log-log relationships to estimate tree height in other plots, the correction factor for such relationships indicated by Mountford and Bunce (1973) was applied

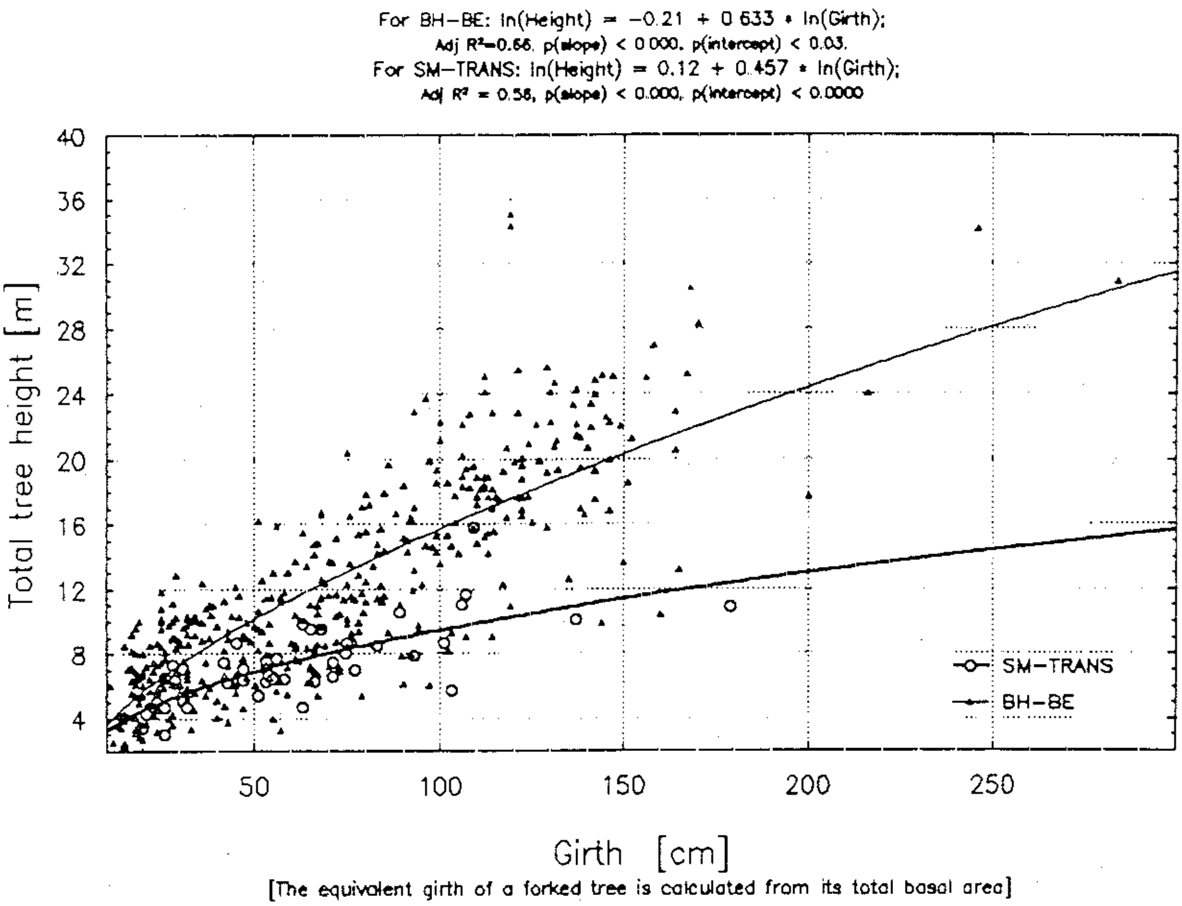

Figure 1. Height-girth relationships for two lopped forest plots

1.3 Recruitment and mortality

The rate at which tree seedlings and saplings survive and grow to cross the smallest measurable girth during any time-series monitoring of tree growth depends upon a number of factors. These include tree density, canopy cover and level of disturbance due to grazing, harvesting, etc. Tree mortality rates, their distribution by tree age/size, and variation by vegetation structure and disturbance are equally complex variables to assess.

Information on rates of recruitment and mortality in natural and (more important) lopped forests in the Western Ghats is even scarcer than that on girth increment, with only partial information on mortality rates provided by Rai (1983). The time-series data provided by CES enabled me to estimate annual changes in tree basal area due to mortality, felling and recruitment at these sites[10]; the results are presented in Table 2.

Table 2. Average annual changes in tree basal area from survivor growth, recruitment, mortality and felling

Location Code	Initial Trees [per ha]§ (1)	Initial Basal Area (BA) [m²/ha] (2)	Survivor Trees (3)	Initial BA of Survivors [m²/ha] (4)	BAI of Survivors [m²/ha/yr] (5)	BAI from recruitment [m²/ha/yr] (6)	Gross BA Increment (7) = (5) + (6)	BA lost to Mortality [m²/ha/yr] (8)	BA lost to felling [m²/ha/yr] (9)	Net BA Increment (10) = (7)-(8)-(9)
SONDA	450	32.14	415	31.99 99.5%	0.45 1.39%	0.06 0.17%	0.50 1.56%	0.06 0.20%	0.087 0.27%	0.35 1.09%
BIDR	200	24.31	176	23.90 98.3%	0.35 1.45%	0.02 0.08%	0.37 1.53%	0.34 1.40%	0.07 0.28%	-0.04 -0.15%
BH-MF	243	20.65	222	20.53 99.4%	0.36 1.73%	0.05 0.25%	0.41 1.98%	0.12 0.59%	0.01 0.02%	0.28 1.37%
SUGAV	310	23.49	300	23.46 99.9%	0.34 1.45%	0.03 0.15%	0.37 1.59%	0.00 0.02%	0.03 0.11%	0.34 1.46%
BH-BE	379	22.99	367	22.87 99.5%	0.16 0.70%	0.02 0.07%	0.18 0.77%	0.12 0.52%	0.00 0.00%	0.06 0.25%
BK-LOP	362	13.03	358.8	12.98 99.6%	0.36 2.76%	NA NA	NA NA	0.02 0.14%	0.03 0.24%	NA NA

§ : Individuals belonging to tree species with girth at breast height greater than 20cm *excluding* those that could not be located later on (these "unaccounted for trees would almost always be part of felling not mortality).
BA: Tree basal area at breast height
NA: For BK-LOP, recruitment was not monitored
All values of change in BA are have been converted to average annual values from measurements 3 to 6 years apart.
% values in each case correspond to the change with respect to the initial total basal area.

Both recruitment and mortality show large variations across sites, but, given just

[10] Three years of mortality data in BK-LOP and six years of mortality, felling and recruitment data for the other five sites were available. CES's efforts were hampered by an inability in some cases to identify the cause of tree loss, and to control or monitor the removal of saplings *before* their recruitment into the adult tree stock.

5 data points, the reasons for these variations could not be identified. No systematic trends were seen when numbers of tree recruits and deaths were used instead of basal area either. But the loss in BA due to mortality in all the sites is small enough (mostly less than 1%) that the overestimation in TWAGB production that might result if one does not subtract mortality from initial basal area before multiplying by the girth-specific fractional rate of basal area increment due to growth (as calculated in section 1.2.1) is quite insignificant (the percentage error would be perhaps twice or thrice as much as the percentage mortality in column (7)). I have therefore ignored loss in growing stock due to mortality in estimating TWAGB production. On the other hand, the average annual recruitment as a percentage of the average annual BAI due to survivor growth (i.e., the ratio of column (6) to column (5) in Table 2) is between 5-15% (mean=11%), which is significant enough to be incorporated in the estimation of TWAGB production. I used a value of 10% to estimate basal area of annual recruits for all the sample plots, thus assuming that recruitment will be higher where survivor growth is higher, within the range of vegetative conditions encountered. Recruitment basal area was converted to TWAGB using the girth-sensitive volume expression described in section 1.2.2.

1.4 Growth in standing crop of twig biomass under lopping

> At Mahim (Bombay) and Hospet (Madras) I saw cultivators lopping around their own fields..... [trees] grown for pollarding. ..... I could not help thinking it was better for the trees thus to yield a triennial supply of shoots for 40 years, than that they should be left alone all the time in order to afford at the close of it one single log of timber. (Voelcker, 1897, para. 169)

Total production of twigs (defined as wood <5cm in diameter) consists of the increase in twig biomass on the tree plus the amount falling as litter. The amount of twig biomass on a tree at any given time is generally poorly related to the girth of the tree (see, e.g., Rai and Proctor, 1986a), and whatever relationship might exist would be modified when the tree is lopped regularly. The use of some controlled harvest method is necessary to estimate the standing twig biomass and its relationship with vegetation structure and lopping practices. Lopping practices include lopping intensity (fraction of crown lopped), timing (season during which lopping takes place), frequency (annual, or less frequent), and age/size of the trees lopped, all of which affect twig and foliar biomass production (Robinson, 1985; Robinson and Thompson, 1988). Information on these relationships is rather scanty; I was able to locate only two articles, Bhimaya (1964) and Srivastava (1978), pertaining to harvestable leaf and twig biomass on traditionally lopped indigenous tree species of tropical forests in the Indian subcontinent. I describe below my construction of estimates of twig biomass that might have accumulated on a tree just before it is lopped again under the local system of lopping. I use data from a set of lopping trials conducted by CES at BK-LOP; estimates of biomass lost in litterfall are constructed in the following section.

Data for three years (1988-1990) of *annual* lopping trials with different fractions of crown lopped were gathered by CES researchers. The lopping was conducted by labourers employed by the *soppinabetta*-holder under the supervision of CES staff in plots that were by and large undisturbed for the rest of the year. Only data from their "100%" lopping plot, consisting of 77 lopped trees, are used in this analysis, because the complete removal of tree foliage and twig biomass most resembles the lopping intensity practiced by the local farmers. The data consist of measurements of fresh weights of leafy and twig matter obtained from the lopping of each tree at exactly the same point on the branch each year[11].

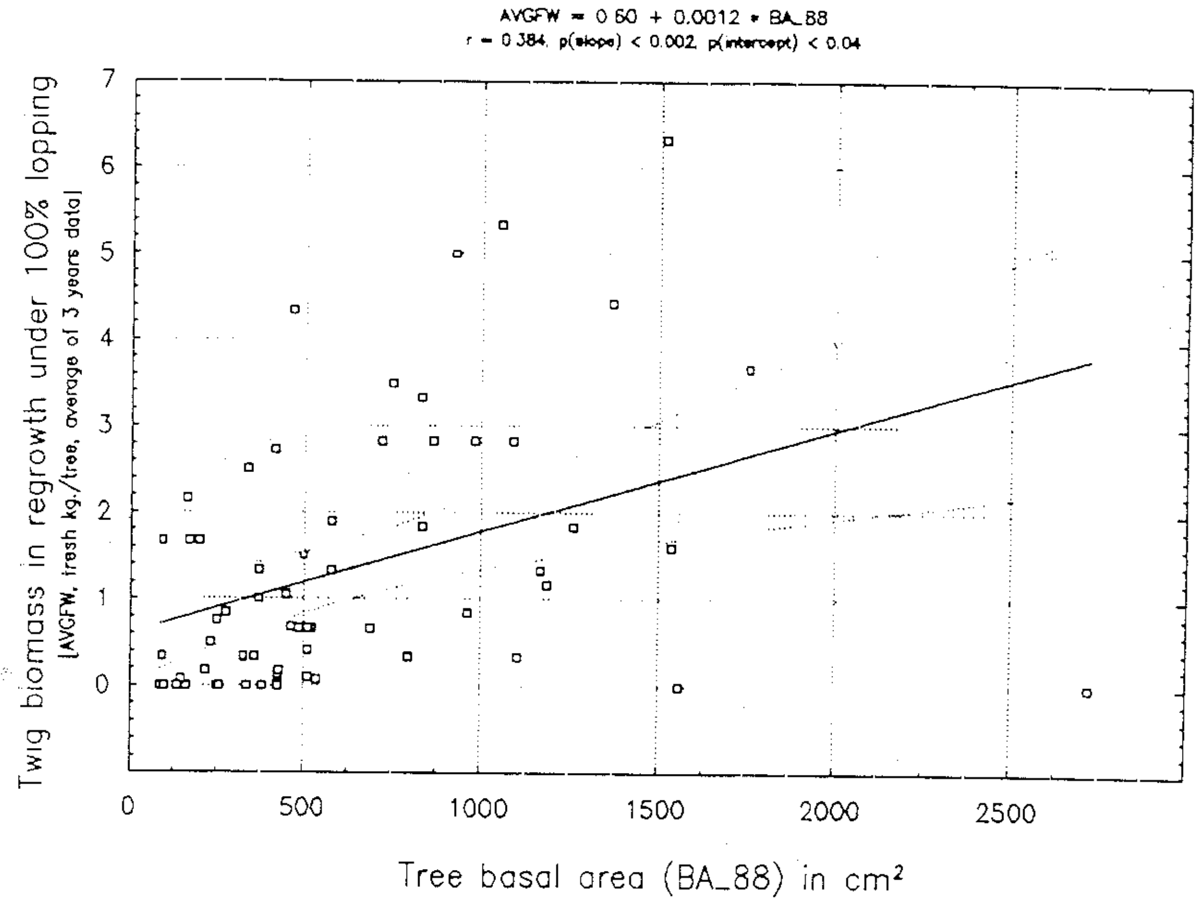

Figure 2. 3-year average of fresh weight of twigs harvested per tree under 100% lopping at BK-LOP

The average amount of twig biomass harvested per tree over the three-year period is plotted against tree basal area in Figure 2. As can be seen, there is large variation in the twig biomass per tree, with a weak but statistically significant ($p<0.02$) trend of

[11] This aspect is important in order to ensure that what is harvested is only what was produced since the last harvest minus material lost to litterfall.

increasing biomass with increasing tree size.[12] The significant non-zero intercept suggests that all lopped trees have some amount of twig biomass. Zero basal area at breast height does not mean zero tree biomass, since it would correspond to the biomass of all trees with girth at breast height less than 20cm. So a non-zero intercept is reasonable. Neither the use of non-linear relationships (linear-log, exponential, square-root) nor separation by species significantly improved the fit.

Two issues need to be addressed before one can use such a crude relationship for estimation of twig biomass on trees. The first pertains to the lopping frequency. The data presented above pertain to trees lopped annually, but most tree lopping in the *soppinabettas* occurs once in two to four years. While the twig biomass that accumulates after two or three years of regrowth will certainly be higher than that accumulating after only one year, what needs to be compared is the equivalent annual yields among lopping cycles. No data are available on this aspect for the region of interest; but estimates of twig accumulation based upon annual lopping are likely to err on the lower side because the partitioning of assimilate between twigs and leaves would tilt towards the former as time after lopping increases.[13]

The second issue is the actual extent of lopping in the village forests, and whether one needs to derive and use different expressions for twig biomass accumulation on

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[12] Four other aberrant data points were removed. One was for a tree with basal area greater than 5000 cm^2, which was driving the regression. Three other points were trees with basal area ≈ 500 cm^2, which yield harvests greater than 8 kg each. All of these points would increase the slope of the regression.

[13] The work of Bhimaya *et al.* (1964) and Srivastava (1978) indicates that annual lopping may yield higher levels of average annual *foliage* harvests than less frequent lopping, suggesting that twig biomass accumulation might be favoured in the longer lopping cycles. Other hypothesized effects of annual lopping, such as on tree mortality (Gorrie, 1937) may also favour longer lopping cycles.

unlopped trees. In six *soppinabetta* plots sampled, the fraction of trees having a "lopped morphology" varied between 55%-88% by number and 62%-93% by basal area. The unlopped trees are usually young ones that villagers prefer not to lop. The sensitivity of the growth of younger trees to lopping appears to confirm the wisdom of their practice. The situation in forests used by paddy-only or landless households will be different, however, since their interest in lopping is not for mulch but for the fuelwood and therefore follows less systematic a pattern. Given the small fraction of unlopped trees in the betta forests, the error in using estimates based on lopped trees for all trees is likely to be small and within the large uncertainties introduced by the poor regression fit; moreover, the contribution of twig biomass accumulation to total TWAGB production is, as we shall see, small enough that the errors are not likely to affect the final results.

1.5 Woody biomass in litterfall

Litterfall plays a key role in net production and nutrient cycling, and there is a substantial literature on litterfall in tropical forests, although much of it appears to focus on leaflitter (see Proctor, 1983 for a review). Some data are available for the Karnataka Western Ghats from the work of Rai and Proctor (1986b), but these data pertain to fairly undisturbed and predominantly evergreen forests.

Results of CES's monitoring of litterfall in 5 plots (3 up-ghat and 2 down-ghat locations, with the former including the BH-BE and SONDA sites referred to earlier) were reported by Bhat (1990). They included estimates of annual smallwood ($<$2cm diameter) and largewood (twigs $\geq$2cm but less than 10cm in diameter). I examined these results to see whether they showed any specific trend. As shown in Figure 3, the amount of litterfall does appear to be reasonably correlated with tree basal area. The unexplained variation is likely to result from a combination of climate, species composition, and tree structure, the effects of which could not be distinguished because of the small sample size.

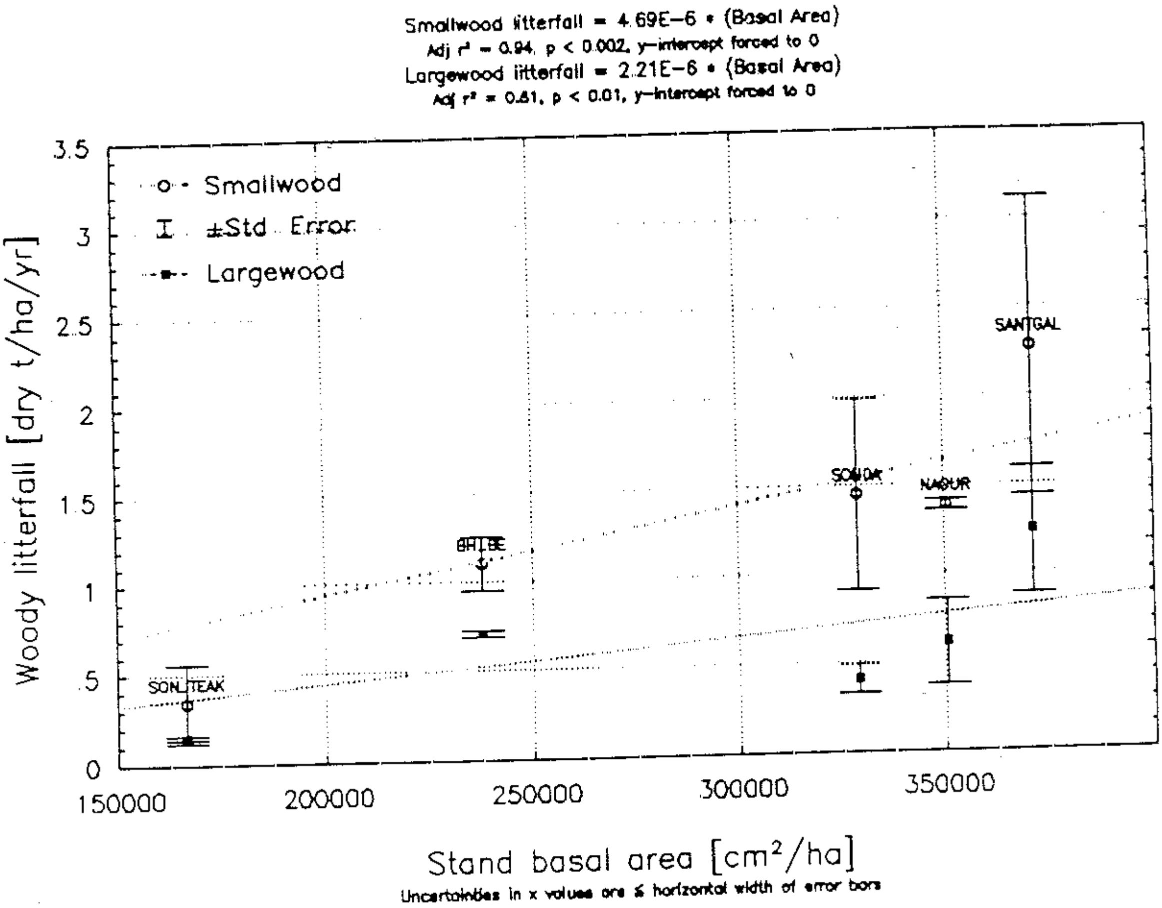

Figure 3: Variation in the woody components of tree litterfall with basal area

One may say that smallwood and largewood litterfall together correspond to the last term in equation (4), i.e, the amount of woody matter that grew and fell off between two successive measurements. However, caution is called for in applying these results, which are mostly from unlopped forests (except BH-BE), to estimating woody litterfall in lopped forests, and also to ensure that the largewood litter does not include the woody biomass from whole trees lost to mortality. It is likely, for instance, that many dead twigs get removed as part of the lopping process, and so would not actually fall to the ground, thus reducing the quantity of woody litterfall in lopped as compared to unlopped forests. The CES data on the BK-LOP plot do not include woody litterfall estimates, so the extent of such decrease cannot be estimated. On the other hand, the BH-BE site in Figure 3 is lopped on a four- or five-year cycle, but does not show particularly lower litterfall. In order to err on the lower side in estimating production, I assumed that a 50% reduction would occur in smallwood litterfall due to lopping, and that 50% of the largewood litter might come from dead tree fall.

2. Estimates of tree biomass production in village forest lands

In the preceding section, I presented data on typical rates of basal area increment, recruitment and mortality, twig biomass growth, and woody litterfall in the Malnaad forests, with particular reference to the forests used by villagers. I attempted to establish approximate relationships between these components of TWAGB production and the key vegetative variable, viz., tree basal area. I also indicated how I would convert basal area increment and recruitment values to TWAGB estimates. Using these data, I now present estimates of tree WAGB production in the sample villages in two stages: first for a sample of tree vegetation plots, and then for the total forest land in each village.

Table 3. Range of estimates of tree biomass production in sampled plots

Plot	Trees	Basal Area	TWAGB Estimate	Survivor AGB Increment		Recruit -ment	Twigs: Lopping	Twigs: Litter		Largewood Litter		TWAGB production	
				Mean	SE	Mean	Mean	Mean	SE	Mean	SE	Low	High
	[#/ha]	[sq.m./ha]	[t/ha]	[t/ha/yr]		[t/ha/yr]	[t/ha/yr]	[t/ha/yr]		[t/ha/yr]		[t/ha/yr]	
SM-BETTA	359	12.6	37	0.9	0.0	0.1	0.2	0.6	0.4	0.3	0.3	1.1	2.0
BK-DVH	555	23.8	92	2.2	0.3	0.2	0.4	1.1	0.2	0.5	0.2	2.9	4.1
BK-LOP	371	13.3	48	1.3	0.1	0.1	0.2	0.6	0.4	0.3	0.3	1.5	2.4
AP-AVH	385	19.5	99	1.9	0.2	0.1	0.3	0.9	0.3	0.4	0.2	2.4	3.6
AP-GMH	444	29.1	156	2.2	0.3	0.1	0.4	1.4	0.2	0.6	0.1	3.1	4.3
GK-GBHAT	495	34.4	201	3.6	0.3	0.2	0.4	1.6	0.2	0.8	0.2	4.7	6.2
TK-GGH	257	11.7	47	1.1	0.1	0.1	0.2	0.5	0.4	0.3	0.3	1.2	2.0
TK-RTH	510	14.6	51	1.5	0.1	0.1	0.3	0.7	0.4	0.3	0.3	1.9	2.9

Notes:

(1) "SE" = standard error.

(2) Uncertainty in the TWAGB estimates is not quantifiable, since it depends primarily on the error involved in applying equation 4. But the parameter values used are believed to be quite conservative, i.e., erring on the lower side.

(3) Annual loss due to mortality does not reduce AGB significantly enough to affect the estimate of increment; hence survivor AGB increment is estimated using all trees.

(4) Errors in AGB increment are based upon the standard errors in the girth-specific annual %BAI, and errors in estimate of basal area (from a 0.5cm error in girth measurement). Errors in height estimate are not calculated, as the uncertainty in the application of the regressions cannot be quantified.

(5) Standard errors for the estimate of twig regrowth are approximate, being the product of the standard error for the "mean tree" (corresponding to the mean basal area per tree) and the total number of trees per hectare.

(6) Standard errors for litterfall estimates are based upon the regressions given in Figure 3.

2.1 Plot-level production estimates

Data on tree vegetation (i.e., girth, species, and in some cases height) were collected from 8 sample plots of *soppinabetta* lands in the villages of interest.[14] The basal area of each tree was calculated, and its woody AGB estimated using the expressions described in section 1.2.2. Mean annual basal area increment and the associated standard error were estimated using the girth-specific averages and standard errors presented in section 1.2.1. Increment in WAGB was then estimated (see appendix B.4). The estimates were summed across all trees ignoring mortality (as explained in section 1.3) and converted to per hectare equivalents. Estimates of additional TWAGB production through recruitment, twig accumulation and litterfall were based upon the stand basal area using the relationships derived in sections 1.3-1.5. The results, along with corresponding measurements and estimates for the BK-LOP site, which is located in Mundagesara village in the Sirsimakki cluster, are presented in Table 3. The estimates of TWAGB production are presented as a range wherein high/low values are the sum of the means ± the quadratic sum of the standard errors.[15]

The values in Table 3 probably represent the first effort to estimate TWAGB

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[14] At each location, a strip of 20m x 100m was marked in a plot controlled by a particular household. The strip was aligned along the slope of the land, if any, because it appeared that the tree density generally decreased as one moved up the slope in most *soppinabettas*. (This may be a combination of higher soil moisture availability at the bottom of slopes and the arecanut cultivator's need to have higher tree density next to the arecanut orchard located in the valley, to protect it from harsh sunlight. Individuals belonging to tree species (i.e., excluding lianas, climbers and shrubs) with girth at breast height ≥ 20cm were chosen, and the species name, girth and lopped/unlopped status were noted. Ocular estimates of height were made. Data provided by CES for SM-TRANS and SM-BETTA had been gathered using essentially the same method, except being from a 10m x 100m strip in the former case and a 100m x 100m plot in the latter.

[15] The litterfall estimates were reduced by 50% before inclusion in the TWAGB estimate, and were excluded completely in those cases where the standard error in the litterfall estimate, whether smallwood or largewood was ≥ the mean litterfall estimate. The quadratic sum of the standard errors is justified since the errors in the individual components of production are largely independent of each other.

production at this level of detail in the Western Ghats forests. Despite of the large uncertainties, the estimates have a number of interesting features. Firstly, the mean estimates of TWAGB increment range between 1.1 to 3.1 t/ha/yr, much higher than the estimate of 1 cum/ha/yr (i.e., ~0.6 t/ha/yr) used by Reddy *et al.* (1986) (see quote at the beginning of this chapter). Secondly, the typical contribution of twig regrowth, twig litter, and largewood litter may be quite significant (~0.3, ~0.5 and ~0.4 t/ha/yr respectively, assuming a 50% reduction in the last two terms as explained before). Ignoring this contribution, as would be the case if one simply equated net production with AGB increment (as Reddy *et al.* do) would lead to a substantial underestimate of *useful* production and would bias any biomass-balance calculation.

Thirdly, the estimated growing stock of tree vegetation is dramatically higher for plots in the Malenalli cluster, a result of the trees there being larger (average basal area per tree being 500-1600 cm^2) and taller (compare the two curves in Figure 1). This indicates significantly better growing conditions, or "site index" in that region, probably resulting from deeper soils. Conversely, the plots in the Tattikai cluster are lowest in basal area per tree, reflecting shallower soils, although the intermittent patches of much taller and heavily stocked evergreen groves (*kans*) observed in this region make one wonder about the relative contribution of edaphic and anthropogenic conditions to reduced standing stock. Fourthly, the variations in per-hectare TWAGB production within each cluster are also significant, and point to the need for disaggregated estimation of total production in village lands.

Table 4. Estimates of tree biomass production in forest lands of sampled villages

Village	Cluster	Tree Density	Used Area [ha]	Woody Productivity Low [t/ha/yr]	Woody Productivity High [t/ha/yr]	Total Woody Production Low [t/yr]	Total Woody Production High [t/yr]
Arasapura	MH	High	59.7	4.7	6.2	316	423
		Medium	14.2	2.4	3.6		
		Low	4.8	0.6	0.9		
Golikoppa	MH	High	52.4	4.7	6.2	254	336
		Medium	2.4	2.4	3.6		
		Low	5.3	0.6	0.9		
Sirsimakki	SM	High	16.2	2.9	4.1	119	189
		Medium	57.8	1.1	2.0		
		Low	17.9	0.3	0.5		
Mundagesara	SM	High	48.0	2.9	4.1	228	348
		Medium	67.9	1.1	2.0		
		Low	32.6	0.3	0.5		
K.Sarakuli	TK	High	20.4	2.6	3.9	77	121
		Medium	20.4	1.2	2.0		
		Low	3.8	0.3	0.5		
Tattikai	TK	High	52.8	2.6	3.9	202	318
		Medium	52.8	1.2	2.0		
		Low	11.9	0.3	0.5		
Malenalli (MF+RF)	MH	High	131.7	4.7	6.2	726	973
		Medium	44.4	2.4	3.6		
		Low	4.1	0.6	0.9		
Malenalli (MF only)	MH	High	48.4	4.7	6.2	234	309
		Medium	2.0	2.4	3.6		
		Low	4.1	0.6	0.9		

2.2 Village-level production estimates

The second stage consists of constructing village-level estimates of TWAGB production. I mapped the vegetation in each village[16]. I used methods described in Appendix D to obtain estimates of the area of tree land in the three "density classes": high density (i.e., tree density > 400/ha or basal area > 20 m^2/ha), medium density (i.e., tree density between 100-400/ha and basal area between 8 to 20 m^2/ha), and low density (i.e., tree density < 100/ha or basal area < 8 m^2/ha). Those lands that did not display a lopped tree morphology or other signs of tree harvest were then excluded, as were areas controlled by households not living in the studied villages. The estimates of area in each density class are given in Table 4, column 3.

The sampled plots for which productivity estimates were presented in the previous section span the range of medium-density to high-density tree vegetation. It would therefore be reasonable to take the estimated range of TWAGB production from these plots as representative of the range of TWAGB production in that density class for that village cluster. I used SM-BETTA/BK-DVH, AP-AVH/GK-GBHAT and TK-GGH/TK-RTH as representatives of the medium/high-density treelands in the SM, MH and TK clusters respectively. Finally, I assumed that the TWAGB production in the low-density tree land would be 25% of that in the medium-density lands for that cluster. These assumed productivity values (given in Table 4, columns 4-5) were used to calculate the total production of woody biomass in the village lands demarcated for this comparison (Table 4, columns 5-6). Corresponding to the low and high production estimates for the

[16] Except the Vadageri and Mulikinakoppa hamlets because they were too small to include, and the piece of Keregadde village in the TK cluster, where the lands owned by the sampled households (a subset of all households in Keregadde revenue village) were too patchily distributed for proper mapping.

sample plot used for each density class, low and high estimates of total village-level production were obtained.

3. Estimation of tree biomass extraction

"Extraction" is the amount of a particular biomass type harvested or collected from a particular piece of land, whereas "consumption" is the final quantity of biomass used for a particular purpose. In assessing the sustainability of use, one would ideally want to compare production with directly measured extraction. In practice, extraction is difficult to monitor and measure, as it takes place over large areas of land all round the year. Monitoring or estimating consumption, on the other hand, is often easier since it occurs at specific locations, such as household kitchens and the users too may have reasonable estimates of their use. But if one is to use household- or village-level consumption to estimate extraction from treeland used by the household or village as a whole, one needs to account for consumed biomass that may originate outside the land of interest and, conversely, harvested biomass that may not show up in the consumption, if for instance, it is exported outside the village. [17]

Woody biomass is used in the Malnaad villages as *fuelwood* for cooking, bathwater heating, processing of arecanut and sugarcane, and some space heating, and as *timber* for house or shed construction or repair, agricultural implements and fencing. In the villages of interest, responses to our questionnaire survey and personal observation by myself and C.M.Shastri (CES, personal communication) showed that

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[17] For discussions of the methods for and pitfalls in estimating fuelwood consumption, see FAO (1983), Bajracharya (1983), Fox (1984) and Joshi and Ramana (1989).

(a) direct purchases from an outside market were negligible in all cases,

(b) villagers did cross individual or village land boundaries while extracting fuelwood and particularly fencing material, but this was done mostly by those who did not have significant forest land (usually *soppinabetta*) under their control,

(c) most (80% or more) of the fuelwood and timber needs of all betta-owning households were met from their betta lands;

(d) extraction by non-betta-holders from betta lands, whether clandestine or with the permission of the betta-holder, was limited to a few landless households that worked regularly for their employer,

(e) in Malenalli village (not the whole MH cluster), there are no betta lands, but the villagers' extraction practices appear to be limited to the MF and RF lands within the village.

Because of these findings, I adopted a two-level strategy in estimating extraction for production-extraction comparisons: (1) plot-level estimates for a limited number of *soppinabetta* plots that could be monitored directly, production estimates were presented in the previous section, and (2) village-level estimates based upon consumption data for only betta-holder households, except for Malenalli village, where all permanently resident households were included.

3.1 Actual harvests from a sample of *soppinabettas*

The harvesting of mulch and fuelwood from *soppinabettas* usually occurs once a year during the early part of the dry season (December to mid-March). During this period in 1989-90, measurements were made of the actual amounts of leafy and woody biomass harvested from the *soppinabettas* that had been sampled for tree vegetation structure. This involved the counting of total number of headloads removed, weighing of sample headloads, estimating the moisture content of the biomass, and measuring the area of the *soppinabetta* plots.

Table 5. Estimates of annual woody biomass extraction from plots monitored in 1989-90.

Hamlet-Household code	*Monitored* woody matter removal [t/yr]	*Estimated* Timber† extraction [t/yr]	Area of treeland harvested§ [ha]	Extraction pressure [t/ha/yr]
AP-AVH*	7.00	0.80	9.794	0.796
AP-GMH	4.60	0.25	2.051	2.365
GK-GBHAT	5.20	0.20	3.268	1.652
TK-GGH	0.95	0.35	1.214	1.071
TK-RTH*	5.60	0.60	9.915	0.625

Note: All households were using improved cookstoves in the year this monitoring was carried out.
* : Household also used bio-gas.
† : Timber includes wood used for beams, pillars, fencing poles and agricultural implements.
§ : Actual forest land area controlled by each household has been adjusted for barren or sparse tree patches, where necessary, so that it corresponds to an area of tree land with tree densities similar to those of the sample plot. The actual area lopped each year is half of the total area, since all the betta-holders were using a two-year lopping cycle.

Due to the distances between the village clusters and the unpredictability of when individual farmers could hire labour to carry out the various lopping and headloading operations, the monitoring of extraction could not be completed for all the plots that were sampled for tree vegetation structure (Table 3). For those plots that monitoring was completed, the results are given in Table 5. Timber extraction could not be monitored because of its sporadic and irregular nature. It had to be estimated on the basis of questionnaire data.

The harvest data in Table 5 are the amounts extracted from the betta-holders' land during a particular year. The amounts may not always represent historical or future extraction. More important, they do not always represent *all* the woody matter used by that household during a year. In particular, the extraction by TK-GGH amounts to a consumption of only ~95 kg/capita/year for fuelwood, an impossibly low figure. The household indicated that much of their fuelwood requirement was actually obtained from MF/RF lands. Finally, it should be noted that the sample presented here is likely to underestimate woody biomass use as it contains two households that use bio-gas for cooking and three that had begun using improved cookstoves by the time this monitoring was carried out.

3.2 Village-level estimates of extraction from *soppinabettas* based upon consumption data for betta-owning households

All betta-holders in the sampled villages reported extracting most (>80%) of the woody biomass they used from *soppinabettas*. It is therefore possible to use aggregate estimates of consumption by these households as estimates of extraction from these lands. The sources of information available for the construction of such estimates were

(a) earlier results of fuelwood consumption monitoring reported by CES researchers for neighbouring villages (Mishra *et al.*, 1985?; Prasad *et al.*, 1987b) and for a village in coastal Uttara Kannada that has substantial betta and MF/RF lands (Hegde, 1986b);

(b) measurements of 1-day fuelwood consumption for cooking carried out in 61 households in the Sirsimakki village cluster (C.M.Shastri, CES, unpublished data);

Table 6. Village-level estimates of annual use of tree biomass

Village	Cluster	Betta house-holds	Betta-holder population	Estimated Woody harvest [t/yr] Low	High	RATIOS OF HARVEST:PRODUCTION FW(hi):Woody(lo)	FW(lo):Woody(lo)	FW(hi):Woody(hi)
Arasapura	MH	15	102	82	133	0.42	0.26	0.31
Golikoppa	MH	12	96	77	125	0.49	0.30	0.37
Sirsimakki	SM	25	194	155	252	2.13	1.31	1.33
Mundagesara	SM	42	327	262	425	1.87	1.15	1.22
K.Sarakuli	TK	11	74	59	96	1.25	0.77	0.80
Tattikai	TK	20	183	146	238	1.18	0.73	0.75
Malenalli (MF+RF)	MH	37	280	224	364	0.50	0.31	0.37
Malenalli (MF only)	MH	37	280	224	364	1.56	0.96	1.18

(c) estimates from weekly and annual recall in questionnaire surveys conducted by CES staff in 1987 and by me with their help in 1990-91, covering all the households in the three village-clusters; and

(d) results of the monitoring in 1989-90 of betta harvests by individual households that were presented in the previous section.

The questionnaire data did not indicate any statistically significant differences between fuelwood consumption levels amongst betta-holder households. Nor did the monitoring in (b) or (d) above indicate any significant trends: the scatter in per capita consumption, though not as much as in the questionnaire data, was quite high. The only significant differences were associated with differences in fuelwood-utilization technologies and, to a lesser extent, with the ownership of sugarcane cultivation which resulted in additional consumption of fuelwood for *jaggery*-making. In particular, households using bio-gas or kerosene for cooking obviously having much lower levels of consumption of fuelwood, and those using improved stoves show about 30% savings over those using traditional stoves. Since in most cases these technologies were introduced to the households recently through the eco-development programme initiated by CES, I decided not to incorporate these reductions in my calculations. In other words, I have estimated what the situation might have been *before* the introduction of the new technologies, the situation prevailing in most other parts of the Malnaad today.

Given the wide scatter in the values observed, and the bias of the currently observed values, I decided to use heuristically derived low and high estimates rather than a statistically derived mean with standard errors. My high estimate is based upon an average per capita woody matter use of 1.0 t/yr (0.9 tonnes for fuelwood, and 0.1 tonnes for timber); the low estimate corresponds to a use rate of 0.65 t/capita/yr (0.60 tonnes for fuelwood and 0.05 tonnes for timber)[18]. These values were then coupled with data on landholding and population of betta-holder households to arrive at the estimates in Table 6. Finally, using the estimates of production in the used betta lands from Table 4, ratios of the high and low estimates of extraction to the low estimate of production were calculated (last two columns of Table 6).

4. Comparison and discussion

Upon comparing production and extraction at the plot-level (Table 3 and Table 5) and at the village level (Table 6), it appears that woody biomass extraction is probably lower than its production in most cases. At the plot level, estimated extraction is below the lower limit on estimated production in all cases. At the village level, the higher estimate of extraction is less than the lower limit on estimated production for three villages (Arasapura, Golikoppa and Malenalli, assuming that all the MF/RF lands in Malenalli are available to its residents). For two other villages (Kelagina Sarakuli and Tattikai), the ratios are such that the mid-value of extraction would be lower than the low estimate of production. Only in two villages (Sirsimakki and Mundagesara, both in the SM cluster) were both the high:low and low:low ratios of extraction:production greater than 1.0,

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[18] Prasad *et al* (1987b) reported average per capita fuelwood consumption for cooking and water heating in Bhairumbe village to be 2.5 dry kg/day for a sample of 62 households. This amounts to 0.91 t/cap/yr. Mishra *et al* (1986) estimated average annual total fuelwood consumption to be 0.4 t/cap for landless households, and 1.2 t/cap for betta-holder households respectively on the basis of survey questionnaire data. Monitoring of fuelwood consumption for cooking in the Sirsimakki cluster indicated an average consumption of 1.6 kg/cap/day (=0.58 t/cap/yr) in households with conventional stoves. Survey data indicated that fuelwood requirements for areca boiling and jaggery making add 50-100 kg/cap/yr in those households that do such processing. The average estimate of timber use from survey data was 0.1 t/cap/yr. Thus, 0.7 t/cap/yr of total fuelwood and 0.1 t/cap/yr of timber appears to be a reasonable low estimate, and 1.1 t/cap/yr of fuelwood and 0.2 t/cap/yr of timber would be reasonable upper limits.

creating a significant possibility of unsustainable use. Such a possibility would also exist if all the villagers in Malenalli village were restricted to using only its MF.

How robust are these results, given the various approximations and uncertainties? At the household level, the sample is biased towards lower consumption values. But even doubling the woody biomass consumption rate for the bio-gas user households and increasing that for the others by 30%, which is the typical saving from improved cookstoves (Hegde, 1986b) does not dramatically increase the probability of unsustainable use. At the village level, uncertainties are introduced due to (a) unquantified errors in estimating tree vegetation densities, and the assumption that the plots sampled are the representative of the production in the high and medium density classes, (b) the assumption of productivity in low density treeland being 25% of that in medium density tree land, (c) the possibility of extraction from bettas by non-betta holders, either residents or seasonal migrant labourers, and (d) the uncertainties in the area accessible to villagers in Malenalli village.

The error in estimating production due to (a) is in fact probably conservative for the TK cluster because the TK-RTH plot appeared to have significantly smaller trees compared to many areas with similar tree densities in the cluster. Assuming that the productivity of low density tree lands is actually zero would reduce the productivity by less than 10% in all villages, which does not affect the conclusions.

The extraction by non-betta-holders from bettas was reported to be significant in the SM cluster, where little MF/RF lands were available in the vicinity. On the other hand, the current consumption estimates for this cluster are probably overestimates because the average per capita fuelwood consumption reported by betta-holders in this cluster was significantly lower (0.5 t/cap/yr) than the other two clusters (0.8-0.9 t/cap/yr) after controlling for technology of use; fuelwood use is reduced further if one incorporates the fact that several households have switched to kerosene or LPG. The net effect may be to reduce but not eliminate the possibility of a quantitative imbalance in woody production and harvest in the SM cluster.

The result in Malenalli village is quite sensitive to assumptions about the area of RF accessible to villagers for fuelwood extraction. Extraction (of any kind) from RF lands is still subject to state scrutiny, regulation, and penalty, and the ban on cutting of green wood, although applicable to all forest lands, is enforced most vigorously in RF lands. Villagers pick up dead material as they are allowed to. But they do not systematically lop trees, or fell any of significant girth (> ~40cm). They prefer to cut young trees or saplings which are less conspicuous and less valuable, to reduce the chances of getting caught. The effect may therefore not be quantitative, but qualitative, i.e., reduced tree regeneration, in spite of a quantitative surplus.

The variations in the ratios of extraction to harvest offer some interesting insights. At the household level, the ratios are nearest to 1 for the TK-GGH and AP-GMH, the households with the least betta land and no bio-gas. (The two phenomena are not unrelated, as we shall see in Chapter VI.) At the village-level, the availability of betta land per capita and its "quality" in terms of woody productivity (see Table 4) is lowest in the SM cluster. While the quality may be related to edaphic factors (see section 2.1), the lower availability is the result of relatively greater fractions of betta areas in the SM cluster being under low density treeland and grassland (see Appendix D). This suggests a trade-off between tree and grass production. The woody biomass availability per capita is the highest in Golikoppa and Arasapura, where it appears that the needs of many locally resident labourers working for the betta holders have been externalized onto the MF/RF lands in neighbouring villages. In short, differences in the margin between production and harvest may relate to inherent differences in land productivity, to larger areas devoted to grass production, and to differences in per capita betta allocation.

On the whole though, there is sparse evidence for unsustainable use of woody biomass in the sampled villages by this criterion. Although this contradicts current belief about the situation in the rural Malnaad[19], it is in consonance with what one might expect, given the combination of incentives, capacities, and control that most betta-holders have in the sustainable management of their lands. Chapter VI develops this point in more detail.

[19] See, e.g., Gadgil (1987a) and Nadkarni *et al.* (1989, p.153).

Chapter IV. Vegetation structure, soil condition, and sustainability of tree biomass production: A preliminary assessment

Over 75% of the forests have no seedling or sapling regeneration. ..... The lack of regeneration is attributed to three major causes: theft for fuel and small-size building material, trampling and grazing by cattle, and fire.

— From a recent official description of the current condition of the Western Ghats' forests (KFD, 1990)

The application of the production-harvest or biomass-balance comparison criterion in the previous chapter suggested that "over-extraction" of tree biomass in its simple quantitative sense may not be a major cause of unsustainability of tree biomass production in most of the tree lands of the sample villages. The criterion assumes that the tree biomass resource is a homogeneous stock resource, with production only dependent upon the current size of the stock. In reality, of course, present and future production depend upon a number of other variables, particularly the age- and size-structure of the tree vegetation and the soil fertility conditions. For instance, destruction of tree seedlings through heavy grazing may contribute little in terms of biomass removal, but will result in a long-term deficit in the productive stock. Continuous removal of leaflitter may expose the soil to erosion, and deplete its nutrients with adverse effects for future vegetative growth. Thus, a production-harvest balance may be a *necessary* condition for resource sustainability, but not a *sufficient* one. The effects of resource extraction and management practices on such structural parameters in the ecosystem that control future vegetative production need to be considered as well.

In this chapter, I present preliminary data on some aspects of vegetation structure and soils in and around the villages of interest. I examine whether, in terms of these aspects, one can make any judgements about the sustainability of useful vegetative production on the basis of vegetation structure and soil condition in different uncultivated lands, and how the trends in sustainability might relate to the manner in which the vegetation is used and the soil is modified.

Two difficulties immediately present themselves. Firstly, unlike the biomass-balance criterion, there is no obvious and simple way of framing a sustainability criterion in the context of vegetation structure or soil condition. For instance, whether a particular age-frequency distribution of trees will result in reduced flows of biomass in the future depends on the interaction between extraction practices and the population dynamics of the forest. An even-aged stand would contribute to a constant total flow of biomass if it were one of a sequence of stands forming a "synchronized stationary forest" (Dasgupta, 1982, p.183) harvested on a fixed rotation, but not if it were the only stand being harvested annually for biomass. "Natural" uneven-aged stands will yield constant flows if their diameter-class distribution remains unchanged after each cycle of growth and extraction.[1] But what initial distribution will ensure this depends upon the pattern of extraction. Similarly, there are no simple benchmarks for soil variables that specify some sustainability threshold; too much depends upon soil "background" (i.e., soil conditions that might have existed in the absence of human use), and the two-way interaction between soil and vegetation.

Secondly, in the context of the Malnaad and many other rural tropics, "human use" encompasses a large variety of activities, such as grazing, firing, shrub removal,

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[1] Recent work also points to the importance of ***individual*** structures such as standing and fallen dead trees in temperate forests (Franklin *et al.*, 1987), and ***stand-level*** features such as "multiple canopy levels, chaotic tree spacing, and gaps" (Franklin, 1992) for the long-term sustainability of the forest ecosystem as a whole.

litter removal, tree lopping, tree felling, fruit or seed harvesting, etc., which affect the vegetation structure and soil conditions in complex and poorly understood ways, and which have varying implications for future vegetative production. "Isolating" the effect of one activity such as grazing on future biomass production through a particular structural parameter such as seedling survival in a situation where fire, shrub cutting, and canopy modifications due to the lopping affect the same parameter, is a huge if not impossible, task.[2]

The approach adopted in this assessment is to use a mixture of (1) absolute and relative comparisons in assessing sustainability, (2) broad qualitative associations between, and some quantitative measures of extraction pressure in defining resource use and management. Although the data are incomplete, this exploratory exercise provides some insights. I present the results for vegetation and soils in that order, beginning in each case with brief overviews of the processes involved and criteria adopted, a short description of the methods, and then the presentation and discussion of results.

1. Structural sustainability of production, tree regeneration, and use regimes

Since the productivity of trees depends significantly upon their girth, an even flow of biomass products can be obtained from a forest stand if its girth distribution is maintained unchanged. The problem of maintaining a constant girth distribution, fairly straightforward in fully managed even-aged forests is complex in uneven-aged forests. According to Meyer (1952), empirical data on girth-frequency distributions in balanced

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[2] And this is in spite of using a narrow definition of sustainability as simply maintenance of undiminishing production under average conditions, ignoring the important problems of maintaining productive capacity in the face of variability, catastrophe and shifts in environmental conditions (Lélé, 1989).

natural uneven-aged stands were first published by F. de Liocourt in 1898. These distributions showed a remarkable fit to a negative exponential relationship[3], now commonly known to foresters as the (reverse) "J-curve".

Although the empirical data from which the curve was derived corresponded to undisturbed virgin forests, if one knows the girth-specific growth and mortality rates for a particular forest stand, one can derive the set of girth-specific harvests that will maintain the J-curve; this would form a prescription for the sustainable management of the stand (Davis and Johnson, 1987, pp.56-63). Even if one does not know and cannot control the rate and distribution of the harvest, if the girth distribution of the stand resembles the J-curve, the stand is probably being used sustainably. The J-curve thus provides an "absolute" benchmark for assessing sustainability with respect to tree stand structure.[4] It is not clear, however, that this girth-distribution criterion can be extrapolated down to young saplings and seedlings, whose girth at breast height will typically be less than 20cm and even zero. For these, one may have to rely on comparisons of seedling/sapling densities and survival rates across sites.

What aspects of forest land use and management by villagers in the Malnaad might affect tree vegetation structure in general, and which of them are likely to show

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[3] De Liocourt showed that the number of trees (N) of a particular diameter in a balanced uneven-aged forest is related to the diameter (D) as $N=k.e^{-aD}$, where k and a are constants characterizing respectively the number of trees in the smallest diameter class and the rate of tree diminution between successive diameter classes. "Balanced" means a forest "in which current growth can be removed annually or periodically while maintaining ...the structure and initial volume of the forest" (Meyer, 1952).

[4] Pascal (1986; 1988) has used an alternative approach to assessing structural sustainability of forests in the Malnaad and elsewhere in the Karnataka Western Ghats. He plots the logarithm of tree height (H) against the logarithm of diameter (D) for all the trees in a stand, and claims that the points to the left of the line H=100D represent the "set of the future". Therefore, the presence/absence of a "sufficient" number of such points indicates the sustainability of stand structure. The logic behind this claim is not quite clear.

up in the J-curve? The quote at the beginning of this chapter identifies the three obvious candidates, viz., cutting of small-sized wood for fuelwood and fencing, grazing of livestock, and fire[5] (and it makes a rather strong claim about the magnitude of their effect!). Removal of wood for fencing and fuel, if it occurs in the form of whole trees[6], is likely to create an imbalance in tree girth distribution. Grazing and fire, on the other hand, directly affect smaller saplings and seedlings, although a continuous deficit in these age-classes would eventually materialize as a deficit in the adult tree population, too. The intensity, timing and distribution of these disturbance variables would in turn depend upon the extent of demand, supply and the institutional regime and technology associated with villagers' use of the land.

The data and experimental design required to distinguish the effects of each of these factors on tree population dynamics would be vast and complex, requiring a level of detail in the monitoring of the quantity, location and manner of extraction, grazing and firing that could not be implemented as a part of this research. I have therefore adopted a heuristic approach, classifying the sampled sites into "use regimes" on the basis of the type and level of disturbance prevailing in them. These categories are as follows.

(1) Privately-controlled but unfenced land, uncontrolled grazing year round, frequent fire, regular lopping of trees (labelled "open lopped forest", code = OPEN_LOP);

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[5] Other factors would include the selective extraction of old growth from village Minor Forest lands by the Forest Department during the 1960s, changes in light and moisture regimes due to the lopping of the canopy, leading to changes in species succession, and colonization by exotic weeds (e.g., *Eupatorium sp.*) leading to suppression of tree seedling growth.

[6] While fencing poles might almost by necessity be whole young trees, users would not cut whole saplings if they could climb and lop grown trees. The inability or disinterest of users in carrying out such systematic lopping is likely to be related directly to their not having legitimate access (as in Reserve Forests) and therefore being in a hurry to cut and remove the material for fear of being caught, or physical limitations (such as when women or children are forced to gather the fuel).

(2) Privately-controlled but unfenced land, located so as to reduce likelihood of uncontrolled grazing, occasional fire, regular lopping of trees (labelled "partially protected lopped forest", code = PP_LOP);

(3) Privately-controlled fenced land, strictly controlled grazing (limited to the wet months of the year and to only the owners' livestock), no fire, regular lopping of trees (labelled "fully protected lopped forest", code = FP_LOP);

(4) Open-access land, grazing of varying intensity (distributed over the year), infrequent fire, little lopping, heavy extraction of saplings and tree branches (labelled "partially protected unlopped forest", code = PP_UNLOP);

(5) Fully protected or inaccessible land, very limited or no grazing, no fire, no lopping, insignificant tree cutting (labelled "fully protected unlopped forest", code = FP_UNLOP).

These categories do not represent all possible combinations of grazing, burning and lopping intensities, but rather the typical variations in use and management found in the village clusters.[7] They are in a very approximately decreasing order of disturbance. The assignment of the use regime for each sampled site was based upon personal observations, interviews with the owners or users of that land, and some measurements

[7] These categories are bound to be partially correlated with the legal category of the forest land, with the first three typically corresponding to *soppinabettas*, the fourth to MF, and the last to RF. In practice, however, enough exceptions and variations are found (see Appendix D) to make a classification based upon legal status misleading.

of disturbance[8]. In most cases, the current pattern of use appeared to have been stable for a few decades.

I use this categorization to examine the possible relationship between sustainability of tree vegetation structure, measured in terms of adult tree girth distributions and seedling/sapling densities, and human use.

1.1 Girth distribution of adult trees

Data on tree vegetation in sample plots from my own sampling of *soppinabetta* vegetation and from plots monitored by CES were combined to obtain a total of 15 girth-frequency distributions. The percentage of all trees occurring in a particular 20cm girth-class interval was plotted against the mid-point of that girth-class. The percentage is used in order to make valid comparisons across varying plot sizes and tree densities. The girth frequency distributions are presented in Figure 1.

The girth distributions resemble the J-curve in a majority of the cases, i.e., in 11 out of 15 sites. A regression of ln(N) against girth yielded a coefficient significant at $p<0.05$ or better and R^2 values ≥ 0.83 for these 11 sites. The exceptions were AP_AVH, AP_GMH, BH_KMH and BIDR, where there are distinct deviations from the J-curve. Deficits in just the lowest girth class are also apparent at sites BK_DVH and

[8] The fractions of seedlings and saplings growing from coppice (for coppicing tree species only) were determined, and in each case were found to be strongly correlated with the presumed ranking of disturbance (OPEN_BETTA > PART_BETTA > WELL_BETTA). Coppicing, the regrowth of a plant after being cut down, may occur when a plant gets cut down, either for its woody matter (in older saplings), or when villagers cut green shrubs during the monsoon (for animal bedding and manure), and possibly to some extent by the browsing of livestock. It is thus only partially related to the key factors of grazing, fire and wood removal.

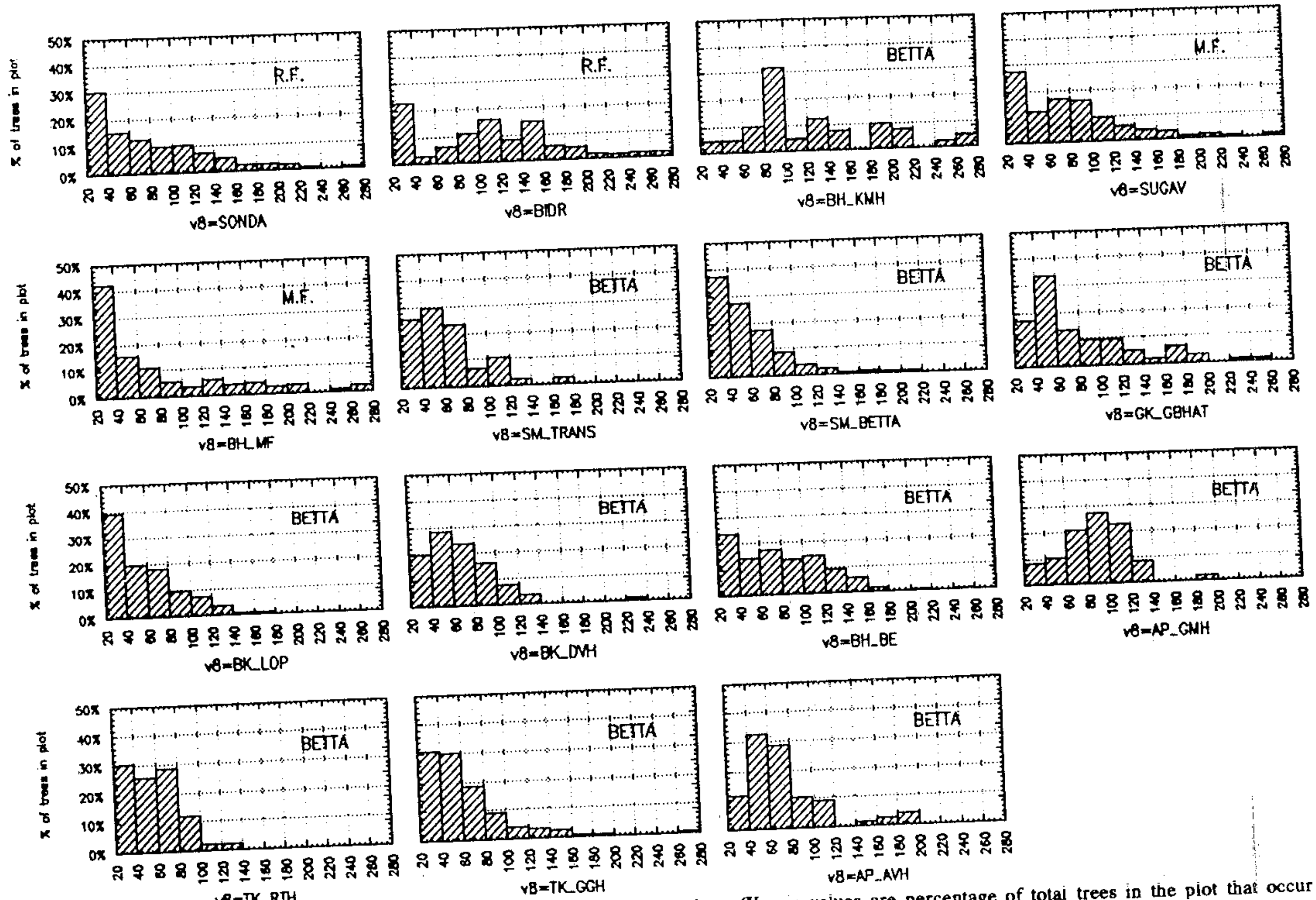

Figure 1. Distribution of trees by girth (at breast height) in sampled forest plots. (Y-axis values are percentage of total trees in the plot that occur in the corresponding girth-class.)

GK_GBHAT [9]

Is the deviation of the girth distribution of a particular site from the idealized J-curve related to its use regime? The graphs in Figure 1 are arranged in reverse order of use regimes defined above. Also indicated on the graph is their legal status. BH_KMH is a betta site that has been included with RFs because its owner claimed to have completely stopped lopping and grazing for two decades. There does not appear to be any general correlation between imbalance in girth distribution and use regime. One RF site (BIDR) shows signs of heavy unbalanced removals, while the other (SONDA) does not, and the site supposedly unexploited for the last two decades (BH_KMH) resembles the former rather than the latter. The open-access Minor Forest sites (BH_MF and SUGAV), on the other hand, show well-balanced girth distributions, as do six of eleven bettas. The four bettas that show some deficit of small trees (BK_DVH, GK_GBHAT, AP_GMH and AP_AVH) include well-protected ones as well as open, unprotected ones, but they are probably under heavier extraction pressure. The last three are under the heaviest pressure among those for which data were presented in Chapter III, Table 5).

1.2 Sapling and seedling densities

Three to five sub-quadrats of 10m x 10m were randomly marked in or near the strips sampled for adult tree vegetation. The number of saplings defined as tree species individuals smaller than 20cm girth at breast height but taller than 30cm and seedlings, tree species individuals shorter than 30cm, were enumerated by species; only those plants

[9] Ideally, one would like to examine species-wise girth-distributions and predict the successional dynamics in the stand. But given the virtual absence of information on such dynamics, it is hard to say what the species-level curves would tell us.

that grow as trees (i.e., as single-stemmed plants) were included.

These seedling and sapling regeneration data are currently available for only 7 sites. The equivalent per hectare sapling and seedling densities for them are shown in Figure 2. The TK-GGH and TK-RTH sites contain the rapidly regenerating species *Hopea wightiana*, a common Dipterocarp in the evergreen belt that does not occur in any other site, making comparisons with these sites misleading. While the small sample size makes generalization impossible, within the sites sampled, decreasing regeneration is not correlated with increasing disturbance.

1.3 Summary

Given the small number of samples, it is necessary to interpret these results with caution. It seems fair to say, however, that the girth distribution of trees in many *soppinabettas* appears to satisfy the J-curve criterion. If plotted using absolute numbers of trees, the flatter of these curves correspond to sites with more open canopy structures. Some sites do show a clear absence of smaller and presumably younger trees, possibly due to recent excessive removals of young trees for wood, or earlier suppression of seedling and sapling growth. But before one concludes that these plots are managed unsustainably, one might ask whether the J-curve is a *necessary* criterion for sustainability. The canopy in these disturbed forests is often quite open (less than 50% closure), and so the mortality in younger trees due to the dominance of larger trees is likely to be much less than in a closed-canopy forest. Further, farmers may actively enhance the survival of some younger (unlopped) trees while maintaining a higher population of medium-sized

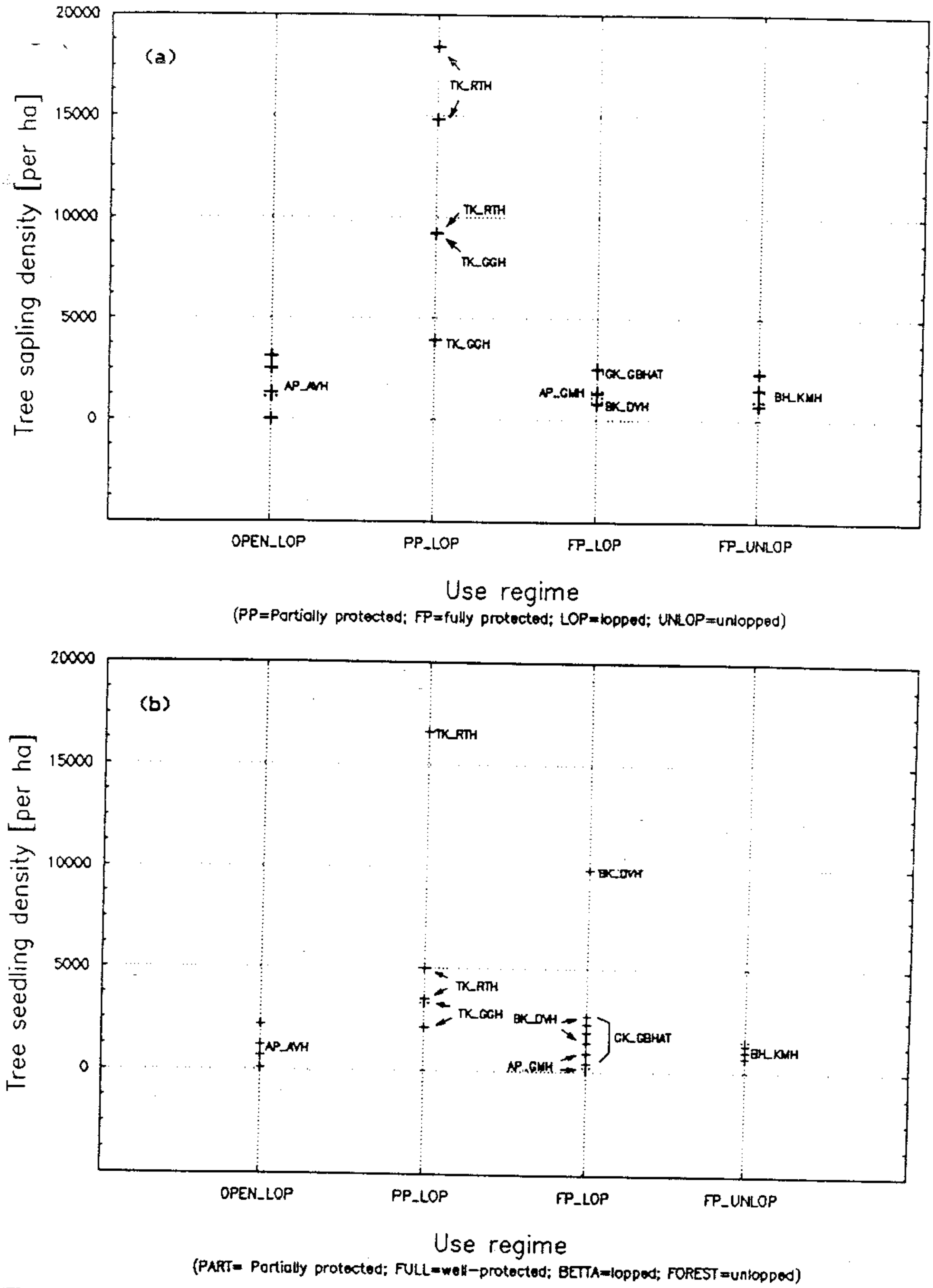

Figure 2. Regeneration in some *soppinabetta* sites: (a) Saplings and (b) Seedlings.

(loppable) trees to maximize useful production and ensure a crop for the future.[10] More research into the population dynamics of such heavily manipulated forests is clearly needed.

The data on sapling and seedling densities are very limited. But at the very least, they show that the statement "..... there is no seedling or sapling regeneration....." would be an exaggeration in the study area. This is not to imply that regeneration is not harmed at any level of grazing pressure, but rather to correct the impression that any level of grazing is guaranteed to destroy seedlings and saplings.

2. Soil condition in forest lands, and the effects of use regimes

Soils are considered to be the "physical basis for [forest] productivity" (Franklin, 1992). It is therefore important to attempt to understand how the use of forests by villagers in the Malnaad might be affecting the soil conditions in these forests. I present here preliminary data on some physical and chemical aspects of soil condition (mainly soil texture, acidity and macro-nutrients), using a sample of sites in the village-forest lands of interest. I attempt to relate these soil variables to the management/use regime and the rate of biomass extraction from the sites.

2.1 Methods of sampling and analysis

(a) Sampling

Soil samples were collected from (a) the *soppinabetta* sites that were sampled for tree

[10] For instance, some *soppinabetta*-holders continue to follow the traditional practice of protecting tree seedlings and saplings with thorns to prevent them from being grazed or trampled by livestock.

vegetation condition (AP-AVH, AP-GMH, ...), (b) herblayer clipping sites located in medium- or high-density tree lands (KS-CLIP, TK-CLIP and CH-CLIP), and (c) a few other sites in or near the TK village cluster sampled to cover a range of open grassland and dense undisturbed forest vegetation types. The locations of all these sites are given in Figure 1 in Chapter II.

Samples were collected from three to five points in each site spanning the upper and lower reaches of the land to the extent possible. At all locations, soil samples from two depths, 0-15cm and 15-30cm, were collected and analyzed. Due to logistical difficulties, only a subset of the samples collected for the 15-30cm depth could be analyzed.[11]

(b) Physical Analysis

Fractions of coarse sand, fine sand, silt and clay in the soil were determined using separation with sieves for coarser particles, and differential rates of sedimentation for finer particles. International standard definitions and methods described in Sarma *et al.* (1987) were used for the classification.[12]

[11] 30% of the samples were lost or corrupted due to breakage of sample bags in transit to Bangalore for analysis.

[12] Coarse matter, i.e., particles with diameter > 2mm, as well as organic matter were removed by sieving and hydrogen peroxide digestion respectively, and were ignored in the calculations of the fractions. International definitions are: 2mm > coarse sand>0.2mm; 0.2mm>fine sand>0.02mm; 0.02mm>silt>0.002mm; clay<0.002mm. In the case of a few samples, the total of the four fractions differs from 100% by up to ±3%, because of some disturbance in the apparatus during the 8-hour long sedimentation times. Their inclusion/exclusion does not significantly affect the statistical results.

(c) Chemical Analysis[13]

Soil pH was determined in water (1:2.5 dilution) with a pH meter; electrical conductivity using a conductivity meter, organic carbon using the Walkley and Black rapid titration method (excess of potassium dichromate with sulphuric acid); available nitrogen (N) using alkaline steam distillation to liberate ammonia which is trapped in boric acid and titrated; available phosphorous (P_2O_5) using Bray's No. I reagent (ammonium fluoride), ammonium molybdate, and photoelectric colorimetry); exchangeable potassium (K_2O) with ammonium acetate extractant and flame photometry.

2.2 Results

The effect of the use of forest lands on soils may be tested in two ways: through a comparison of soil conditions in plots under different use regimes, and through an examination of the relationship between soil condition and the extraction levels observed for these plots. The former would give the gross effect of multiple management variables acting over a long time period. The latter could provide insight into the specific effects of nutrient drain through biomass removal. Before examining the soil data from these two perspectives, I briefly summarize the range of values observed for the variables, and compare them with earlier studies in the region.

2.2.1 Average values, ranges and comparison with other studies

[13] Much of the chemical analysis, viz., for organic carbon, P_2O_5, K_2O, pH and Electrical Conductivity, were carried out by the Agricultural Development Laboratory of Zuari-Agro Chemicals Ltd. in Bangalore.

Table 1. Summary results of soil analysis

Variables	This study(a)			Singh(b)		Yadav (c)		Bourgeon(d)	
	Min	Max	Mean	Low	High	Low	High	Low	High
Depth=0-15cm:									
pH	5.5	6.3	5.9	5.3	6.4	5.6	6.8	4.83	6.22
EC (mhos/cm)	0.02	0.05	0.03						
Org.C (%)	1.40	2.81	2.15	1.64	2.78	2.28	3.91	1.78	5.29
Avail N (%)	0.018	0.046	0.028	0.17(e)	0.4(e)	0.15	0.30	1.32(e)	3.53 (e)
Avail.P_2O_5 (%)	0.018	0.043	0.031			0.0007	0.0019	0.0	0.1
Exch.K_2O (%)	0.026	0.060(f)	0.049(f)	0.034	0.134	0.003	0.026	0.005	0.033
Coarse Sand (%)	6.3	19.5	11.2			13.2	36.1	8.5	26.0
Fine Sand (%)	31.2	58.1	44.5			9.6	34.6	12.6	28.3
Silt (%)	6.5	24.3	14.0			7.5	37.5	18.5	42.8
Clay (%)	25.1	35.4	29.6			12.5	45.0	23.3	36.1
Depth=15-30cm:									
pH	5.8	6.3	6.0	5.4	6.4	5.7	6.3	4.76	6.10
EC (mhos/cm)	0.01	0.03	0.02						
Org.C (%)	1.07	2.00	1.51	0.95	1.58	0.96	2.10	1.06	3.14
Avail N (%)	0.013	0.027	0.020	0.15(e)	0.22(e)	.070	147	1.10(d)	2.57 (d)
Avail.P_2O_5 (%)	0.019	0.032	0.024			.0007	.0015	0.0	0.1
Exch.K_2O (%)	0.020	0.068	0.047(f)	0.027	0.154	.006	.037	0.005	0.019
Coarse Sand (%)	6.6	27.1	12.5			17.6	23.6	12.4	23.3
Fine Sand (%)	29.5	52.5	41.1			9.7	25.4	9.0	26.9
Silt (%)	7.6	13.9	11.5			15.5	28.8	19.3	32.1
Clay (%)	29.5	40.2	34.2			18.3	52.5	28.5	48.4

(a): The values reported here are averages of the values obtained for three or more samples collected at each site.

(b): Singh (1968). His values for 5-10cm and 30-35cm depths are reported here under 0-15cm and 15-30cm respectively. Vegetation at the sampled sites includes moist evergreen, semi-evergreen and moist-deciduous forests and scrub.

(c): Yadav *et al.* (1970). Only data for 4 profiles from Uttara Kannada are used, with the first depth (ranging from 0-8cm to 0-23cm) and second depth (from 8-46cm to 23-91cm) reported here under 0-15cm and 15-30cm respectively. The convention used for textural classes not specified. Vegetation is only evergreen and semi-evergreen forest.

(d): Bourgeon (1989). Only data for profiles from the Mainaad region of Uttara Kannada are used (11 profiles), with values for first depth (ranging from 0-10cm to 0-40cm) and second depth (ranging from 10-30cm to 20-50cm) reported here under 0-15cm and 15-30cm respectively. The convention used for textural classes is not specified. Vegetation includes evergreen, moist-deciduous, dry-deciduous forests and scrub.

(e): Singh clearly reports this as total nitrogen; others do not indicate whether total or available, but their values suggest that what they report is total.

(f): Value is a slight underestimate due to calibration problems at the Zuari-Agro soil testing laboratory.

Summary results for each soil variable, in the form of minimum, maximum and average values[14], are presented in Table 1. Also presented for comparison are the ranges of values reported in the only other studies of uncultivated soils in the Malnaad region of Uttara Kannada district.

Despite of the large variations in the soil textural variables, all the samples belong to the *sandy-clay-loam* or *sand-clay* textural class as per the USDA "textural triangle", even after allowing for the differences in the International and USDA definitions of sand and silt. The noticeable differences in the percentage of fine sand observed here compared to that reported by the other studies may also be due to this difference in definition of textural classes.

All the sites sampled have acidic soils, with significant variations in organic carbon, N, P and K values. It is difficult to compare N values reported in this study with those reported in the other studies, since the former correspond to available N, and the latter probably to total N (see footnote in Table 1). However, if one uses the uniform C:N ratio reported by Singh (1968) with the C values reported here, one obtains a mean value for total N of 0.21%, which is within the range reported by him and Yadav *et al.* (1970). Bourgeon's values for N, even assuming that they correspond to total N, appear to be anomalously high, as they yield a C:N ratio of less than 2, far lower than that obtained from Singh or Yadav *et al.*'s data or any other reported in the literature for such sites. On the other hand, the phosphorous values observed are significantly higher than those reported by Yadav *et al.* It therefore seems that my results are most meaningfully compared with those of Singh (1968).

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[14] Althougn significant variations were sometimes observed in the soil variaoie values for samples collected from *within* a particular site, only average values of these variables for each site are presented and used hereinafter, amounting to 14 values for the 0-15cm depth, 9 values for the 15-30cm depth.

All of the previous studies have focussed on "natural" forests rather than on more managed or disturbed ones like *soppinabettas*. Furthermore, only Singh has attempted to establish relationships between vegetation type (i.e., evergreen, moist deciduous, or dry deciduous), condition (dense forest or scrub) and soil characteristics. He reports that soils under scrub vegetation were markedly poorer, i.e., lower in OC, N, K, and more acidic than those under dense forests, although it is not clear whether differences in geology, topography and rainfall had been controlled for. As we shall see, the results reported here suggest that the relationship may not be so simple or strong.

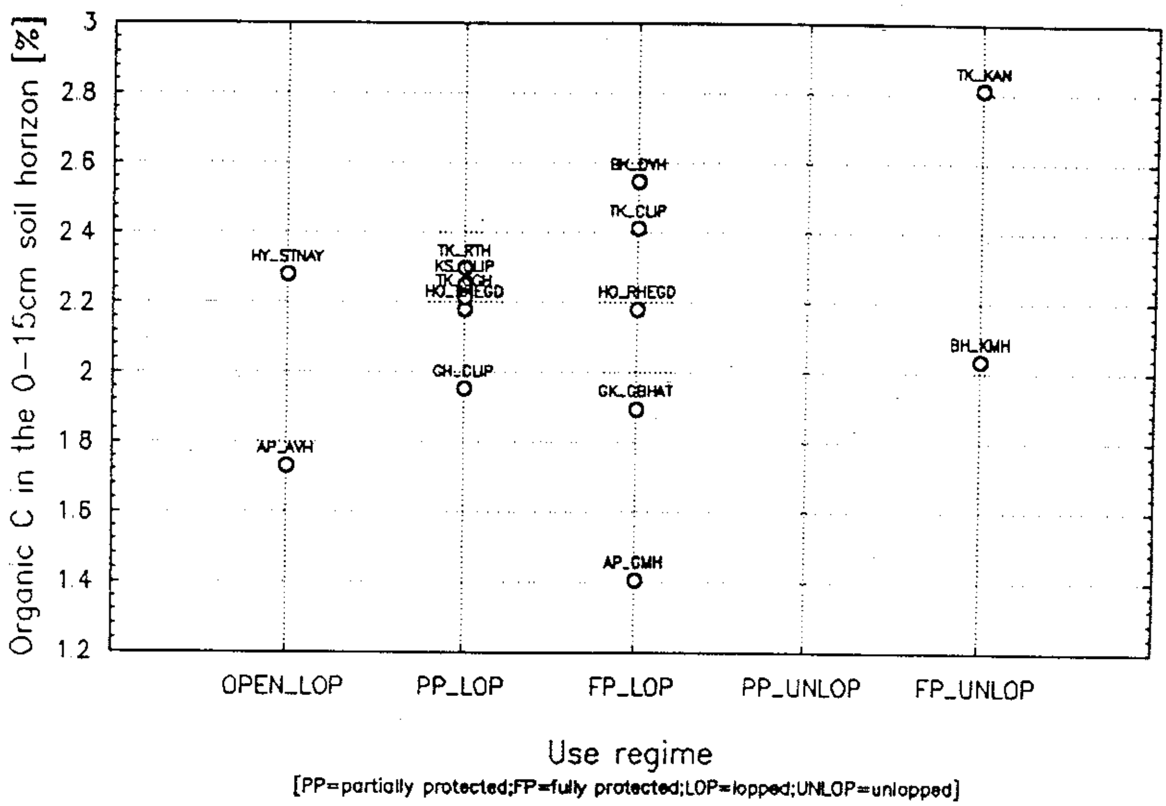

Figure 3. Variations in soil organic carbon at 0-15cm depth with "use regime".

2.2.2 Soils and management regimes

I adopted the "use regimes" categorization outlined in section 1 to look for a possible relationship between the mode of land use/management and its soil condition. Values for soil variables at both depths, and the ratios of these two values, were plotted against the use regimes assigned to the sites. No trend was apparent for any variable or ratio, except perhaps a very slight increase in organic C in the 0-15cm horizon with decreasing disturbance, the graph for which is given in Figure 3. It is likely that organic C is more sensitive to increases in disturbance than other nutrients, but more sampling will be required before one can conclude that the range of differences in management/use spanned by the sample sites really matters.

2.2.3 Soil macro-nutrient status and extraction intensities

Given that the amount of tree biomass extraction from the village forest lands can be as high as 3-8 dry tonnes/ha/year, that a large fraction of this consists of leafy matter which is known to be higher in N, P and K content than woody matter, that possibly half of this leafy matter is in fact green leafy matter (when it is lopped) which has a higher nutrient content than dead leaves in the litter,[15] and that this extraction of leafy matter for mulch and manure has been practiced for at least a century, one would expect to see some nutrient depletion in the forest soils.

For a number of the sampled sites, the current rate of tree biomass extraction had

[15] Comparison of the nutrient content of leaflitter and lopped leaves showed that mean total N was 1.2% and 1.9%, and mean K was 0.25% and 0.50% respectively.

been monitored and partly used in the woody biomass balance presented in the previous chapter (section 3.1). These data, supplemented with less certain questionnaire data for one site (BK_DVH) and assumptions of zero extraction of woody and lopped leafy biomass from two other sites (BH_KMH and TK_KAN), were used to examine whether continuous removal of biomass might result in depletion of soil macro-nutrients (organic C, available N, P_2O_5 and K_2O).

It appears that an extraction-induced nutrient depletion might actually be occurring in some cases. In particular, soil organic C, available N, and available P appear to show some decline with increasing rates of fuelwood extraction, and to a lesser extent with increasing extraction of lopped leafy matter[16]; these data are shown in Figure 4 and Figure 5. With the small sample size, it is not surprising that only one relationship shows a statistically significant (95% or better) Spearman's rank correlation coefficient. I believe that the low values of organic C and particularly of P_2O_5 for BH_KMH are due to the fact that although the farmer has not lopped the site for the past two decades, the nutrient depletion caused by biomass extraction over the preceding many decades is likely to continue to be felt (particular since phosphorus is rather immobile and does not return to the soil through rainfall). Similarly, there is reason to believe that the leafy matter extraction data for TK_GGH are anomalously high: the betta-holding household reported that in the particular year the monitoring was carried out, they were able to mulch the whole of their arecanut orchard with lopped mulch, as against only half the orchard in normal years. Removal of these outliers of course improves the correlations significantly.

[16] This corresponds to the leafy matter removed from trees at the time of the winter lopping. Data on rates of collection of leaflitter from these plots were not very reliable, and so have not been used.

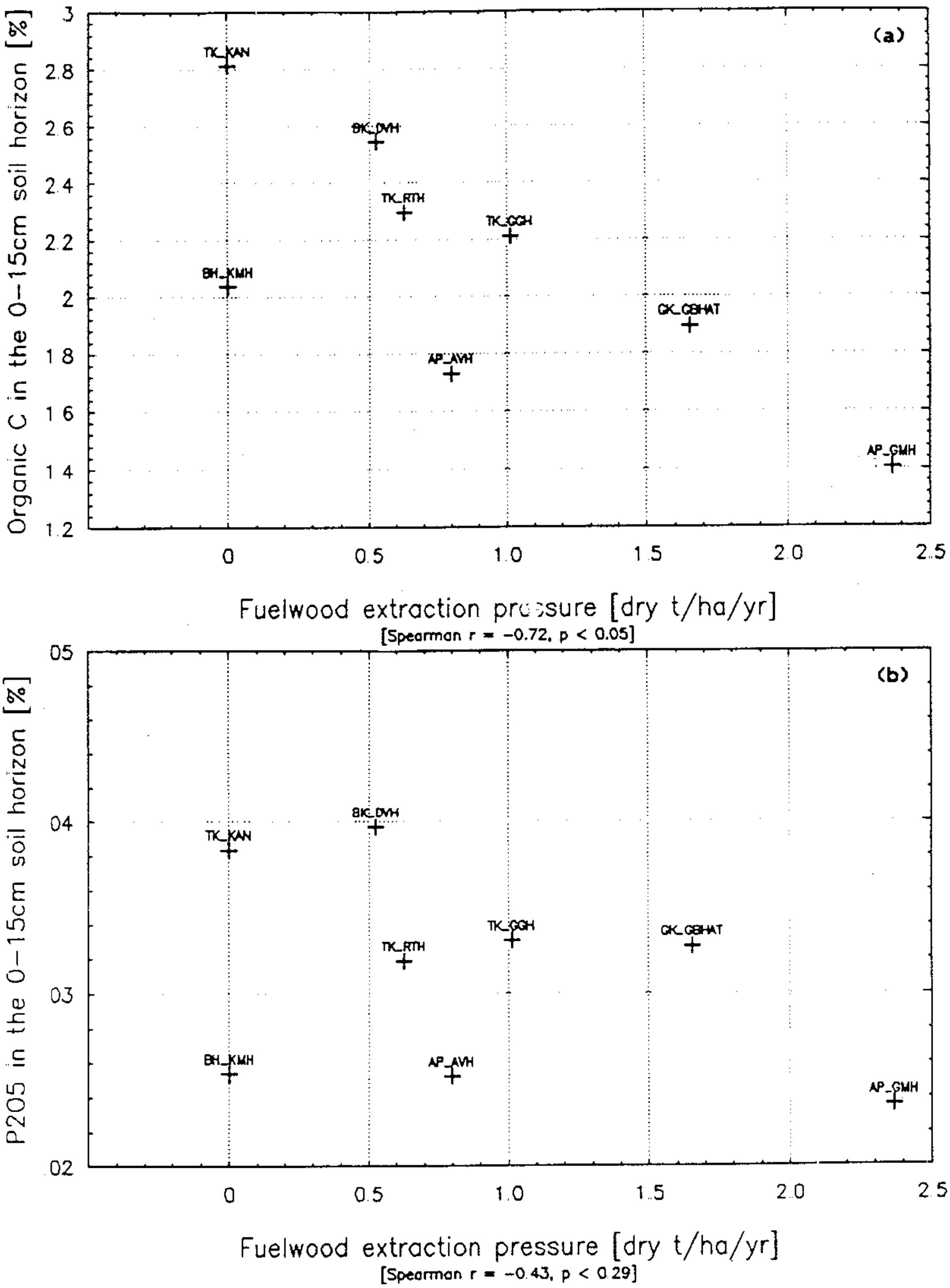

Figure 4. Changes in nutrient content of the 0-15cm soil horizon with changes in rates of fuelwood harvest: Data for (a) organic C and (b) P_2O_5.

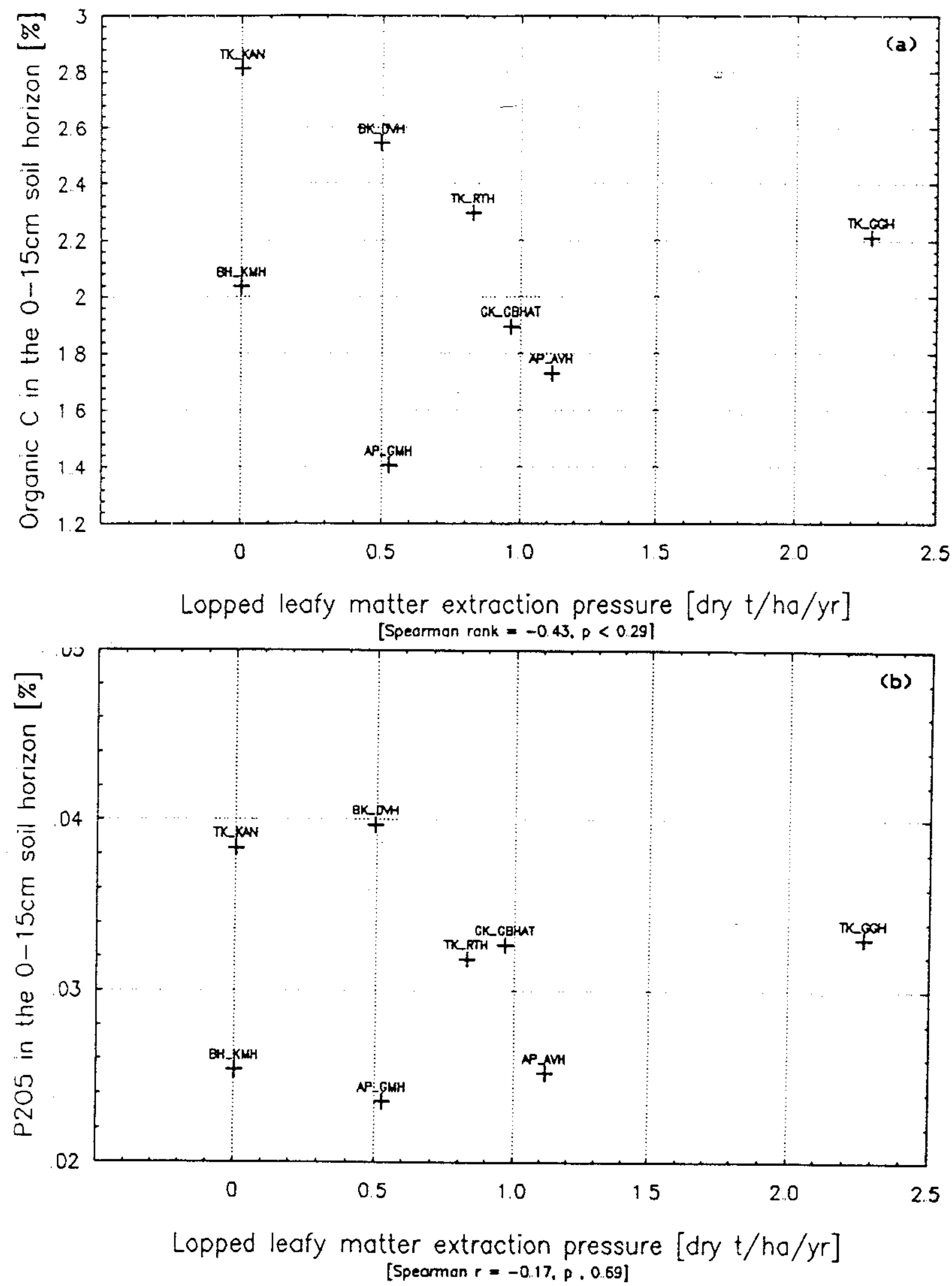

Figure 5. Changes in nutrient status of 0-15cm soil horizon with changes in leafy matter extraction rates: Data for (a) organic C and (b) P_2O_5.

2.3 Summary and discussion

Despite of being constrained by small sample sizes, and limited data on use and management variables, the results presented here provide some useful hints as to the effect of rural use of forest lands on soil condition. On the one hand, they suggest that gross differences in use or management regimes are not likely to correspond to differences in soil conditions. On the other hand, even for a smaller sample size, soil nutrient levels show some interesting trends with specific data on biomass extraction intensities.

The relation between soil condition and land management is quite complex, and the micro-level variation in soil background due to geology and topography quite high, calling for far greater control and sampling densities than have been achieved in this study. Nevertheless, there is some reason to believe that the continuous extraction of biomass at rates that are at the higher end of the spectrum observed in the Malnaad may lead to the depletion of at least immobile soil phosphorus, and affect soil organic matter content.

If verified by future studies, these observed trends might suggest that removal of green leaves ought to at least be substituted by the removal of leaf litter (since green leaves have higher nutrient content). This and other reasons (such as possible effects of lopping on tree mortality and exposure of soils to erosion due to reduced canopy cover) have been used to promote the idea of arecanut cultivators stopping the lopping of their betta lands. But the reduction in soil erosion due to increased tree canopy cover may be more than offset by the increase caused by higher rates of leaflitter removal, since amount of ground cover more strongly affects soil erosion than the amount of tree canopy cover (Moench, 1990). Similarly, as we shall see in the next chapter, increased tree canopy cover will likely reduce grass production. Thus, while reduced total removal will probably always help, the complex interactions between trees, grass and soils need to be better understood before strong prescriptions can be developed.

Chapter V. Comparing production levels:

The case of grass[1] production and grazing effects

> There is a pressure to produce 1.5 tonnes of fodder from every hectare of the available forest areas. It is observed that in the case of unprotected wooded areas, the fodder production is hardly 0.2 tonnes per hectare. ..... In other words, the grazing pressure on the forests of Uttara Kannada is more than 7 times the carrying capacity of the forests. This has resulted in total depletion of grass and in most of the cases the cattle is [sic] underfed.
>
> – Reddy *et al.* (1986)

Grazing by livestock in forests, pastures, and post-harvest cultivated fields is a ubiquitous feature of the Indian landscape. In the Malnaad, given the absence of official *gomaal* (pasture) lands, most of the grazing takes place by definition on "forest" lands, although the current and historical vegetative status and use of these lands may be quite different. Many *soppinabettas* contain patches of grasslands which may be protected, while the remaining betta may be fully grazed during the growing season, harvested at the end of it, and burned in the summer. Private uncultivated dry lands constitute the other important source of fodder and/or grazing land, and are managed in similarly diverse fashions. The distribution of grazing pressure therefore varies from household to household; but the importance of betta, Minor and (to a lesser extent) Reserve Forest lands for grazing is indisputable.

That these practices cause "degradation", not only in terms of loss of tree

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[1] The "herblayer" or "herbaceous layer" consists of the plants that have "no persistent parts above ground", as distinct from shrubs and trees (Abercrombie *et al.*, 1973), and thus includes all "grasses", which are annual or perennial monocotyledons ("monocots"), as well as some dicotyledonous plants ("dicots"). Given the dominance of grasses in the herblayer at virtually all of the sites studied, however, it would not be terribly inaccurate to use the more popular terms "grass growth" or "grass production" in place of the more accurate "herblayer production".

regeneration, but also in terms of reduced grass production and livestock performance, appears to be the current conventional wisdom.[2] The quote at the beginning of this chapter exemplifies this wisdom, and indicates the analytical method used to reach that conclusion, viz., the carrying capacity criterion. While it would be irresponsible to insist that the existing situation regarding livestock management is not creating problems for tree regeneration and for grassland productivity in certain locations in Uttara Kannada or elsewhere in India, the application of the "carrying capacity" criterion to assessing the magnitude and nature of these problems suffers from many limitations, conceptual and methodological.

Fundamental questions about the appropriateness of the concept of stable carrying capacity are being raised in the context of annual grasslands such as those in the African Sahel, where grass production is extremely sensitive to widely fluctuating rainfall (Mace, 1991). In humid tropical forest lands, on the other hand, production is likely to be much more stable, and hence the carrying capacity approach may still be valid. But the sensitivity of grass production to rainfall, tree canopy, edaphic conditions, fire and grazing regimes, the difficulty in determining the "use factor" (the fraction of forage that must be left uneaten to ensure future production), and the subjectivity in choosing the "daily forage requirement" which depends upon what purpose the animal is kept for, makes the criterion quite difficult to apply in practice. Moreover, it does not help one

[2] As Mace (1991) points out, the combination of "simple predator-prey models of herbivory [that] illustrate how high grazing pressure can hold a system below its maximum productivity" and Hardin's "theorem" about the intrinsic propensity of individuals to overuse commonly owned resources have led to the conventional belief that rangelands in the tropics are being overgrazed by domestic livestock. Add to that the equally general belief that the population of livestock in the Indian subcontinent is exploding apace with the human population, and the case for concluding that the livestock population is far above its "carrying capacity" seems to become watertight. (Actually, in the case of Uttara Kannada, the bovine population rose at an annual compounded rate of only ~0.9% between 1951 and 1983 (Shetty, no date)).

understand the dynamic, because it does not tell us what happens if carrying capacity is exceeded. Does grasslands continuously degrade (i.e., show steady decreases in production over time)? Or do animals remain "underfed" at some new (lower) equilibrium level of production? And what are the reasons for carrying capacity to be exceeded, i.e., for the "mismanagement" of livestock and fodder resources? Thus the carrying capacity criterion, which is an extension of the "vegetative balance" criterion, suffers from many of the same problems identified for the latter in Chapter II.

An alternative to the carrying capacity criterion would be to monitor production levels over time. If one monitored such temporal trends at many locations that are similar in eco-climatic conditions (soil, climate, etc.) while corresponding to different management regimes, one could understand what components in the management regime are causing the drops in, or a lower level of, production.

Conducting longitudinal studies is not easy, particularly within the time frame of dissertation research. It is possible to substitute cross-sectional data for time-series, but one then requires some benchmark against which to compare. Thus, one also needs to develop estimate(s) of "potential" production under the different eco-climatic conditions occurring within the region of interest, where potential production is defined as the production that might be obtained under "best" management practices, however defined. Given the heterogeneity in eco-climatic conditions as well as in grazing pressures and management regimes even within one village, the full implementation of such an approach would require a large number of sample sites in the uncultivated lands of interest. Moreover, the ubiquitous presence of animals during the growing season at most sites would require the setting up of exclosures at all of these sites.

Given the paucity of information on herblayer productivity in the Malnaad region on the one hand and the observation that grassland management and grazing practices fell into two or three distinct categories on the other, I adopted a more selective and experimental approach, and limited the objectives of the research to

(1) estimating "potential" production under "best" management, and its variation across the region;

(2) using data gathered earlier by my collaborators at the Centre for Ecological Sciences (CES) to assess the likely effect of tree canopy on grass production;

(3) conducting some controlled experiments to arrive at a preliminary assessment of the likely impact of light and heavy grazing on same-season production.

In presenting the results here, I attempt to elucidate whether there exists a trade-off between grass and tree biomass that shapes vegetation patterns in the forest lands. I hope also to examine whether or not the beliefs that grass resources in forest lands are generally "depleted", and that this depletion is necessarily the result of grazing are well-founded in the Malnaad.

I begin with some basic definitions, and then present the results for each aspect that was studied.

1. Basic definitions

(a) Useful production

Ideally, one would define useful production not in terms of kilograms of total biomass produced, but in terms of the nutrient content of the palatable biomass produced.[3] These complexities could not be addressed in this study. Total biomass production is used indiscriminately as a surrogate for useful production.

(b) Herblayer NPP, net aboveground production, and peak above-ground biomass

Net primary production (NPP) is the difference between total photosynthesis and respiration during any period, and thus includes increases in both above-ground and below-ground (root) biomass.

Further, net aboveground production in the herblayer in any location will in general be *greater* than the peak biomass measured at that location because different species have different growth cycles, and some species may therefore have already died or shed some of their biomass and others may still be growing at the time the overall peak is reached (Golley and Leith, 1972). This problem may be mitigated by including in every biomass measurement the herb-litter that may have accumulated in that location.[4] The problem will also be less serious in sites consisting of few, similar species (such as maintained grasslands) as compared to sites with a mixture of dicot and monocot species.

In what follows, above-ground herblayer biomass (AGHB) always includes

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[3] The nutrient content would be defined in terms of some weighted average of the total amount of crude fibre, crude proteins, fats and mineral content of the biomass. The palatability would be defined in terms of the preference for and digestibility of different herblayer species by the livestock.

[4] The sum of live AGHB and herb-litter will differ from actual production by the amount of litter that decomposed or was consumed by small animals in the community before the measurement took place. While this is a matter of concern in this moist tropical region, one could argue that this component of production is not likely to be available to the livestock anyway, and hence may not represent a major problem when comparing available production across sites.

undecayed litter and standing dead, and therefore the peak value of this AGHB in an ungrazed quadrat is considered equivalent to total "net above-ground community production" in the herblayer (following Odum's terminology quoted in Singh (1968)).

(c) "Potential" production = production in "pure", managed grasslands

Implicit here is the assumption that some conditions (such as climate and soil) are outside the control of the rural livestock owner, while other conditions such as tree canopy, frequency and timing of fire, frequency, timing and intensity of grazing, and frequency and timing of fire, can be manipulated or controlled. That some opening of the tree canopy is required for grass production will be shown later on. Protection from grazing is generally recommended as the management strategy for grasslands. The regular use of fire is virtually necessary for grassy vegetation to persist in the moist tropical climate of the Malnaad, where moist-evergreen or deciduous forest is the "natural successional climax", except at those locations where extreme soil conditions inhibit tree growth (Yadav *et al.*, 1970). As Sanchez (1976, p.538) points out, in regions where fire has been historically used, local species of grasses are often well adapted to burning; he specifically mentions the *Themeda* genus, which happens to be the dominant genus in the Malnaad grasslands as an example. One might therefore think of "potential" production as the maximum production attained by native grass species under traditional management practices evolved locally, viz., those involving opening of the tree canopy, regular fire and controlled grazing but not fertilization or irrigation.

2. "Potential" herblayer production and its variation across the Malnaad

Given the variation in eco-climatic conditions within the region chosen for this work, an understanding of the "exogenous" factors becomes important if, for instance, one is not to erroneously conclude the presence of human-induced degradation on the basis of lower production that is caused by some non-anthropogenic factors. Rainfall in the Malnaad varies very rapidly along a direction perpendicular to the Western Ghats, i.e., along a line approximately 15° north-of-east. The geology also appears to vary more in the direction perpendicular to the Western Ghats than parallel to it. While the pattern of variation in soil properties is likely to be more complex (Bourgeon, 1989b), visual examination suggested that the soils in the westernmost parts of the Malnaad are significantly stonier than those in the east; this impression was backed up by local informants. I therefore attempted to estimate the "potential" production along an approximate west-east line.

Methods

Using local information regarding when the peak biomass in grasslands is reached, one-time samples were collected from 3 locations spanning the Malnaad region from east to west. To these data were added the peak biomass values from similarly managed sites in the villages where additional experiments and socio-economic surveys were being carried out, giving a total of five sites: Mattighatta, Chipgi-*bena*, Arasapura, Malenalli and Banavasi. Their location is indicated in Figure 1 of Chapter II, with the location codes as in Table 1 below. All of the sites had the following characteristics:

(a) zero or almost zero tree canopy cover (trees in the vicinity but no shading of the -

sampled plots);

(b) located on a piece of land managed for grass production, with a history of similar management for at least ten consecutive years preceding 1990-91 that was characterized by (i) full protection (i.e., complete exclusion of livestock) throughout the growing season (except the Banavasi site, where some grazing by bullocks occurred during the first two months of the growing season), (ii) open grazing during the rest of the year, and (iii) firing at the end of the dry season (except in the case of the Malenalli site, which was not fired);

(c) a slope of less than 5° (except in the case of Mattighatta, where, being in the hilliest part of Sirsi taluka, the slope varied between 5°-30°);

(d) a well-drained sandy-clay or sandy-clay-loam soil;

(e) considered to be one of the most productive sites by the local residents.

At each site, 9 quadrats of 0.5m x 0.5m each were selected in a stratified random fashion (3 each from the top, middle and bottom parts of the slope in the grassland). At two sites (Arasapura and Malenalli), the peak biomass was taken to be the maximum biomass harvested in monthly clippings of "control" plots as a part of the clipping studies described in section 3 below. At the three remaining sites, the above-ground biomass was completely harvested on a date around the known peak of biomass growth.[5] Fresh weights were recorded, and well-mixed sub-samples of about 1/10th of the total biomass

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[5] An estimate of the potential error involved in this method of "guessed" dates for peak biomass may be obtained from the growth curves in Figures 3 to 5. The sampling dates for all three "one-time sample" sites were between 26 October and 6 November 1990, which coincides closely with the peak for Arasapura. Little dead biomass was obtained from these sites at the time of clipping, suggesting that they were at or before their peak. Moreover, as can be seen from the growth curve for Arasapura in Figure 5, the difference between the peak and the total biomass harvested a month later is only ~0.1 t/ha. (The Malenalli site peaked a month later, probably due to the fact that the Malenalli site was relatively more protected from the western sun and from winds by a belt of trees, resulting in higher soil moisture retention and a longer growing season.)

harvested were oven-dried to constant weight at 50°C (except in the case of the Arasapura and Malenalli sites, where all the full sample was oven-dried) to convert to dry-weight values.

Table 1. Herblayer productivity estimates for "pure" grasslands across the Malnaad region

Location	Code in map†	Peak AGHB ± std. error [dry t/ha/yr]
Mattighatta	MATTI	3.36 ±0.21
Chipgi-bena	CH-BENA	4.45 ±0.23
Arasapura	AP-CLIP	4.13 ±0.39
Malenalli	MH-CLIP	5.23 ±0.35
Banavasi§	BANAV	5.89 ±0.27

†: See Figure 1 in Chapter II.
§: Value for Banavasi may be a slight underestimate because of grazing by bullocks at ploughing time.

Results

The estimates of peak herblayer biomass at the five sites, along with sampling error values, are given in Table 1. They range from approximately 3 t/ha/yr to 6 t/ha/yr. These values underestimate net aboveground production by the amount of growth that occurred early in the growing season and decayed before it could be captured in the peak measurement.

Discussion

Several points are of interest here. Firstly, the productivity levels are much higher than the estimate of 0.2 t/ha assumed by Reddy *et al.* (1986) for woodland in Uttara Kannada

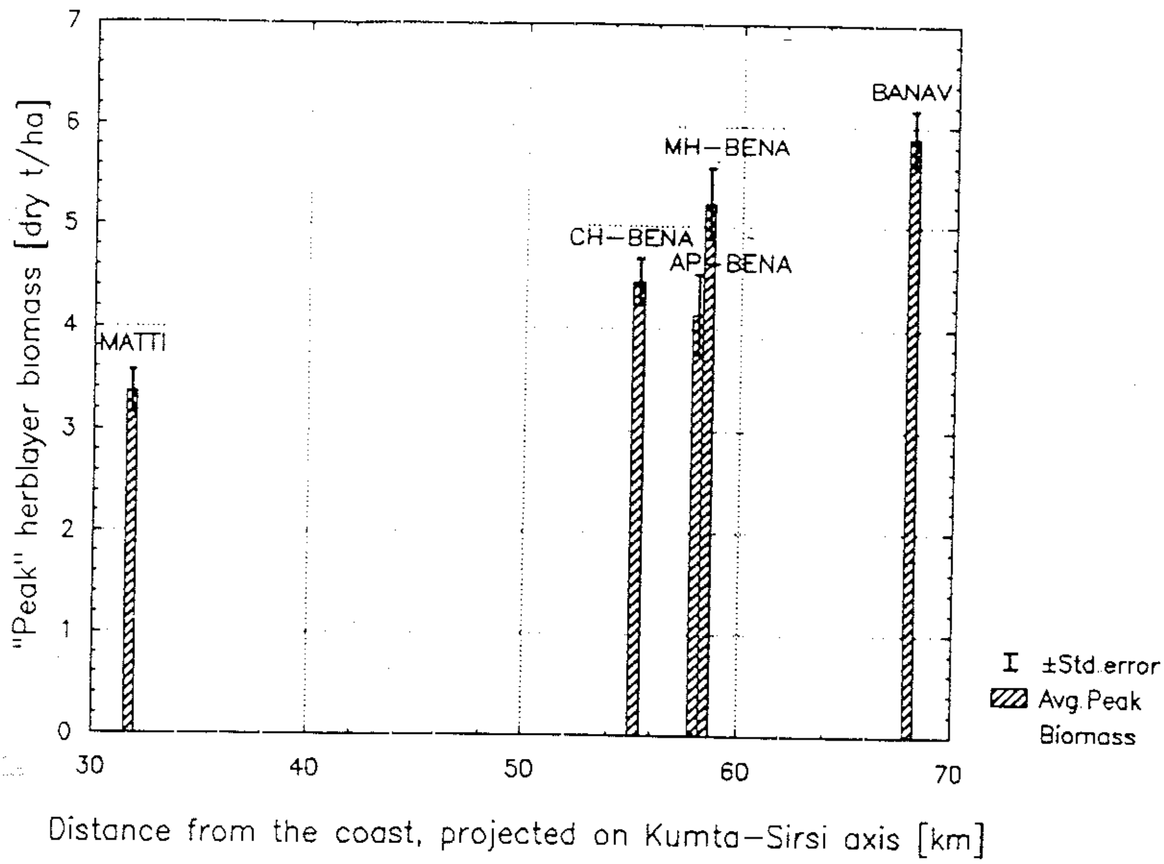

Figure 1: Variation in "potential" herblayer production across Sirsi taluka

(possibly an unfair comparison, but at least illustrating the need to incorporate into their calculation the area of well-protected zero-canopy grasslands that exist within "forest" lands). The estimates are also significantly higher than the estimate of 2.5 t/ha reported by Nadkarni *et al.* (1989, p.122) for pure, maintained grasslands (*benas*) such as my sites.[6] The higher end of the range of values observed here is close to the value of 6.2 t/ha/yr reported by Swamy (1989) for natural grasslands occurring next to high altitude *sholas* (dense evergreen forests) in the neighbouring district of Shimoga, or the 5.7 t/ha/yr reported by Narayanan and Dabhadgao (1972, p.11) for (unfertilized) grasslands near Bombay. This shows that maintaining uncultivated land as grasslands can be a productive use of the land.

Secondly, one observes a clear trend of increasing production from west to east across the Malnaad. Figure 1 is a plot of the estimated production at each site against its distance from the coast, as projected on an axis joining Kumta to Sirsi. Within the Malnaad, a number of variables are likely correlated with this distance variable, including rainfall (negatively correlated), slopes (negative), and possibly soil quality (positive). Data for soils, the most likely candidate, are not available at this stage. More sampling is also clearly required. But the observed geographical trend is in consonance with what local experts say is the trend in productivity of the lands. Hence, for practical purposes, one may simply say that potential herblayer production probably increases from 3 t/ha/yr to as much as 6 t/ha/yr as one goes from west to east across the Malnaad.

2.1 Canopy effect in tree savannahs or *soppinabettas*

Increased tree canopy negatively affects herblayer production through reduction in light availability (Satoo and Madgwick, 1982, pp.90-91). Others have reported similar results

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[6] Their data are from villages located longitudinally between Sirsi town and Banavasi. Unfortunately, they provide no information on their method of estimation, bu t appears that their data are simply based on oral interviews. If so, the large uncertainties involved in such estimates raises serious doubts about their conclusion that plots owned by poor peasants yield significantly less grass (2.1 t/ha) than those belonging to landlords (2.9 t/ha).

specifically for moist tropical forests in India (Singh *et al.*, 1980). Robinson (1983) points out, however, that trees may increase <u>useful</u> production through (a) increased nutrient availability (especially under leguminous trees), and (b) shading, which reduces soil moisture evaporation, delays maturation and hence increases digestibility of the grass, and which may also improve the grass-legume ratio in the production. But he indicates that the negative effect of shading may exceed these positive effects at canopy cover values above 20% or so.

I used data gathered by CES on herblayer production in wooded areas to examine the effect of tree canopy. I used raw data for only the Malnaad sites from the data set reported by Bhat and Gadgil (1987), and supplemented them with production data for one open canopy *soppinabetta* site, SM-BETTA, and percentage tree canopy data at all sites (D.M.Bhat, CES, unpublished data)[7] to plot the graph in Figure 2. Except for SM-BETTA, all the sites were open to grazing and no exclosures were set up around the sampled quadrats. Hence the values of peak biomass harvested are likely to underestimate the actual production by the amount grazed away. An examination of the sites provides some means of placing bounds on and direction of the errors so introduced. SONDA and BIDR are in Reserve Forests, where the incidence of grazing is likely to be (and anecdotally observed to be) lower than that in SUGAV, which is a Minor Forest site with open access. BH-MF is a protected Minor Forest site with almost no grazing. The largest

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[7] The values I report here are slightly different from those reported by Bhat and Gadgil, because of a number of minor calculation errors that were corrected when I re-examined their data. Note also that the values for herblayer productivity reported in Prasad (1987a, p.34) for apparently the same locations appear to be erroneous. Percentage tree canopy cover was estimated using a 10m x 10m grid in a 1-ha plot and counting the number of grid points above which the sky was visible (D.M.Bhat, CES, pers.comm.).

error is therefore likely to be for SUGAV, which, given the direction on the error (see arrows in Fig. 2), supports the conclusion that canopy cover greater than about 40% appears to have a significant negative impact on herblayer production.[8]

Production probably does not decline to 0.2 t/ha/yr (the value for "woodland" used by Reddy *et al.*) till one reaches canopy cover of 90%, corresponding to SONDA, which, is the most heavily forested of all forest plots sampled. In other words, it is possible to obtain an intermediate level of about 0.75 to 2 t/ha/yr of production on a piece of land that has substantial amount of tree growth (100-250 trees/ha, or more if their canopy is regularly lopped).

3. Assessing effects of grazing through clipping experiments

The effect of grazing on herblayer production is probably the most difficult aspect to understand, and yet is perhaps the biggest source of generalizations in the rural biomass resource management literature. Grazing has often been equated with degradation, and consequently, stall-feeding is recommended wholesale. These pronouncements ignore the complex dynamic between grazing and herblayer production, the importance of timing and intensity of grazing in determining changes in total production and its usefulness, the possibility of stimulation of production by grazing under certain conditions, and the nutrient return to the grassland due to dung deposition by the livestock.

Grazing affects herblayer production over different time-periods (intra-annual or

[8] Plotting herblayer productivity on a logarithmic axis against canopy cover gives an approximately linear relationship, which resembles the log-linear relationship between herblayer productivity and leaf area index of overstorey proposed by Satoo (1982, p.91). It is also interesting to note that the 40% canopy cover threshold for obtaining high herblayer production is fairly close to the conventional definition of degraded forest by the Forest Department, viz., forest with less than 33% canopy cover (Urs, 1991)!

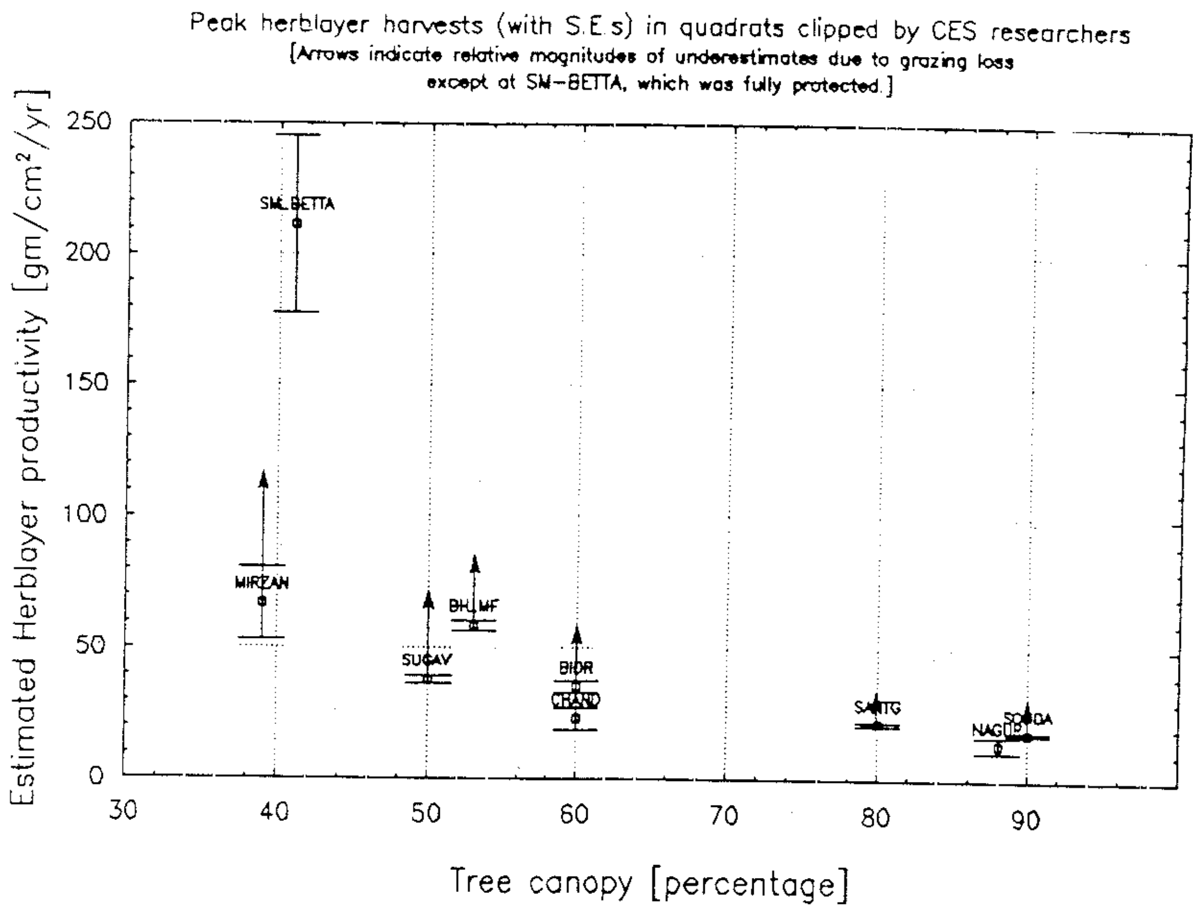

Figure 2: Effect of tree canopy cover on herblayer productivity

short-term, and inter-annual or long-term) in a number of ways (see Turner, 1992 for an overview). Firstly, grazing essentially results in the direct removal of plant leaves and possible flowering organs. Such defoliation will (i) affect the productivity and nutrient content of the grazed plant as it grows during the remaining part of the growing season (largely a short-term effect), and (ii) affect seed formation and/or patterns of dispersal (critical for annual grasses) and root stock available for future (critical for perennial grasses such as those in the Malnaad), which is largely a longer-term effect. Secondly, animals graze selectively, depending upon the palatability of the plant; grazing therefore modifies the species composition of the herblayer, sometimes leaving the plant community dominated by or susceptible to invasion from unpalatable species. Finally, grazing affects soil condition through (i) the trampling action of the animals, which, especially in the case of large herbivores such as cows or buffaloes, can cause significant soil compaction, leading to reduced infiltration, and (ii) the removal of herbaceous cover, exposing the soil to the rains during the growing season.

The extent and even the direction of these effects depends critically on the intensity (fraction of plant matter removed), timing and frequency of grazing, as well as on sheer livestock presence (in the case of trampling effects), acting in conjunction with the eco-climatic regime, species composition, fire regime, etc.

I was not able to locate much research on the effect of grazing-induced defoliation on perennial grasslands that are maintained in moist tropical forested regions through the use of fire, such as those in the Malnaad. A large number of experiments would be required to understand all the effects of grazing on useful production in this region. Keeping in mind, however, that the typical systems of grazing management are either to graze lightly during the early part of the growing season (followed by protection till the peak is reached) or continuous grazing, two different types of experiments were conducted to explore the effects of these patterns of defoliation on net above-ground production. The methods and results for each are described below.

3.1 "Single-clip" experiments

In order to examine the variation in cumulative production due to a small amount of grazing at different points in the growing season, single-clip and regrowth measurements were carried out in five exclosures, one next to the CES field station (CH-CLIP), and two each in the Tattikai and Malenalli village clusters.

Methods

Starting mid-June 1990, each month 9 or more fresh (i.e., previously unclipped) quadrats, each 0.5m x 0.5 m, were clipped to ground level at each site.[9] Since each such monthly harvest represents the untouched growth up to the date, the maximum of these harvests would represent our estimate of the peak biomass reached in the absence of any grazing, i.e., the "control". All these quadrats (originally clipped in different months) were re-harvested at the end of the growing season, i.e., in December. The biomass was separated into monocots and dicots, dried to constant weight in an oven at 60°C, and weighed. The sum of the biomass obtained in these two harvests is the cumulative net community production in that quadrat over the growing season. These cumulative values can then be compared the control, to test for a "grazing effect".

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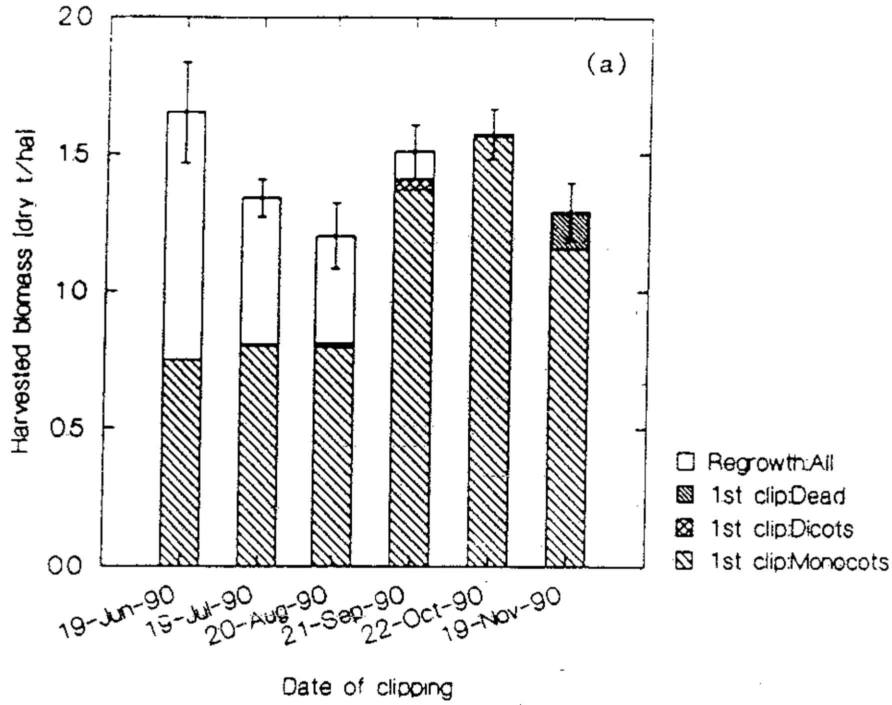
[9] 10m x 10m exclosures were set up with barbed wire fencing within *soppinabetta* or privately owned grassland (*khushki*) lands with the permission of the owner. A block of 3.5m x 4.5m was marked out with pegs and strings at 0.5m intervals, leaving sufficient buffer strips on either side. Each 4.5m strip was sequentially assigned to a monthly clip. The exclosure at CH-CLIP was, however, much bigger because it was set up by CES for other experiments. In this exclosure, 24 quadrats were chosen: 3 each at 4 spots under the tree canopy and 3 each at 4 spots in the open. The original idea was to look for a possible canopy effect. However, the likelihood of higher historical grazing pressure on the open sites along with the indirect shading of these sites by trees located to the south and the east necessitated the abandonment of any such comparison.

The history of grazing pressure on these lands was not quite the same. Three sites (AP, MH and TK) were protected during the monsoon, and grazed moderately during the dry season. The KS site, though unprotected, was moderately grazed year round. But the Chipgi-betta site was heavily grazed till 1990, when the exclosure was set up.



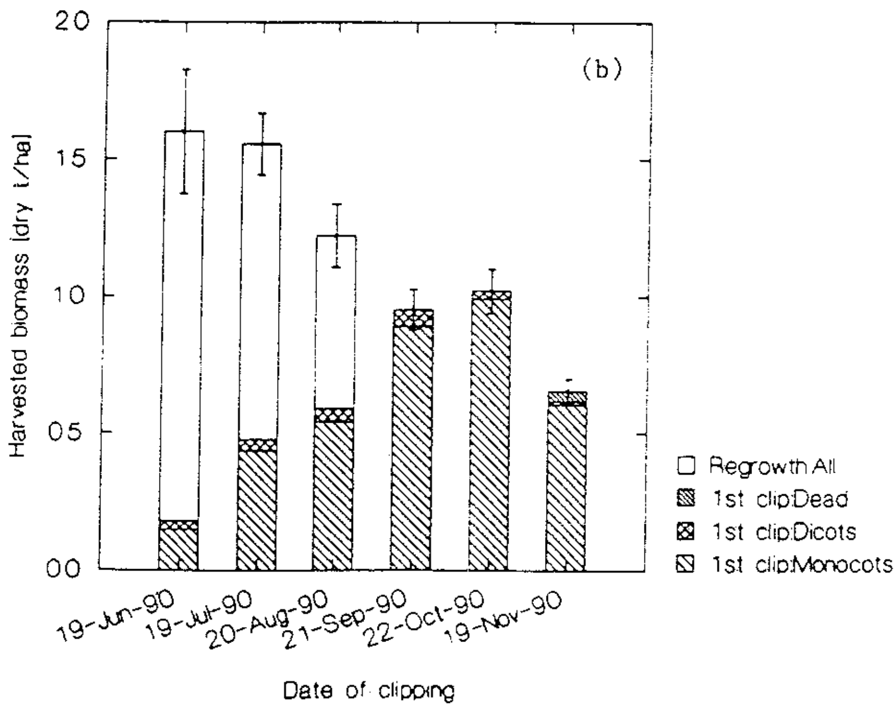


Figure 3: Growth and single-clip effects in (a) TK-CLIP (b) KS-CLIP sites.

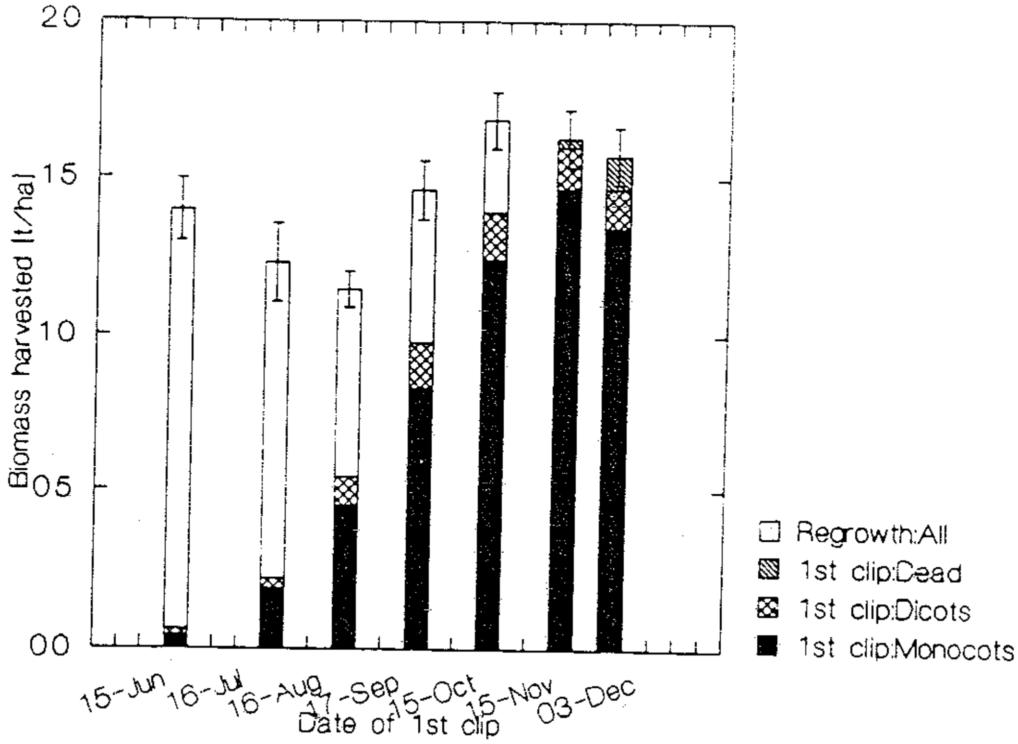
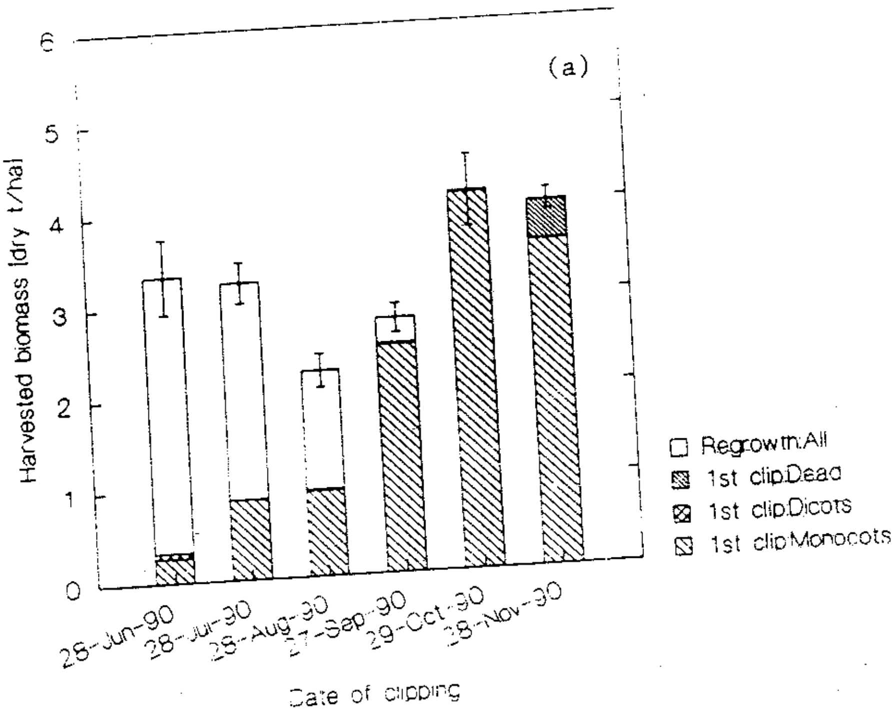


Figure 4: Growth and single-clip effects in CH-CLIP site.

Results and discussion

The amounts of biomass harvested in the first clip and the regrowth (second clip) are shown in Figure 3-Figure 5. The control, and minimum and maximum levels of cumulative biomass are also presented in Table 2. Those cumulative totals that are significantly different from the peak biomass harvested in the first clip (control) are marked with '*' ($p < .05$), '**' ($p < .01$) or '***' ($p < .001$).



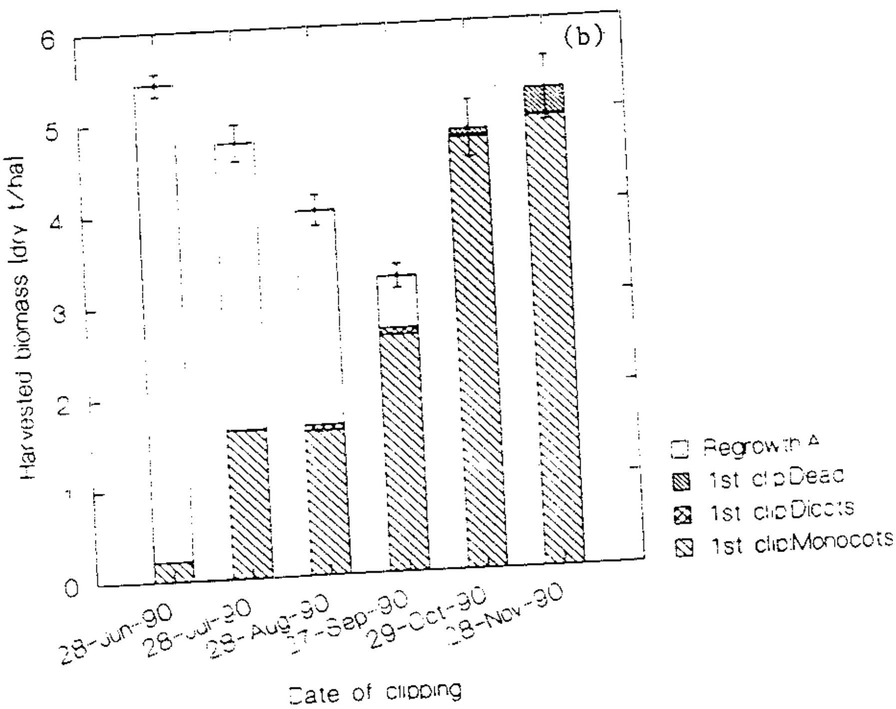


Figure 5: Growth and single-clip effects in (a) AP-BENA (b) MH-BENA sites.

Single clips *early* in the growing season result in either no significant reduction in cumulative production. In some cases, as the graphs suggest, they might even result in some *increase* compared to the control: compare average cumulative production from June-clip treatment (total height of the bar) with the peak biomass reached on the initial clips (shaded region) for K.Sarakuli, Tattikai and Malenalli. As the table indicates this increase is statistically significant only in the case of KS.[10]

The clipping of the regrowth on the quadrats clipped earlier was done at the time of the last round of clipping, and so the last clip by definition cannot have any regrowth. This method may lead to an underestimate of the regrowth in those cases where the regrowth may have peaked before or after the date on which the last clipping was carried out. An examination of the growth curve (represented by the locus of the 1st clip values) indicates that the control peaked at between two weeks and a month before the last clip (except for Malenalli, where the peak coincided with the last clip). Given that a clipped quadrat is likely to peak later than the control, the possible error is less than the difference between the peak biomass and the biomass at the last clip. This difference was negligible for three plots (AP, MH, Chipgi) but somewhat significant (20-30% of the peak) for KS and TK. If one were to add such an "off-peak" adjustment to the cumulative biomass from the June clip, it would only strengthen the results that a single clip in June produces more cumulative biomass than the unclipped control.

Cumulative production is, however, quite sensitive to clipping *halfway* through the growing season. At all the five sites, single clips in mid-August or mid-September

[10] It is hypothesized that the increase in total production results from a stimulation of tillering due to the removal of older tillers.

result in the least cumulative production.[11] At three sites (CH, AP and MH), this value is significantly lower than that of the control ($p < 0.001$). In KS, the mid-September clip resulted in zero regrowth, making its cumulative production significantly lower than that of the clip in June and July clips. In TK, although statistical tests yield no significant difference, the trend in the average values is the same: cumulative production is the least for the mid-Aug clip. Thus, the timing of grazing is important and, what is equally important, this fact appears to be well known and appreciated amongst the local community.

3.2 "Multiple-clip" experiments

An attempt was made to examine the effect of continuous heavy grazing and of *partial closure* on herblayer productivity. The latter was reported to be the practice followed by many livestock owners in the region, viz., to allow full grazing in the grasslands until the end of the initial heavy rains of the monsoon, and then to fence off the grassland to allow proper grass growth for harvest at the end of the season.

Methods

Two treatments were implemented in the exclosure nearest to the CES field station (Chipgi-Betta). The first treatment (approximating continuous heavy grazing) consisted

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[11] The "U-shaped" curve of cumulative production is also reported by similar single-clip experiments conducted under quite different growing conditions (Hiernaux and Turner, 1992, whose work in the Sahel inspired a number of the ideas used here). The "dip" in cumulative production appears to coincide with or just precede the point in the growing season at which the growth rate of the control is at its maximum. This aspect, however, needs further investigation, since the seasonal growth curves have been sampled at the fairly coarse "resolution" of once-a-month clipping.

Table 2. Summary of results of single-clip and multiple-clip experiments

Location (Code in map in Fig. 1, Chap. IV)	Vegetation	Peak biomass of control ± std. error [t/ha] & its date	Single-clip treatment: Cumulative biomass [t/ha], date of clip, and significance		Multiple clipping treatments	
			Minimum†	Maximum†	Continuous	Partial closure
Tattikai (IK-CLIP)	Open forest/ savannah	1.58 ± 0.09 (late Oct)	1.20 ± 0.12 (20-Aug)	1.65 ± 0.18 (19-Jun)	NA	NA
K.Sarakuli (KS-CLIP)	Open forest/ savannah	1.02 ± 0.08 (late Oct)	0.95 ± 0.07‡ (21-Sep)	1.60 ± 0.23 (19-Jun)	NA	NA
Chipgi-betta (CH-CLIP)	Dense, lopped betta	1.63 ± 0.09 (mid-Nov)	1.16 ± 0.06 *** (16-Aug)	1.69 ± 0.09 (15-Oct)	1.01 ± 0.08 ***	0.97 ± 0.03 ***
Arasapura (AP-CLIP)	Open grassland	4.13 ± 0.39 (late Oct)	2.24 ± 0.18 *** (28-Aug)	3.33 ± 0.41 (28-Jun)	NA	NA
Malenalli (MH-CLIP)	Open grassland	5.23 ± 0.35 (late Nov)	3.23 ± 0.13 *** (28-Nov)	5.43 ± 0.12 (28-Jun)	NA	NA

†: From only those quadrats that were clipped once before the control reached its peak.
‡: Significantly different from maximum cumulative production ($p < 0.01$).
*: Significance of difference from peak biomass of control is indicated as: * for $p < 0.05$, ** for $p < 0.01$, *** for $p < 0.001$.

of clipping to ground level of 24 quadrats at 15-day intervals. The second treatment (approximating partial closure after heavy grazing) consisted of clipping to ground level of 24 0.5m x 0.5m quadrats at 15-day intervals (as in the first treatment) till mid-August, when clipping was stopped completely till the final harvest at the end of the growing season. The biomass was separated, dried and weighed as before.

Results

The results for these treatments are provided in the last two columns of Table 2. They indicate that

(1) both continuous clipping and partial closure resulted in a virtually identical level of cumulative production, and this level was significantly less than the peak biomass of the unclipped control; and

(2) the reduction in total production due to such severe clipping was 40% of the peak unclipped biomass.

The absence of difference between continuous clipping and partial closure is somewhat puzzling, until one realizes that the last clip before closure was on 16 August, the point at which clipping resulted in the most damage to future growth in the single-clip experiment. It is therefore possible that if clipping had been stopped even a fortnight earlier, the partial closure treatment would have shown significantly higher cumulative production.

The choice of clipping intensity, viz., removal of all above-ground foliage, was dictated by convenience. It was perhaps not the best choice, since clipping treatments that leave some foliage would probably better represent actual grazing by cattle and buffaloes and have been shown to yield cumulative production values greater than the control even though complete clipping showed a reduction (Singh and Mall, 1977). If the harsh "grazing regime" of complete defoliation every 15-days (the continuous clipping treatment) results in only 40% reduction with respect to the ungrazed control, it would be reasonable to infer that 40% is the *maximum intra-annual reduction* that might result from heavy grazing, and that, in general, the effect of grazing on intra-annual production is likely to be less severe than that, especially given the positive effect of clipping to only 15cm from ground level reported by others (Singh and Mall, 1977).

It should also be noted that the site on which these experiments were conducted (CH-CLIP) had historically suffered from much higher levels of grazing than all the other sites (as also suggested by the higher dicot fraction in the biomass). The response at the other sites may be different.

3.3 Long-term effects of grazing: some speculation

Given that all the data collected and presented here pertain to a single year, it is not easy to talk about long-term effects of different grazing regimes. Some contextual and historical information may, however, be used to speculate on what these effects might be.

An example of a possible long-term grazing effect may be the data from the two sites at Chipgi. Here, a historically protected and managed grassland (CH-BENA) yielded 4.5 t/ha, whereas the yield in a historically openly grazed tree land (CH-CLIP) just 50-100 metres from it yielded only 1.6 t/ha. Some of this difference could be the result of the shading due to the tree canopy (which was more than 40% in most parts of CH-CLIP). But it was also observed that the fraction of soil surface actually covered with vegetation was lesser at the CH-CLIP site, a possible symptom of grassland degradation. The number of stray cattle observed grazing in the Chipgi-*betta* location year-round suggests that such degradation will typically occur in and around towns with large free grazing cattle populations (usually owned by wage labourers as supplemental sources of nutrition/income). If this is indeed evidence of the extent of decline in production under persistent heavy grazing, personal observation suggests that such grazing occurs only in few patches of open-access uncultivated lands in some of the sampled villages.

4. Summary

The relationship between livestock management and herblayer productivity is complex even in "pure" grasslands. In the Malnaad, interactions between trees and grass, as well as micro-level variability of growing condition and grazing regimes serve to further complicate matters, and the relative paucity of ecological research, possibly driven by the notion that grasslands are unimportant in this forest- and agriculture-dominated region, does not help. The research presented in this chapter is a very small beginning towards understanding some of this complexity.

The results highlight a few basic characteristics of the grassland-treeland-livestock systems of the Malnaad, viz., that production in historically maintained "pure" grasslands is, at 3-6 t/ha/yr, quite substantial by any standards, that the production is quite sensitive to tree canopy cover, with rapid drops beyond canopy cover values of about 40%, and that the effect of light grazing depends critically on the timing, while that of very heavy continuous grazing is obviously negative, although not devastatingly so (a 40% reduction).

The implications are interesting. Firstly, one can now understand the existence of a range of tree canopy covers or densities, including zero canopy (i.e., treeless) grasslands in the "forest" lands as probably active choices by the land-users. Secondly, if obtaining high levels of production requires zero or sparse tree canopy, controlled grazing, and probably regular use of fire, such management regimes were observed at a number sites within the sampled villages, and they appeared to coincide with differences in control that the households exert on the land. Thus, most of the uncultivated *khushki* (dry) lands, which are privately-owned, had such management regimes. A number of plots within the betta lands (especially in the SM and TK clusters) also had similar management. While households in MF/RF lands in Malenalli village had also established control over some grasslands, they did not appear to use fire, possibly because their control was illegal, and fire is anathema to the Forest Department. This suggests that effective "control" over that land, not just in terms of usufruct but in terms of the authority to reduce tree densities and/or lop canopies, set fire and exclude others' livestock, is important in increasing grassland resource productivity.[12] Thirdly, even where over-grazing exists, reaching "sustainable" use may not necessitate complete stoppage of grazing, but only some scheme of rotational grazing across grasslands that mature at different points in the season (such as under varying tree canopy). Fourthly, the lopping of trees for obtaining leafy matter as mulch and manure might be a technique evolved by the betta-holders to reduce tree canopy effects on grass production while maintaining higher tree densities. But non-betta-holders do not have the right to carry out such systematic manipulations of the vegetation in open-access uncultivated lands. Since grazing reduces intra-annual production by 40% or less, but high canopy cover reduces it from 3-6 t/ha/yr to as little as 0.25-0.75 t/ha/yr, perhaps the real tragedy-of-the-commons in the Malnaad is not heavy grazing, but the "heavy" forest, both physically and metaphorically, in terms of this inability to modify vegetation in the "commons" to best utilize their resources.

[12] Nadkarni *et al.* (1989) reported similar levels of protection and management in privately owned grasslands in their villages.

Chapter VI. Biomass resource management, household characteristics and forest rights: Complementarities and contradictions

We have seen that the sustainability and productivity of the uncultivated biomass resources in the Malnaad villages is a complex function of the quantity and manner of extraction, the area available for resource extraction, and the manner of resource protection. In this chapter, I examine the relationship between these factors and micro-level conditions and constraints of the household, in particular, household size, ownership of cultivated land assets, and access to and control over uncultivated lands.

Previous explanations of villager-induced forest degradation in the Malnaad have asserted that biomass use is directly related to human or livestock populations (Reddy *et al.*, 1986), or that agricultural assets drive biomass use (Nadkarni *et al.*, 1989), and of course that use leads to degradation. The nature and impact of the property rights regime governing the use of forests is considered to be either open-access and therefore leading to a tragedy-of-the-commons (Gadgil, 1987a), or partly privatized yet irrelevant to the outcome (Nadkarni *et al.*, 1989).[1] I shall show that, while the size of the household and village populations does relate to the demand for some biomass resources, cultivated lands play a more complex role, creating both demands on and alternatives to

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[1] Nadkarni *et al.* interpreted their results as showing "that private and exclusive access to forests, as in the case of *bettas*, has not ensured their sustainable use" because "what was scarce from the point of the society as a whole and from a long-term perspective, was not equally scarce in the eyes of the richer sections of society who enjoyed the lion's share of the benefits from the forests" [p.153]

uncultivated biomass use, while also creating opportunities for more efficient or productive resource utilization for some social groups. The peculiar link between household assets and access to or control over uncultivated lands that is characteristic of the Malnaad creates conditions largely favouring sustainable use by one class of users, but a range of outcomes for the other classes that depends upon contextual factors.

This chapter is organized as follows. I begin by hypothesizing the nature of the relationship between key household characteristics (size, cultivated land ownership, access to and control over uncultivated lands, and geographical location) and the demand for, availability of, and ability to implement conservation measures for a particular biomass product.

Following this, I show how cultivated land assets of households are strongly correlated with household income, education and caste status. I also discuss the relationships between cultivated land assets and other hypothesized independent variables, and the consequent difficulty in using all the variables in the analysis. I show how the access to and control over uncultivated lands for some households is peculiarly and almost inextricably tied to the household's ownership of historically cultivated areca land, while that for households without historical areca land is more variable and context-dependent. This necessitates treating access as only semi-independent of household land assets. I therefore categorize households on the basis of the type and quantity of their cultivated land assets for convenience of use in the analysis, differentiating them into landless, marginal, paddy-only, small-medium areca, and large areca-owning households.

I then examine the relationship between the use of the three major types of uncultivated biomass, viz., fuelwood, leafy matter, and grass biomass, and the reduced set of household characteristics. In each case, the variables constituting "use" are described briefly, their relationship with household variables examined, and the results interpreted in the light of other qualitative information.

I then show that the mosaic of tree and grass vegetation on betta lands, initially considered an independent variable, is itself partly related to the balance between other household land assets of the betta-holders, suggesting a historical manipulation of uncultivated vegetation to suit household needs. The presence of barren lands, on the other hand, might be explained by external pressures for fuelwood that depend upon location.

I conclude by highlighting the key differences between broad household categories.

The data on household characteristics used in the analyses in this chapter are primarily from the survey questionnaires administered to the full set of 259 households in the three sample village-clusters, augmented with information from village land records, land-use mapping, key informant interviews, and personal observations. The data on biomass use are a combination of the survey questionnaire data and monitoring of actual use carried out by me as a part of this study (described in Chapter III) and by my collaborators at the Centre for Ecological Sciences prior to my field work. The analysis is a combination of correlation and multiple-regression analysis, non-parametric comparison tests, and some qualitative comparisons.[2]

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[2] Correlation matrices and scatter-plots were initially examined. Results of the step-wise multiple regression were checked for linearity and homogeneity of variances by examining the plots of predicted values vs. residuals, and partial residual plots. Unless mentioned otherwise, comparisons of two independent samples were carried out using the non-parametric Mann-Whitney U-test.

1. Hypothesizing the relationship between resource sustainability and household characteristics

The general conclusion of the ecological analyses of tree and grass biomass use was that unsustainable use is not widespread. Nevertheless the analyses indicated ecological conditions or regimes under which the resources *might* be unsustainably used. These conditions include (a) an imbalance in woody tree biomass production and extraction, (b) reduction in tree regeneration due to the cutting of young trees and saplings or browsing by livestock, (c) depletion of immobile nutrients from the soil due to heavy extraction of tree leafy and woody biomass, and (d) decreases in grassland productivity due to heavy grazing through the growing season. Broadly speaking, one may say that degradation, i.e., reduced current or future production, is likely to occur when (i) demand directly exceeds production (such as in woody biomass extraction), or (ii) when a demand that is higher than availability forces users to exceed certain thresholds that govern future production, by, say, lopping or cutting of young trees or grazing at wrong times, or (iii) a household's economic position constrains its ability to invest in resource protection and management, or (iv) the property rights regimes governing forest access and use fail to provide adequate incentives for the household to invest in such management. What determines a household's demand for biomass or its access to and ability to manage the resource?

First of all, it is important to recall the division of rights in forest products described in Chapter I, whereby villagers are alienated from the direct commercial use of these products. Villagers do not have *de jure* rights to sell forest produce in the larger market. In practice, the forest department is quite vigorous in its enforcement of the prohibition of commerce in timber.[3] Many "minor" produce such bamboo, fruit, seeds, etc. are also contracted out by the department. Villagers can sell fuelwood and leafy matter, but there is really no market for either in the village, since the landlords can obtain the produce themselves (so that poorer households are essentially hiring out their labour-time). A small market exists for manure, which is prepared from the dung of animals grazing in forest lands and from leafy matter also obtained from these lands. But the market is not big; it is more a situation of the landowners paying a small premium for not having to supervise hired labour to produce their manure. The only major market is that for fuelwood in urban areas, and for practical reasons, it is relevant only to the Sirsimakki cluster. Even here, all the forest land in the sample villages was betta-land, and the households did not report being involved in fuelwood exports. In short, the bulk of the demand created for the resources originates in the households or lands of the users. One can therefore safely ignore external demand, and locate the sources of biomass demand within the households or the village as a whole.

The major uses of uncultivated biomass are woody matter for fuel, fencing and house construction, leafy matter for mulch and manure, and grass biomass for fodder. I hypothesized that the household demand for these biomass types is primarily a function of (a) number of people in the household (for woody matter), (b) cultivated land holdings

[3] The restrictions are quite comprehensive and onerous, and cover even the felling and/or sale of trees on private lands. Felling, transport and sale all require permits. Forest guards routinely patrol well-forested areas. Checkpoints along major roads routinely inspect vehicles for timber that might not have the markings of being transported under permission. Thus, felling of a tree or two for personal use might be possible, especially since forest guards are always susceptible to bribes, but felling activities on a commercial scale require a large operation that hardly any villagers are capable of; such operations are the realm of timber merchants or contractors in the towns, and are likely to occur in sparsely populated areas and valuable timber forests, such as the northern parts of Yellapur taluka, and Mundgod, Haliyal and Supa taluka. Reports of timber smuggling in the Sirsi- Siddapur area did surface while I was in the field, but they were invariably allegations against operators based in towns.

and crop types (driving demand for mulch and manure), (c) livestock assets (driving demand for fodder), and (d) household ability to adopt resource conserving technologies, access to local substitutes, or ability to externalize the demand through a regional market.[4] A common methodological problem, however, is that one can only measure consumption, (if at all), not demand. Since consumption is likely to be influenced by both demand and availability, one has to be careful to incorporate the possible effect of the latter before deriving the level of demand. Alternatively, one can internalize the effect by saying that manifested demand (i.e., measured consumption) is also a function of availability.

The area of the tree or grass land accessible to the household would depend upon (a) its direct ownership of uncultivated lands, and (b) the area of uncultivated lands within collecting distance to which household members (or their hired labourers) have *de facto* access, and (c) the relative share of tree and grass biomass on these lands. In the Malnaad, owned uncultivated lands are mainly khushki or "dry" lands. *De facto* accessible lands would mainly consist of lands to which households have sanctioned access, i.e., own *soppinabetta* or the village's Minor Forest (MF). They would also

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[4] Other possible variables would include household demographic composition, cultural attitudes towards food, bathing and rituals which might drive demand for fuel, attitudes towards milk and meat influencing livestock numbers and management, and climate. Household composition is said to affect demand for fuelwood, with, e.g., aged individuals needing more hot water or children requiring less cooking relative to average adults. While data on age-composition were available, those on fuelwood use were too uncertain to indicate any effect. Data from the monitoring of cooking fuel consumption did not show any effect of differential weighting of children and adults. Climate, and the taboo against beef are similar across the villages and communities sampled in this study and prevailing in most of the Malnaad region. Cultural attitudes and rituals are likely to increase the "need" for hot water for the Brahman community relative to the others; on the other hand, other communities might be imitating this lavish use of hot water, (Mani, 1985, p.15 and personal observations). Moreover, given that most betta-holders are Havyak Brahmans, and betta-holders generally enjoy the best access to fuelwood resources, the separation of cultural effects from access effects is not possible with the available data.

include those lands from which households are not excluded in practice, i.e., Reserve Forest (RF) lands that are not fenced and guarded by Forest Department officials and, (to a small extent), *soppinabetta* lands belonging to but not fully controlled by other households.[5]

Finally, the household's ability to manage and care for the resource so as to ensure future production would depend upon (a) its economic ability to invest labour, capital and resources in such work[6], (b) its ability to exclude others from a privately controlled resource (including the ability to physically exclude others or their animals through fencing or through threats of retaliation, and the social and economic ability to put up the fencing when desired), and (b) the extent of cooperation/conflict with other households, particularly if the resource is to be managed communally.

[5] A variable important in other regions with higher biomass scarcity would be the availability of labour to go in search of the fuelwood or leafy matter. The Malnaad region is, however, characterized by a general abundance of but skewed access to biomass resources. Labour is a constraint in resource protection, not collection. Moreover, it is incorporated in the variables for household size and asset condition, since the latter is assumed to determine the purchasing power of the household.

[6] The household also needs an incentive to spend such labour (own or hired) in resource protection and "cultivation". This incentive exists to the extent that there is no alternative to that resource (nor to the household's need for it), the household's benefits from it, and possibly in cultural attitudes (beyond those shaped by such dependence) towards natural resource amenities. On the basis of my observations and discussions with households, I assume that the last variable does not change across household categories. Differences in alternatives to and benefits from uncultivated biomass resources follow the differences in agricultural assets. Those with areca land benefit highly from leafy and grass biomass, as it maintains the physical productivity of the highly remunerative areca and spice crops. Those with paddy lands also benefit significantly from uncultivated biomass, its relative contribution to household income being estimated by Nadkarni *et al.* (1989, p.153) to be similar or higher (18-24%) than that for arecanut cultivators (14-17%); the contribution to the incomes of landless labourers is the least (12%), but still significant.

2. Household characteristics, resource access, and the definition of household categories

Many of the household characteristics hypothesized as influencing biomass use and management are correlated with the type and extent of agricultural assets in the Malnaad. Access and control over "forest" lands are also partly but peculiarly related to areca holding, and partly to location. I discuss these correlations in this section, as they enable us to reduce the set of variables and caution us in the use of some of them in multiple regression analyses. The correlations also enable us to classify households into representative categories that are easier to use in some analyses. The data used in the following discussion consist primarily of data from the survey questionnaires administered to all the households in the three village-clusters, supplemented by interviews and personal observations.

2.1 Correlation between household socio-economic status and areca ownership

It is easy to argue that the area of areca land owned is the prime determinant, and paddy land ownership a secondary determinant of household income and assets. Agriculture is the primary activity of rural households in the Malnaad even today. This is illustrated by the facts that none of the households in the sample of 259 was solely dependent upon non-agricultural income, that only 21 out of 1196 working age adults had salaried jobs (with another 12 being involved in full/part-time business activity), and that none of the households reported salary or business as being the dominant source of income. All but one of these salaried workers come from areca-cultivating Brahman households. The adults in 49 of the 50 landless households (and often children older than age 12) work as agricultural labourers, or domestic labourers in other agricultural households, the remaining one being an artisan's. No household reported animal husbandry as its primary activity (although a few such households were reported in neighbouring villages).

The primary agricultural forms in the sample villages and in the Malnaad are arecanut orchards and paddy fields. Coconut and sugarcane are typical subsidiary orchard crops and field crops respectively. Of these, areca cultivation is by far the most profitable activity. An acre of well-maintained and mature (>20 years) areca garden yields between 10-16 quintals of nuts each year (survey data). At 1989 prices of ~Rs.2000/qtl,[7] the typical gross income from areca would be Rs.28,000/acre or Rs.69,000/hectare. Paid-out costs for areca cultivation range from 15-30% of the gross income (Mruthyunjaya, 1972; Krishnaraja, 1981; Nadkarni *et al.*, 1989), with the higher values being for recently established gardens whose capital cost is being repaid. Thus, the net return from just arecanut would be at least ~Rs.48,000/ha. That from cardamom and pepper would be highly variable, due to the large variation in the area under these crops from plot to plot, village to village, and year to year; it may range from 0%-20% of that from areca.

On the other hand, the yield from an acre of paddy ranged from 1-3 t/ha for the monsoon paddy crop in well-cultivated and fertilized plots[8], which, at 1989 prices of ~Rs 4000/tonne[9] would yield a gross return of Rs 4000-12000/ha. The net income per

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[7] Totagars' Co-operative Sale Society, Sirsi, various annual reports.

[8] Productivity data are from harvest experiments carried out by CES staff in 1987 (Y. Kanade, unpublished data). Summer crop areas were less than 20% of monsoon crop, due to lack of water.

[9] From records of Agricultural Produce Marketing Committee, Sirsi.

hectare of an areca orchard would therefore be at least 4 and more typically 8-12 times that from a hectare of paddy. Thus, households with 0.5 acres (0.2 ha) of areca cultivation, the lower limit of land holdings among traditional areca cultivators, are likely to have incomes comparable to households with 5 acres of paddy, the typical high end of paddy ownership among paddy-only cultivators. Moreover, hardly any paddy cultivated here is sold on the open market. Jaggery from sugarcane and wages from part-time agricultural work are the main sources of cash income for paddy-only cultivators.

Landless households have to survive on wage labour in areca and paddy cultivation or domestic work. The incomes and asset positions (e.g., quality of housing) of these households were observed to be generally lower than those of paddy-only cultivators (Nadkarni *et al.*, 1989, p.152 , and data from the survey in this study).

There was also a strong correlation between areca ownership on the one hand and caste and educational status on the other. Of the total 259 households, 141 belonged to the Brahman caste, which traditionally had highest caste status in the region. Of these, only 7 were paddy-only cultivators or landless. On the other hand, of the 118 non-Brahman households, only 7 had mature areca gardens larger than 0.5 acres (0.2 ha) while 49 were landless. Similarly, all 83 individuals with bachelor's level or higher education came from arecanut cultivating households, and all belonged to the Brahman community. All the salaried workers and businessmen also belonged to this community.[10] Thus, the typical arecanut cultivator household has high cash income, educational status and caste position; the typical paddy-only cultivator has lower cash

[10] All other indicators of educational level were similarly correlated with land asset type and caste.

income but security of livelihood and some assets, some formal schooling and (more recently) access to political power; and the landless labourers depend totally on the areca economy to provide employment and the generosity of their employers for the piece of land on which their hut is erected, and have little formal education.

It seems to be reasonable to assume that a household's current income, assets and social status primarily determine its ability to invest in technologies for efficient resource utilization (such as bio-gas for fuel), to spend on resource protection measures (such as fencing of large plots of tree or grass lands) or on purchases of fuel/fodder inputs from the regional market. Caste also determines cultural attitudes about cleanliness and religious ritual, and about dependence on milk as a major source of protein, characteristics that have some implications for fuelwood use for bathwater heating and livestock holding respectively. It then follows from the above discussion that separate variables for caste, status or economic condition would be well correlated with areca and paddy ownership. It is therefore not advisable to use variables for caste or economic condition as independent variables simultaneously with those for areca and paddy assets as in a regression analysis.

2.2 The question of incentives and attitudes

Even if the household has the ability to mobilize the labour, capital, or technology to required for the protection and management of an uncultivated resource, it needs an incentive to do so. The amount of the incentive required would depend upon the absolute value of the future gain from better resource management, and the relative value the household puts on the current costs of management and the future production benefits from it.

Differences in benefits from uncultivated biomass resources are well-correlated with differences in agricultural assets. Those with areca land benefit highly from leafy and grass biomass, as it maintains the physical productivity of the highly remunerative areca and spice crops. Those with paddy lands also benefit significantly from uncultivated biomass, its relative contribution to household income being estimated by Nadkarni *et al.* (1989, p.153) to be similar or higher (18-24%) than that for arecanut cultivators (14-17%); the contribution to the incomes of landless labourers is the least (12%), but still significant.[11]

The tradeoff betweeen current investment and future benefits is, within a conventional economic model, represented by the household's short and long-term discount rates. A rigorous estimation of these discount rates was impossible, but general observations suggested that virtually all households had a sense of being tied to their land, and were not easily tempted to give its management (and hence their own or their progeny's future) short shrift.[12]

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[11] The exact marginal benefit from one tonne of biomass input to a particular activity is difficult to estimate, hence Nadkarni's average values are taken as the reference.

[12] The one major difference across households was the access to higher education and the white-collar employment and income opportunities it creates. The Brahman households, with their tradition of interest in education, scriptures and literature, have rapidly adapted to and diversified into modern white-collar jobs, particularly teaching, law, and engineering. Their investment in the education of their children pays off in terms of higher return per capita than if the children had remained in agriculture, especially as completed family sizes were rapidly expanding rapidly during the past four or five decades. The emigration of household members to town-based white-collar jobs has complex implications. Some betta holders spoke of a reduction in their ability to supervise forest harvest operations, and a consequent tendency to obtain biomass inputs from their own or MF/RF lands on the basis of unsupervised contracts, wherein labourers tend to be more careless about the method of harvest, leading to resource degradation. This might be thought of as an increased tendency to trade off future production benefits from harvest supervision against immediate benefits from family members obtaining white-collar jobs. However, whether this is a change in discount rates or in utility functions is not clear, and its effect could not assessed in any meaningful sense from the data collected.

2.3 Other correlations among household land assets

Ownership of areca and of paddy is partly correlated: Within areca-cultivating households, larger areca holders generally have larger paddy holdings. Ownership of private grasslands is, skewed, however. Marginal and paddy-only cultivators have virtually no privately owned grasslands. Ownership of coconut orchards, which have proliferated in the past few decades, is similarly sharply skewed towards large areca owners, suggesting that the investment requirements of coconut plantations favour their adoption by the wealthier families. Since the total area under coconut is small (about 1/10th of that under areca) and evenly distributed across clusters, and its impact on biomass use is rather limited, I decided to drop coconut holdings from the list of household landholding variables used in the regression analysis. For the same reason, I also dropped the area of sugarcane and mulberry cultivated by households from the analysis.[13]

2.4 The role of location

The households are located in three distinct village clusters. The location of a household in a particular village cluster appears to have important but complex implications. On the one hand, the results in Chapter III show that the forests in the Malenalli region may be inherently more productive than those in the other two clusters; soil fertility in areca gardens is also believed to be higher in that region (C. M. Shastri, personal communication), but is not easy to compare between Tattikai and Sirsimakki. The

[13] Areas under sugarcane or mulberry did not exceed 1 ha each in any village unit.

hilliness of the terrain decreases systematically as one proceeds from Tattikai to Sirsimakki to Malenalli, resulting in greater availability of paddy and dry lands in the Malenalli cluster.

On the other hand, access to new technologies (such as kerosene or LPG for cooking) and to markets (for selling milk) depends partly on the distance from the town or distance from the nearest market point. While all three village clusters were on or near major roads, the Sirsimakki cluster is right next to Sirsi town. But many households in the Malenalli cluster are next to and actively connected with the Hulgol Group Villages Cooperative Society, an association of areca cultivators that has developed credit marketing and infrastructural facilities for its members. The systematic trends in productivity and terrain led me to assign the non-parametric variable CLUSTER values in the sequence TK < SM < MH, but the other factors make this ranking debatable and need to be kept in mind while evaluating the results.

2.5 Uncultivated public lands: access, control and relationship with areca ownership

The assignment and practical operation of the rights of villagers in forest lands play a crucial role in mediating the use and management of uncultivated lands by them. In the Malnaad, two distinct "regimes" of access to and control over forest lands may be distinguished - the regime of *soppinabetta* privileges and the MF/RF regime. I shall discuss each regime in terms of four aspects: (a) kind of extraction permitted, (b) area of access, (c) initial condition of vegetation, and (d) nature of control. In addition to specific references and data cited, the discussion below is based on interviews with forest officials and local elders, and personal observations.

Table 1: Differences in area of accessible uncultivated lands across major household groups, and their variation across villages

Village unit	Betta-holders*					Non-betta-holders			
	Popu-lation	Total Betta area [ha]	Betta area per capita [ha]	Tree-land/ person† [ha]	Betta: Areca ratio	Popu-lation	Open-access MF area [ha]	Total RF area [ha]	MF area per capita [ha]§
K.Sarakuli	74	49	0.66	0.55	7.7	26	0	0	--
Tattikai	183	134	0.73	0.58	6.7	67	0	5	--
Mundagesara	327	216	0.66	0.35	7.7	57	0	0	--
Sirsimakki	194	118	0.61	0.38	6.0	61	0	5	--
Golikoppa	96	53	0.55	0.57	5.7	64	0	8	--
Arasapura	102	85	0.84	0.90	6.9	24	19	0	--
Malenalli	0	0	--	--	--	230	70	142	0.30

Note: "Total" betta/MF/RF are for the *uncultivated* part of the land legally classified as betta/MF/RF in that village unit.

* : Note that betta-holders can (and sometimes do) use MF/RF lands too.

§ : In the case of Arasapura, all the non-betta-owning population is of landless labourer households whose needs are provided from the bettas of their employers.

† : Treeland available to betta holders = all land with high or medium density trees with lopped morphology or other signs of harvest. Values are from tables in Appendix D

The soppinabetta regime

Soppinabettas in the Malnaad were allocated in the area ratio of 8:1 for areca orchards that were under cultivation at the time of the settlement of forest rights by the British colonialists. They were given the right to extract fuelwood, green and dry leaves, graze animals, and a host of other usufructs.[14] This ensured that the areca cultivator had access to green and dry leaves and grazing area in proportion to the needs generated by areca cultivation. The actual availability of the products would of course vary by the quality and relative distribution of tree and grass vegetation. Moreover, the exact "needs" of manure and mulch for areca cultivation are hard to pin down, to which the vigorous debate ever since the time of settlement bears testimony.[15] Nevertheless, the allocation appears to be systematic and substantial by any count.

Per-capita availability of betta land is important from the point of view of fuelwood and timber, and perhaps indirectly for the milk from grazing animals. Table 1 provides an idea of the variation in average per capita betta area across clusters. The calculations were made from village-level land area values from the village land records. Although the areca-based allocation results in large variations in per capita values, per capita availability is generally quite significant, with a mean of 0.65 ha (median of 0.57 and mode of 0.4 ha) when calculated on the basis of the survey questionnaire data.[16] On the other hand, the area-based allocation ensures that betta land availability per capita for a household generally increases in direct proportion to the household's areca holding per capita.

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[14] Betta-holders have rights to dig wells, erect shelters, and remove soil and plant areca in the flat land so created (Anonymous, 1944). They even have the right to harvest timber upon obtaining permission from and paying some "upset price" to the Divisional Forest Officer. This price was a very nominal rate of Re. 1 per tree till 1981, and even today the rate charged is about half the market price (Government of Karnataka, 1987). The only responsibility a betta-holder has is to maintain a minimum of 100 trees per hectare, and not lop five valuable tree species, viz., teak, sandal wood, rose wood, ebony and *Halmaddi*.

[15] See, e.g., Davidson (1891;1894), MacGregor (1894) and Nugent (1894).

[16] These data were found to be underestimates of total betta availability to the extent that they exclude the area that is barren, used for other purposes, or inaccessible to the betta-holder.

At the time of allocation, the nominal betta:areca ratio of 8:1 did not vary significantly across the three village clusters, or across the Malnaad region in general. Today, however, the ratio of betta:areca area varies significantly (ranging between 4 to 10) for a number of reasons. Firstly, no additional betta has been allocated to areca orchards that were established after the 1930s, usually by converting land from paddy cultivation. The area of such orchards in the village clusters sampled here was difficult to determine. My estimates, based upon the land that is legally designated as wet land but is currently under areca cultivation, range from 0% to 9% of the total areca area.[17] Most of this expansion has occurred in the lands of households that already were traditional areca cultivators, usually with substantial old holdings (and so already with substantial betta lands). Only a few households (3 in SM, 0 in TK and 3 in the MH cluster) hold areca land that is all recently developed (and therefore without betta). Secondly, the divisions of large *soppinabetta* "survey numbers" (plots of land demarcated for survey purposes) amongst households has been on the basis of customary use and are therefore approximate. Thirdly, some parts of the bettas may be lost to roads, transmission lines or be just too far from the household's areca lands to use. Moreover, the share of grass vegetation in the betta land varies. In collecting the data, betta-holders had been asked to separate the household's betta holding into two variables: grassy area (denoted by NPVTGRAS), and tree area (denoted by TREELAND). I found that the tree area was still highly correlated with areca holding (denoted by ARECA); it was therefore

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[17] Although large areas of areca cultivation were abandoned during the early part of this century due to a combination of influenza, British taxation, and restrictions on forest use (Masur, 1927), virtually all of that area has been reclaimed for areca by now. Only one household in the sampled villages held land that had been areca cultivation earlier but is now under paddy, although they have begun replanting areca in a small part.

excluded from the regression analysis.

As regards the historical quality of the betta vegetation, information specific to particular villages is very scarce. One can only say that most of the lands allocated were already being used by the areca cultivators as lopped forests and are likely to have had some tree cover.[18]

Finally, it is important to understand the nature of control over the betta lands. Betta-holders enjoy an exclusive usufruct; thus, they have the right to fence or trench the land for the purposes of enforcing exclusive use (Nugent, 1894). In practice, though, the betta-holders have found it easier to fence off large common areas rather than individual plots, partly because exigencies of day-to-day use militate against multiple fences criss-crossing the landscape, partly because of the high costs of such fencing, and partly because individual plots may split or merge as areca plots change hands with inheritance. Nevertheless, the general situation in the bettas is that of fully privatized usufruct for most of the products (except perhaps timber), not of a tragedy-of-the-commons as suggested by Bhat and Huffaker (1991).[19]

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[18] E.g., see Cleghorn (1861, p.16).

[19] Bhat and Huffaker base their argument on the ambiguous official assignment of betta lands in many villages. The ambiguity results from the assignment of a single betta "survey number" (i.e., plot of land) to many orchard survey numbers, hence allowing usufruct rights to the various owners of *all* those orchard plots. Further, even where a one-to-one assignment was originally made, subsequent division of the areca orchard plot (usually due to the splitting of inheritance) would require the division of the corresponding *soppinabetta* lands; no mechanism for such division was ever set up and implemented. Bhat and Huffaker argued that these "common betta assignments" create a situation in which one betta-holder cannot conserve trees without the fear that another might lop them, thus leading to betta mismanagement and degradation.

My critique of this interpretation is presented in Lélé (1993). In brief, while the ambiguity in control exists on paper, in most cases the villagers have long ago divided the commonly-held plots into individually controlled ones on the basis of customary usage. Furthermore, disputed locations were not any more "degraded" in any sense than undisputed ones; the remaining land held by "losers" in the dispute was usually enough, or else they simply used the MF/RF lands. A public announcement from the Tahsildar of Siddapur (taluka-level head of the land revenue department) dated 26 Sept. 1964 indicates an attempt by the administration to solve the

(continued.....)

The MF/RF regime

The situation is rather different for households that do not hold betta lands by virtue of ownership of old areca orchards. Relative to the betta-holders, their extraction rights are restricted, and the area accessible to them highly variable, generally lower, less conveniently located, with probably lesser historical tree vegetation. The regime is an almost fully open-access one.

All villagers have rights to extract fuelwood, leafy matter and fodder from and to graze animals in MF lands, if present in the village or neighbouring villages. They have no timber rights. Villagers are also permitted to graze animals in or collect deadwood from certain RFs. In practice, this right extends to cutting smallwood and leafy matter also, unless the forest is particularly heavily guarded. On the other hand, the forest department may choose to shut off access to a piece of RF land at any point, and does so routinely with the use of barbed wire fences and permanent watchmen when timber plantations are created. For instance, most of the RF in Malenalli village is currently indistinguishable from its MF, but large parts of the RF in neighbouring Belale are under eucalyptus plantations.

The area of MFs was supposed to be allocated in the ratio of 2 acres per head of livestock but this policy was not implemented in practice (Masur, 1918). Although historical livestock data are not available at the village scale, a graph of MF allocations against the human population in 1921 in a sample of villages with no historical areca

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[19](...continued)
"problem" of common assignments (No. FOR-MSC-SR-304, 26-9-64, Siddapur). The fact that this move evoked virtually no response from the betta-holders (Ramachandra A. Bhat, Tattikai, pers.comm.) fits with my contention that the problem is not a serious one.

cultivation (no betta area) showed that the allocation was poorly correlated with the number of users. Today, the area per capita has decreased and also has become more variable due to the growth in local populations, immigration into the region, and the selective establishment of housing colonies for landless families as well as allocation of parts of MF lands for new agriculture by the state government. The highly variable distribution of per capita MF areas in the sampled villages, and the contrast with the availability of betta land for betta-holders are shown in Table 1. For six of the seven villages, no MF area exists within the village.[20]

Historical data on the vegetation in specific MF lands are as scarce as those for betta lands. However, Masur (1918) stresses the fact that many of the MF lands were *gai-raans* (literally, "cow-jungles" or grazing lands). This suggests that there may have generally been lesser tree vegetation in MF lands than in betta lands at the time of their allocation.

Villagers do not have the *de jure* right to exclude others (whether village residents or outsiders) from the use of their MF/RF lands, making the MF/RF regime an open-access one. Does this automatically create a tragedy-of-the-commons? Two aspects need to be explored here: (a) Is the resource open-access in practice? and, (b) Are other conditions for a tragedy-of-the-commons always present?

On the one hand, villagers often attempt to establish *de facto* exclusive control over uncultivated lands, converting an open-access regime into one of private or

[20] It is nearly impossible to estimate what fraction of the MF in neighbouring villages is available to the non-betta-holders in the sample villages. But estimates based on the total area of MF and its location on the village maps indicate that areas of 30 to 160 ha are likely to be shared between these users and the neighbouring villagers, who might be 150-300 in number.

communal control. However, in the absence of legal sanction, the control is quite tenuous and contentious. It is therefore likely to be exercised for the most valuable products, and unevenly across households. This prediction is for the most part borne out by observed situation in Malenalli village. Households have encroached significant pieces (12 ha) of the RF for paddy cultivation, and have fenced off an additional 17 ha in RF/MF lands for exclusive grazing and lopping. The management is communal in one case, but individual in all others.

On the other hand, even the remaining open-access lands of Malenalli village do not show signs of rampant over-harvest, illustrating that other conditions for the tragedy-of-the-commons may not be met in every case. In particular, the marginal net benefit from resource use needs to be positive even after the last unit of sustainably harvestable biomass has been extracted. This condition is more likely to be met as individual demand increases relative to availability, or when a market for the product develops, thus keeping the marginal return high. While timber is strictly prohibited from being extracted and sold, and fuelwood is generally abundant, there appears to be a market for dung, which the landless households produce by grazing their animals in MF/RF lands and sell to areca cultivators.[21]

Role of location

Location also affects availability of uncultivated lands. While the official ratios of betta to areca land are similar across all clusters, the actual ratios are generally lower in the

[21] One may say that the situation for particular kind of fuelwood, e.g., logs for sugarcane processing, is somewhat similar, with large land-owners contracting poorer individuals to obtain the material from "somewhere in the jungle", as most residents put it.

SM cluster for reasons outlined above (see also Table 7 in this Chapter). The same is therefore true of treeland, as larger fractions of bettas in the SM cluster are in the form of grasslands. Finally, the availability of MF/RF lands is the lowest in the SM cluster. Although there are no MF lands (and small RF lands) in all villages in all clusters except Malenalli village, the area of MF land in the villages adjacent to the SM cluster is low and the number of competing users there quite high, particularly due to its nearness to Sirsi town. These lands are mostly scrub vegetation today.

Summary

Betta-holders clearly enjoy better control over their betta lands than do non-betta-holders over MF/RF lands. In villages with only betta lands, non-betta holders depend upon neighbouring village lands and probably end up with less accessible area than the betta holders. In one village in this sample without betta lands, it appears that the availabilty of unclutivated land is comparable to that for the betta-holders elsewhere, especially if one also includes the RF land. In these lands, some households have already established some *de facto* control over grassy areas, and the area is included in the variable NPVTGRAS (as if they had betta lands). Thus if the uncultivated MF/RF land controlled by non-betta-holder households is measured separately, then the presence/absence of areca ownership and a variable for location would together explain most of the variation in the availability of uncultivated lands to households. In the multiple regression analysis, however, a binary variable for presence/absence of old areca cultivation did not explain any additional variation when used in conjunction with areca holding (ARECA), and was therefore dropped. The grass or tree land exclusively controlled by households in MF/RF lands was added to NPVTGRAS (grassy area) and TREELAND (tree area) respectively.

2.6 Categorization of households

I have argued that the household's income, assets and social status are determined by or strongly correlated with ownership of agricultural lands, particularly of areca and paddy lands. I have also argued that access to and control over uncultivated lands, which consist of private grasslands, grassland and treeland in betta holdings, and grassland and treeland encroached in MF/RF lands are related to areca ownership, though not as systematically. Thus, one could differentiate the rural society into categories that are likely to be relevant with respect to understanding patterns of biomass use and management, and so would serve as convenient clusters of household attributes when discussing the nature of biomass use.

At least three categories are immediately obvious -- landless, paddy-only cultivators (including those with recently developed areca), and traditional areca cultivators. Closer examination suggests that there are (a) a number of households with very small areca (<0.1 acres) and paddy (<0.5 acres) holdings that are mostly dependent upon agricultural labour[22], and (b) significant differences in the level of ownership of areca lands, ranging from 0.4 acres to 5-7 acres. I have therefore decided to split the households into five categories:

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[22] These typically consist of households that are cultivating small plots of paddy in encroached MF/RF lands, and a number of households in the TK cluster who obtained small strips of areca cultivation as a part of the state-wide land reform of 1974-75. I use acres instead of hectares for convenience, given the small size of the holdings.

Table 2: Distribution of agricultural and uncultivated land assets across socio-economic classes

Household category (code)	Basis		Number of households				Other variables				
	Areca	Paddy	All	TK	SM	MH	HH Size	Coco-nut	Pvt. Grass	Pvt. Grass	Tree land
Landless (0)	0.0	0.0	50	14	12	24	5.1	0.00	0.00	0.0	0.0
Marginal (1)	0.1	0.5	39	23	7	9	6.1	0.00	0.01	0.1	0.2
Paddy (2)	0.1	1.0	27	9	2	16	7.7	0.02	0.04	0.4	0.4
Small areca (3)	0.6	0.5	86	24	39	23	8.2	0.05	0.34	1.0	2.8
Large areca (4)	1.2	0.6	57	16	29	12	6.9	0.20	0.43	1.2	5.4
All	0.47	0.5	259	86	89	84	7.0	0.06	0.21	0.6	2.2

Notes:
1. "Paddy" and "Small/large areca" categories do own some other lands (see text).
2. HH = household, Pvt=private land, NPvt=non-private, i.e., betta, MF or RF land actually controlled by the household.
3. All area values are in hectares, and are averages across all households in that class.

- landless labourers: code: 0
- marginal farmers: code: 1
- peasants including new areca cultivators : code: 2
- small-medium traditional areca cultivators: code: 3
- large areca cultivators: code: 4

Categories 1 and 2 were distinguished on the basis of whether most labour-time is hired out or is used on own land. Categories 3 and 4, both corresponding to households mainly cultivating areca, were distinguished using a "normalized" areca holding of 0.8 ha (2 acres) as the cutoff.[23] This categorization, along with the number of households in each category in each village cluster and the corresponding average values of each of the household characteristics, is given in Table 2. The categories will be used as a proxy for socio-economic condition in the following analysis.

3. Fuelwood use [24]

In observing rural life in the Malnaad, one is immediately struck by the abundance of forest-based biomass, and its lavish use by the villagers. Fuelwood use is a case in point. When one visits an areca-cultivating Havyak Brahman's household, one is often offered hot water to wash one's hands - a hospitality hardly warranted by even the somewhat cooler micro-climate of the areca orchards. Many analysts have commented upon this lavish level of consumption (Mani, 1985; Reddy *et al.*, 1986; Nadkarni *et al.*, 1989), and much attention has been focused in official eco-development programmes on promoting fuelwood-conserving technologies.

Is household fuelwood use in the Malnaad higher than in other regions? And more important, does this use relate to household characteristics of assets/position, access and location? I shall try to answer these questions using a combination of secondary data, and data from questionnaires and monitoring of use, disaggregating fuelwood use into its

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[23] The normalized holding of a household is its actual holding corrected for household size, by multiplying it by the ratio of average household size across households to the household size of that particular household. It thus brings household land holdings to a comparable per capita basis; it ignores the possible advantages of large households and the effects of differences in household demographic structure.

[24] In considering woody biomass use, I shall focus on fuelwood consumption. Fuelwood consumption for cooking, water heating, and processing of arecanut and sugarcane is the dominant use of woody matter, constituting an estimated 80-95% of total woody biomass consumption in the three village clusters, while only 20%-5% was for house construction and repair, fencing, and agricultural implements (CES and KSCST, 1990, and questionnaire data from this study).

components (cooking, bathwater, heating and agricultural processing) where possible.

3.1 General level of consumption

The results of single-day measurements of fuelwood consumption in Bhairumbe village, which is adjacent to the Malenalli village cluster sampled in this study, were reported by Prasad *et al.* (1987b, sample of 62 households). They estimated that the average per capita consumption of fuelwood for cooking and water-heating in households using conventional woodstoves was 2.5 dry kg/day (Prasad *et al.*, 1987b, sample of 62 houses), which amounts to at least 0.9 dry t/capita/yr: Comparing this value with the Karnataka-wide average of 0.6 dry t/capita/yr reported by Ranganathan (1987), and the even lower values reported by others (NCAER, 1981, as quoted in Agarwal, 1987; Bhagavan and Giriappa, 1987), it is clear that the first impression of lavish use is not misplaced. To what extent may this lavish consumption may be sensitive to the social availability of forests? To what extent may the ability to reduce consumption through the adoption of fuel-conserving technologies or alternative fuels depends upon household assets/income position?

3.2 Variation in fuelwood use

Fuelwood consumption by a household depends not only upon the number of people in the household, but also upon additional requirements for agriculture-related activities (in this case, *jaggery*-making and arecanut processing), the availability of the fuelwood, the availability of alternatives, and the technology of fuelwood use. The data on fuelwood use obtained from CES' questionnaire surveys have large variance, caused largely by the errors in household recall of consumption. Measurements of fuelwood consumption are available only for cooking, through actual one-day measurements in a sample of 61 households (29 with conventional woodstoves and 32 with improved ones: C.M.Shastri, CES, unpublished data). A comparison of measured values with those reported in the survey questionairre for these households indicated that the absolute values of fuelwood use estimated from the questionnaire are likely to be significant underestimates, but the errors were randomly distributed across household categories. Thus drawing inferences on relative consumption levels is still valid. The trends discerned from the two data-sets are as follows.

(a) Effect of type of agricultural holding on consumption level

Households with areca or sugarcane cultivation reported additional fuelwood use for the processing of these products. The quantity of fuelwood required for these activities varies, particularly since only a fraction of the arecanut harvest is boiled and coloured (10%-20%, depending upon relative prices). Survey data indicated that these activities may add approximately 50-200 dry kg/capita/yr to the annual fuelwood consumption of the households involved in such processing.

(b) Effect of availability on consumption level

Betta land or treeland per capita is a reasonable measure of fuelwood availability for most betta-holders. For a measure that is applicable to all households, however, one has to use household category and location as a proxy. I examined whether differences in these variables related to differences in fuelwood consumption for *domestic* purposes, i.e., cooking and bathwater heating, using only those households with conventional woodstoves and no other source of heating energy. The results were as follows.

(i) The actual monitoring of fuelwood consumption for *cooking* (C. M. Shastri, unpublished data) does not reveal any significant variation across economic classes or with betta holding per capita. These measurements were taken in the Sirsimakki cluster, which has the least availability of treeland per capita for both betta and non-betta households (Table 1). It seems unlikely then that an effect of availability on use would show in other clusters if they were monitored since they generally have more fuelwood available.

(ii) Survey data on *total domestic* fuelwood consumption, however, indicate systematically increasing averages of per capita consumption with the sequence of household categories from reported levels of about 500 dry kg/capita/year in the landless class to 700 dry kg/capita/year in the small and large cultivator classes (households with only conventional woodstoves were considered). The application of non-parametric (Mann-Whitney U) tests to compare the landless class and each higher class indicates that the differences are significant ($p < 0.05$). Given the absence of significant differences for fuelwood consumption for cooking, this result suggests that there may be significant variations in fuelwood consumption for *bathwater* heating. My personal impressions from visits to various households support such a conclusion.[25]

(iii) Interestingly enough, there appears to be a general effect of location on consumption levels too. For a sample of betta-holders with conventional stoves (to control for habits, availability and technology), reported domestic fuelwood consumption in the SM cluster was 520 dry kg/capita/year, while that in the other two clusters ranged between 820-920 dry kg/capita/year (the difference being significant at $p < 0.02$ in a parametric multiple-comparison test, viz., HSD for unequal N). Now, the climate is somewhat more damp in TK, but there is no difference between SM and MH. Access to commercial fuels is greater in SM because of its proximity to Sirsi town, but the few (< 15) households using such fuels were not included in this sample. Therefore, the only plausible variable that appears to correspond to this difference is the availability of treeland per capita.

3.3 Availability of substitutes

Use of agricultural waste as a substitute fuel was found to be clearly related to household categories. Landless, marginal or paddy-only cultivators use virtually none, and the medium and large (areca) cultivating households reported use of 200-300 dry kg/capita/year. This result is to be expected, because the main agricultural wastes that can be used as fuel are areca husks, areca sheaths (lower part of the frond), and coconut

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[25] Mishra *et al.* (1986) estimated the annual fuelwood consumption in landless and landed households in Bhairumbe village (which is neighbouring to the MH cluster) to be 0.4 t and 1.2 t respectively, possibly on the basis of a questionnaire survey. Similarly, Nadkarni *et al.* (1989, p.147) reported a difference in these values by a factor of 2 or more. While my values may appear to be much lower, it should be noted that Mishra *et al.*'s values are for total (domestic+agricultural) consumption, and Nadkarni *et al.*'s values appear to include agricultural waste, whereas my values are only for fuelwood. Furthermore, neither source reports confidence intervals. In my survey data, the typical standard deviation in the per capita total fuelwood consumption values calculated from the questionnaire responses is 400-600 kg/capita/yr. If similar variances exist in the survey data used by these authors, the differences between their results and mine would not be statistically significant.

husk, all of which are available only to orchard-owning households, underlining the disadvantages faced by the poorer sections of the population. Thus, the differences in *total* biomass fuel consumption across classes are higher than those apparent from the examination of fuelwood consumption alone in (b-ii) above.

3.4 Access to fuelwood-conserving technologies

Bio-gas is a popular "appropriate technology" promoted by rural development agencies for quite some time. This technology involves the fermentation of animal-dung in a closed chamber (digester) to produce methane, which is then burnt as a fuel, while the digested slurry forms manure. Bio-gas is considered highly resource-efficient since it uses elements of the dung that would otherwise be wasted, without reducing its value as manure (but see Kishore *et al.*, 1988).

Data from the questionnaire survey showed that users of bio-gas stop or reduce their consumption of fuelwood (see Table 5 in Chapter III). The question is: Do different household groups have different capacities to invest in and use bio-gas? Like all technologies, bio-gas comes with its own baggage of technical and social requirements. A bio-gas plant requires substantial investment in its construction, the digester drum (in the floating-chamber model that is popular in India), and accessories. The cost of a 300 cubic-foot bio-gas plant was around Rs.10,000-12,000 in 1990 (C. M. Shastri, CES, personal communication), which is at the higher end of the gross return from 1 ha of paddy land. Even after the 50% subsidy currently offered by the state government to select households (P. R. Bhat, CES, personal communication) the investment required is substantial. Moreover, to supply a family of four with its typical cooking fuel needs would require the supply of 40 kg (fresh weight) of dung every day (N. H. Ravindranath, CES, personal communication). Such dung supply requires maintaining a significant number of animals: CES's monitoring showed that the average dung obtained of a stall-fed animal was 6-9 kg/day (fresh weight). More important, stall-feeding of the animals is needed to ensure that all their dung is available. As will be shown later on, the number of animals owned and the extent of stall-feeding by a household depend upon its access to fodder and labour.

Table 3: Distribution of bio-gas technology across household categories

Class	Total # of Households	Households with Bio-gas
0	50	0
1	40	0
2	32	1
3	80	13
4	57	19
Total	259	33

Given these stringent socio-economic requirements, the observation that the spread of bio-gas technology in the Malnaad has been limited to the affluent cultivators would seem almost self-evident.[26] As Table 3 shows, this technology is inaccessible to the poorer sections of the rural populace. Nor does the use of bio-gas completely eliminate the consumption of fuelwood in the Malnaad. Users claimed that the bio-gas production was not sufficient to meet their cooking *and* bathwater heating needs, especially during the monsoon, when reduced solar insolation leads to lower temperatures in the digester and hence to less gas production.

[26] But the continued existence of this subsidy and the inclusion of bio-gas in all recent discussions of ways of reducing fuelwood pressures (e.g., KFD, 1990) indicates a need for restating the obvious, and raises the question whether eco-development programmes are being captured by the rural elite through their judicious use of the environmental ("save the forests") rhetoric.

They therefore have to use fuelwood for bathwater heating.

Another fuelwood-conserving technology that has received much attention in recent years is the improved wood-burning stove. Literally hundreds of designs of improved cookstoves are now available in India (Maniates, 1990). One design particularly popular in Karnataka state is the ASTRA-olé, developed by researchers at the Indian Institute of Science, Bangalore. The measurements in the Sirsimakki cluster indicated that this design yields savings of around 30%: average per capita fuelwood consumption for cooking was 1.0 dry kg/capita/day in households with the improved ASTRA-*olé* stoves as compared to 1.4 dry kg/capita/day in households with the traditional stove (the difference being significant at $p<0.001$ in a parametric t-test).[27] Similar improvements are also possible in the energy-efficiency of traditional bathwater-heating stoves (Hegde, 1986a). The initial cost of the cookstoves is quite low, especially when compared to bio-gas: an ASTRA-olé costs only about 75-100 Rs. (at 1990 prices), and the design also eliminates the health hazard from indoor wood smoke through its use of a chimney.[28] These stoves have therefore also been an integral component of many eco-development strategies for this and other regions (Gadgil, 1987b; KFD, 1990).

The low capital cost and limited baggage of behavioral changes can make at least some models of the improved cookstove much more socially appropriate than the bio-gas. Nevertheless, the acceptanace of the stove in the Malnaad has been limited. While the limited interest in changing cooking habits when fuelwood appears to be abundant is

[27] Virtually identical savings were reported from more extended field trials of the ASTRA-olé across several villages in the district (Hegde, 1986b).

[28] The improved bathwater stove is more expensive (500-600 Rs.).

probably the most important constraint to effective dissemination (C. M. Shastri, CES, personal communication), it has also been shown that the efficiency of the improved cookstove depends critically on the availability of appropriately-sized vessels with the household, which are often in short supply in the poorer households.

In short, the ability of a household to switch to the most fuelwood-conserving technology (bio-gas) is sharply limited by its access to productive land resources. Except for the poorest households, most households would be in a position to adopt the improved cookstove, though the improved bath-water stove (which is as important given the high use of hot water in the Malnaad), is much more expensive and therefore less accessible to landless, marginal and even small areca households.

3.5 Fuelwood use: summary

Household consumption of fuelwood is generally high relative to other regions, reflecting at least a perceived abundance. It is higher for households with more areca or sugarcane to process, and is somewhat sensitive to differences in social availability across classes and locations. It can be substituted for with agricultural wastes by those households with areca lands, and with bio-gas by the richer of these households. It can also be reduced by virtually all households by adopting improved cookstoves. Further reductions through improved bathstoves are possible, and perhaps necessary, only for the well-off households. Thus, the pressures on, and the availability of, the fuelwood resource are not evenly distributed across households. The land-owning classes have a distinct propensity to consume more than the landless, but also the ability to alleviate some of this pressure if felt necessary by them.

4. Use of leafy mulch and manure

Leafy matter is used for animal bedding, manure and mulch. It is harvested by lopping and is gathered as litter. Specific results on the implications for future leaf production, of amount of lopping, lopping frequency, choice of trees to lop, etc., are not available at this stage. But the soil nutrient data did suggest the possiblity of phosphorous and organic matter depletion at the high end of current extraction rates. It would be therefore useful to examine whether the quantity of extraction relates to household characteristics. Given the purposes for which leafy matter is used, one would hypothesize that areca area and availability of tree land and its quality, would primarily influence the extraction levels of leafy matter for mulch and manure, with the latter also being influenced by animal holding, since it is usually used as animal bedding prior to dumping in the manure pot.

As in the case of fuelwood use, data on quantity of extraction came from two sources: questionnaire survey and monitoring. Complete round-the-year monitoring of leafy matter extraction could be carried out in six locations.[29] These data show a strong linear relationship between lopped leaf mulch and areca holding, and a weaker one for leaflitter used as mulch. But the sample size is not large enough to understand the effect of household characteristics. Data obtained in the questionnaire survey did not match well with monitored values of leafy matter use. Errors of ±50% were common. Questionnaire values also showed large changes in resurveys. The size and dry matter content of the units in which households report consumption, i.e., headloads or

[29] These data were gathered as part of the monitoring of *soppinabetta* extraction, from which data on woody biomass extraction were presented in Chapter III.

"back"loads, varies dramatically due to large variations in the moisture content and type of the green leafy matter. Thus, a regression analysis with the quantitative data was not considered meaningful.

One qualitative feature of mulch use is, however, worth noting as it suggests the effect of availability on use. Some households reported using grass instead of leaflitter as mulch in their areca orchards. The fraction of areca-cultivating households reporting such use was found to be much higher in the Sirsimakki cluster than in the other two: 79% as against 11% and 9% in the Tattikai and Malenalli clusters respectively. Given the significantly lower extent of treeland per unit area of areca in this cluster than in the others (see Table 1), it seems reasonable to interpret this diversion of grass from fodder to mulch as an adaptation to conditions of scarce tree leaf resources. This would seem to be supported by the results of the woody biomass balance presented in Chapter III, which suggested that the balance may be most precarious for the Sirsimakki cluster. Thus, mulch demand is susceptible to modifications in light of availability; as to whether the modifications have come early enough to prevent rapid resource degradation cannot be answered with the data we have.

5. Livestock management

Livestock have historically been an integral part of the rural economy of the Malnaad, representing one of the many forms in which the symbolic agro-pastoral equations have been played out across the Indian landscape (George, 1985). Just as in the case of uncultivated biomass inputs to agriculture, peoples's use of livestock varies depending upon which social category they belong to. Areca cultivators have traditionally maintained livestock for *dung* and *milk* production. Paddy cultivators are more interested in dung and *draught power* for ploughing. Some communities (such as the Gowlis of northern Uttara Kannada) have specialized in milk production. The common feature across all the uses is the dependence of households on uncultivated lands for fodder for the animals, most of it obtained by directly grazing the animals on the land.

We saw in Chapter V that the consequences of this grazing pressure on the productivity and sustainability of tree and grass biomass resources in the Malnaad may not be universally drastic or even unidirectional. One would need detailed information on the magnitude, location and timing of grazing and the ability to relate it to the productive ecology of the grass and tree lands to arrive at clear understanding of these consequences. Given the constraints of practical research, I assume that the consequences are substantially captured by three variables: (a) the number of animals, (b) the fraction of time they are fed in their stalls (as against being openly grazed), and (c) the area of grass and treeland accessible to the household for grazing them.[30]

I then hypothesize that these aspects of the livestock management system are related to household characteristics of population size, cultivated land assets, and access to uncultivated lands. The relationship is complex. The household's population can create demand for milk as well as supply labour for livestock management. Agricultural land can similarly create demand for animal outputs (as in areca), or supply animal input (as

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[30] Other plausible variables would include composition of livestock (intensive vs. extensive feeders), area structure, specific timing of grazing, presence or absence of a cowherd, and timings and extent of fencing of grassland. All livestock in the villages except those held by one household, consisted only of cows or buffaloes, i.e., extensive feeders. Data on some of the other variables were gathered but were found to be either unreliable upon cross-checks, or incomplete, or difficult to use in a regression analysis. Their likely effects are discussed later.

in grassland) or do both (as in paddy). The household's economic condition (tied inextricably to cultivated land assets) determines its ability to hire labour and/or purchase fodder for the livestock. Household holding of uncultivated lands would indicate the supply of guaranteed fodder/grazing, while some idea of the variation in the availability of open-access land would be provided by location. I present and interpret the results of a multiple regression analysis for herd size and stall-fed fraction. The issue of grazing land availability will then be discussed more qualitatively.

5.1 Animal holdings

The results of the multiple-regression analysis for livestock holding are presented in Table 4. The strong correlation of total herd size with areca holding, which is a major consumer of manure but not a significant source of fodder, suggests that it is the *demand for dung* that primarily drives livestock holding in areca cultivators. Alternatively, it can be argued that since betta area owned is very much in proportion to areca area, the correlation with areca area is actually the fodder/browse supply effect of betta land. The high degree of collinearity between areca and betta holding forced me to drop betta holding from the list of independent variables for the step-wise regression. However, additional regressions with a sub-sample of households with neither paddy nor private grassland, but variable NPVTGRAS and betta:areca ratios indicated no relationship with these last two variables after controlling for areca area. This suggests that it is the demand from areca for manure, not the availability of fodder from areca via betta allocations, that primarily determines herd sizes.

The second regression suggests that paddy area is the strongest determinant of number of male animals. This would follow from the tendency to keep male animals for ploughing[31], which is required only for paddy cultivation. Upon regressing only the number of female animals with the same variables, the results were essentially similar to those with total animals, suggesting that paddy land relates to herd size not just through its demand for male animals but also through its supply of fodder in the form of paddy straw.

Table 4: Results of step-wise linear regression of livestock holding (total and male) against household land resources

Dependent variable	Independent variable§	ß*	Partial Corr. Coeff.	p-level	R^2, variables out**, & N†
Total number of animals owned by household	ARECA	0.41	0.44	0.000	0.59, PVTGRAS & CLUSTER, 251
	PADDY	0.38	0.46	0.000	
	HHSIZE	0.17	0.21	0.001	
	NPVTGRAS	0.13	0.18	0.009	
Number of male animals owned by household	PADDY	0.55	0.60	0.000	0.43, PVTGRAS & CLUSTER, 251
	NPVTGRAS	0.13	0.15	0.066	
	ARECA	0.11	0.12	0.016	
	HHSIZE	0.09	0.10	0.125	

§ : HHSIZE = household size, NPVTGRAS = grassland area under household's control that is in forest land, i.e., betta, MF or RF land. The TREELAND variable was dropped, because of its strong correlations with areca.
* : ß are the standardized partial regression coefficients.
** : Independent variable that did not enter in the forward step-wise regression at an F-to-enter cut off of 1.0.
† : Eight households were dropped due to missing or discrepant data.

If areca-cultivating and only-paddy-cultivating households are analyzed separately, the importance of the variables changes as follows. For areca cultivators, household size

[31] Bullock cart use for transport has diminished with the rapid expansion of bus facilities.

is more significant ($\beta=0.17$, $p<0.03$), followed by paddy ($\beta=0.15, p<0.06$) and privately owned grassland ($\beta=.15$, $p<0.08$). This change may be explained in terms of the areca cultivators' greater interest in livestock for household milk consumption than in draught power, and their control of almost all the private grassland. For the paddy cultivators, the significant variables are paddy area ($\beta=0.44$, $p<0.001$), grassland controlled in "public" forest lands ($\beta=0.30$, $p<0.003$), village cluster ($\beta=0.19$, $p<0.015$) and household size ($\beta=0.13$, $p<0.12$), corresponding to their having neither areca lands nor almost any private grasslands. The variation across clusters corresponds to the variation in the dominance of the two household categories, and the presence or absence of the corresponding land types.

Livestock ownership thus appears to be driven primarily by agricultural landholding[32]. But this does not mean that landless households never maintain animals at all. Four out of fifteen landless households in the TK cluster, and eight of twenty-four landless households in the MH cluster kept some animals, typically one to three. But none of the twelve landless households in SM cluster had any livestock. The likely explanation for this difference is the scarcity of open-access lands in the SM cluster, making it difficult for the landless to graze animals anywhere. In the other clusters, all of the landless and marginal farmers who maintained livestock sold the manure to

[32] Does the correlation of livestock ownership with cultivated land indicate that agricultural assets create a demand for livestock inputs? Or are both variables driven by some other factor? For instance, it could be argued that livestock are independent productive assets and households with high disposable income from their areca lands invest it in livestock assets. The income from livestock could be of three kinds: from sale of dung manure, sale of milk, and sale of the animal itself. Survey data indicated that dung manure is sold only by the landless households. Discussions with villagers and observations suggest that many households are gradually moving into milk production as a commercial enterprise, with the active support of the Karnataka Milk Federation and other state agencies. However, the strategy they adopt - a few cross-breed cows, stall-feeding, artificial insemination, and many purchased feed inputs - does not lead to the increase in livestock numbers or in grazing pressure; it likely externalizes the pressure onto the dryer regions that provide the feed inputs.

neighbouring arecanut cultivators, while only a few of them obtained milk from the animals. The income obtained from sale of dung varied between Rs 125-450, compared to a typical cash income of Rs 360 from 30 days of unskilled male agricultural labour. Thus, when public grazing lands are available, livestock are a significant source of supplementary income to the poorest sections of the society;[33] however, they essentially provide another means of exporting organic matter and nutrients from public forest lands to the agricultural lands of the richer sections.

5.2 Stall-feeding requirements: fodder and labour

If all the animals of a household were always kept in the stalls and fed by hand, the presence of livestock would likely have little negative impact on tree regeneration, grass growth and soil conditions that affect resource sustainability. This has largely been the argument behind the idea of promoting stall-feeding as a part of eco-development in the Malnaad and elsewhere (see, e.g., Singh, 198?). What conditions enable or limit a household's desire and ability to stall-feed its animals is the question I shall explore here.

Livestock owners express the need for stall-feeding to avoid the negative effects of searching for browse in the dry season on cattle productivity, the trouble involved in rounding up the free grazing animals, and the loss of dung manure resulting from free

[33] In passing, it is worth noting that the male fraction in the total livestock population ranged between 0.21 (large farmers) to 0.50 (only paddy cultivators), with an average of 0.34. This suggests that households manipulate the sex ratio of their herds. While the manner in which this is done is not clear and not openly discussed, a combination of differential nutrition and indirect sale to butchers are likely to be the methods used to reduce the excess male animal population (as is particularly likely in the case of households without cropland). This phenomenon would appear to negate the commonly held view that "the Hindu taboo against killing cows is responsible for the exploding population of livestock in India" (see also George, 1985, p.30 for a critique of this view).

grazing.[34] I hypothesized that the key factors determining stall-feeding/grazing regimes are the availability of (a) fodder and (b) household labour. The strongly seasonal climate of the Malnaad places important constraints on the availability of fodder. While green grass is available during the monsoon, little growth can take place during the dry season unless there is irrigation. The traditional livestock management system therefore consists of different degrees of free grazing during the monsoon, and feeding of stored fodder to the extent possible during the dry season. The stored fodder is a combination of *karada* (dry grass) harvested from protected grasslands and/or *soppinabetta* lands in November-December, paddy straw from the monsoon crop and wastes from the dry season crop, whichever are available. In the absence or inadequacy of fodder-yielding land resources (or water to cultivate them with), the household is forced to either purchase these inputs or take/let the animals out into public forest lands in search of grass or browse. Clearly then, the propensity of a household to stall-feed its animals should be correlated with its access to and control over harvestable fodder resources, either in the form of land or in the form of cash income that enables them to purchase the fodder and feed. The advent of modern irrigation technology adds another dimension, viz., the household's ability to invest in irrigation pumpsets.

The extent of stall-feeding was assessed in terms of the ratio of animal-months of grazing to total animal-months in a year. Average "stallfed fraction" calculated in this manner ranged from 11 % in the case of marginal farmers to 57 % in the case of big

[34] Stall-fed fraction comes in as the next significant variable after number of animals in a multiple regression of amount of manure obtained by a household from its manure pit for two of the three clusters (partial correlation coefficients = 0.41 for TK and 0.36 for MH at p-levels <0.01).

farmers, suggesting a distinct effect of socio-economic condition.[35] More detailed regression analysis indicated that the stall-fed fraction depended upon animal type (cross-breeds or buffaloes being more likely to be stall-fed), and, after controlling for animal type by looking at partial correlations, on the endowment of privately-owned grassland and paddy land per animal. This is an interesting result. It suggests that having grassland does not mean that the household necessarily grazes the animal on that land, but that, having a secure source of fodder for the dry season, the household may be able to shift to a more stall-fed regime.

In conjunction with assured fodder resources, stall-feeding requires human labour to replace the work of foraging earlier performed by the animal itself. This requirement appears to be a significant constraint on the household's ability to stall feed. Labour would also be required for cultivating fodder-yielding paddy and other crops, but this did not appear to be a major constraint. The largely rain-fed paddy cultivation was constrained by water availability. Some idea of the former labour requirement was obtained from the survey data gathered on allocation of household labour-time for different activities, which indicated that green fodder procurement during the wet season took anywhere between 20 minutes and 1.5 hours of one person's labour-time to gather

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[35] The average for landless households was a surprisingly high 40%. This was due to the fact that a number of households in Golikoppa had received cross-breed animals as a part of the national Integrated Rural Development Programme (IRDP). They found that these cross-breed animals are not able to tolerate the heat of the dry season or moist conditions of the wet season very well. So the households claimed to be stall-feeding them all year round. In order to do so, they had to purchase significant amounts of paddy straw and green fodder. They claimed, and showed in calculation, that the expense of fodder could be just about met from the income through the sale of the manure (which would be higher due to the stallfeeding), and this left them with a net benefit in the form of the milk the animals provided. When asked what they would do after the animals went dry, the households generally responded that they would revert to their earlier practice of maintaining indigenous breeds with free grazing. When asked how they would repay the IRDP loan, they said it was impossible to do so, and that they would likely default on the repayment. Thus, what superficially appears to be successful reduction in the free grazing pressure of animals, does not appear to be a viable programme in the long-term.

a head load (20-35 kg) of green grass. During the detailed monitoring of livestock management carried out by CES (seven households, four times a year, two days each time, during 1987-88: Sadanand Hegde, CES, unpublished data), it was observed that typically 45 minutes of an adult's time were required to collect and bring 20 kg of green grass from the edges of the fields, and this provided partial feed for about 3 adult animals.

This labour requirement places important limitations on the ability of the households to stall-feed. One may therefore hypothesize that households that are in an economic position to hire labour are more likely to stall-feed their animals. Indeed, the survey indicated that 15-30% of all households in the clusters used hired labour for stall-feeding and other work related to their livestock, and most of these were from the large farmer class (i.e., with areca orchard holdings of more than 0.8 ha or 2 acres for an average-sized household). In particular, 80% of the households that had adopted the modern "package" of bio-gas plants and fully stall-fed cross-breed cattle for dairying were found to be hiring one or even two labourers to fulfill the labour requirements of this package.

Simultaneously, land-owning households that do not hire any labour for livestock management, viz., the only-paddy cultivators, are likely to stall-feed if they have adequate household labour. The stall-fed fraction related most strongly to household size ($\beta=0.60$, $p<0.02$). In the interviews too, many small households expressed the inability to stall-feed their animals as they could not spare the time to gather the grass. Others who happened to work for land-owners with substantial grassland, indicated that they sometimes purchased (from their wages) the fodder that they could quickly gather in or near the field that they would be working in anyway. Clearly, the labour requirement is highly sensitive to the access to and control over fodder resources: if the green grass has to be competed for in the open lands, the time spent collecting it is likely to be much higher.

Table 5. Average animal ownership, grazing level, and fodder & grazing land per animal

Class	# of Households	Total herd size	Male animals	Stall-Fed Fraction	Grazing Level [animal-months]	Paddy land per animal [ha]	Pvt. Grass land per animal [ha]	NPvt. Grass land per animal [ha]	Grazing land per animal [ha]
0	9	3.6	0.9	0.40	24	0.00	0.00	0.00	0.00
1	25	4.4	2.3	0.11	44	0.12	0.00	0.02	0.07
2	18	9.4	4.1	0.16	89	0.10	0.01	0.04	0.08
3	72	7.0	1.9	0.51	40	0.10	0.05	0.19	0.51
4	51	9.9	2.4	0.57	55	0.05	0.05	0.20	0.68
All	175	7.5	2.3	0.43	49	0.08	0.04	0.14	0.43

Notes:
1. The number of households above is much lower than the total number of 259, because the above sample corresponds to those households with *non-zero* livestock holding and for which full data on grazing practices were available.
2. Grazing land is the area of forest land (betta/MF/RF) controlled exclusively by the household that is not primarily maintained as grassland. Thus, area of open grazing in MF/RF is not included.

The "grazing level", i.e., the net combination of the number of animals owned and the stall-feeding regime adopted, expressed in animal-months of grazing, showed essentially no relationship with economic status (see Table 5), while being negatively related to the fraction of cross-breeds and buffaloes in the herd ($\beta = -0.28$ and -0.14, $p < 0.001$ and < 0.09 respectively). Therefore, although the number of animals owned increases with economic class, its effect on grazing pressure appears to be canceled out by a corresponding increase in stall-feeding.

5.3 Availability of grazing land and fodder

The grazing pressure exerted by a herd of animals should, as a first approximation, be inversely proportional to the area available for grazing per animal. As in the case of tree biomass extraction, the area on which the extraction pressure is exerted is easier to define or at least delimit for the betta-holders than for the other households. As Table 5 shows, the per-animal treeland and grassland in bettas (classes 3 and 4) is quite significant in an absolute sense.[36] The area of grazing land accessible to the non-betta households is difficult to determine, but the total forest area accessible to these households is often much lower than that available to the betta-holders. Given the lower livestock holdings of the former, one may assume that the per animal availability is at best similar to that of the large betta-holders, but more often much lower.

Although stall-feeding and grazing have been characterized so far as almost mutually exclusive activities, they are in fact often practiced simultaneously. Animals are fed some fodder or feed in the morning, and then let out to graze during the day. The intensity with which the animal grazes when let out will therefore also depend upon how well-fed its condition is. The ability to supply such fodder will depend partly on the household's access to fodder-producing lands, and partly on the household's ability to purchase additional fodder and feed. The former differs significantly across household categories; while paddy land per animal is similar across most categories except the

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[36] Very approximately, half a hectare of grassland can yield between 1.5 to 3 dry tonnes of grass biomass in a year, which would provide 4-8 kg of dry biomass per day which, might account for 30-60% of an adult animals requirement.

landless, the availability of private grassland (which is usually protected for fodder production) sharply favours the better-off categories (see Table 5). The latter is found to be strongly related to the economic condition of the household in the case of paddy straw and feed purchases, while being modified by other land assets (Table 6).

Table 6: Results of step-wise linear regression of fodder and feed purchases against household productive assets

Dependent variable	Independent variable§	ß*	Std. Error of ß	p-level	Multiple-r², variables out**, & N†
Annual paddy straw purchase	ARECA	+0.70	0.08	0.000	0.51, HHSIZE & CLUSTER, 134
	PADDY	-0.38	0.08	0.000	
	PVT_GRAS	-0.26	0.08	0.001	
	ANIMALS	+0.29	0.09	0.003	
	NPVTGRAS	-0.19	0.07	0.01	
Unweighted sum of annual purchases of feeds and concentrates	ARECA	+0.54	0.07	0.000	0.47, HHSIZE & CLUSTER, 217
	ANIMALS	+0.34	0.07	0.000	
	NPVTGRAS	-0.20	0.06	0.001	
	PADDY	-0.06	0.06	0.30	
	PVT_GRAS	-0.06	0.06	0.30	
Annual dry grass purchase: No variable entered the regression at F-to-enter = 1.0.					

§ : HHSIZE = household size, NPVTGRAS = grassland area under household's control that is in forest land, i.e., betta, MF or RF land.

* : ß are the standardized partial regression coefficients.

** : Independent variable that did not enter in the forward step-wise regression at an F-to-enter cut off of 1.0.

† : Number of households is smaller for paddy straw because the data on purchase were not separable from data on own straw production in one cluster.

Finally, the effect of the institutional regime associated with the different grazing lands needs to be considered. Betta-holders are able to trench and fence off their lands to exclude other animals, and are also able to erect fences within these lands to cultivate fodder. Households, that must depend upon MF lands are rarely able to enforce any form of exclusion or control unless they essentially "encroach" onto such land and establish joint or individual control. Even in these cases, the control can be challenged by others and is often a source of conflict. In the case of RF lands, the household faces the additional hazard of harassment from forest guards. Moreover, the high canopy cover in many RF lands results in poor grass growth.

5.4 Livestock: summary

Livestock are traditionally linked to agricultural land resources in a partly symbiotic relationship. But the gap between the supply of fodder from and demand of animal products/services for agriculture is particularly wide in the Malnaad due to less crop land and more orchard land. This gap is filled largely by fodder from uncultivated (mostly forest) lands. Household herd sizes appear to be largely driven by the demand for manure in agriculture, but are limited by the availability of own or purchased fodder. The extent to which the livestock are stall-fed is also determined by the household's access to controlled fodder resources, and to own or hired labour. Finally, the impact of grazing depends upon the area of grazing land available and the extent of managerial control the household can exert upon it.

The net result is quite mixed: Areca cultivators are generally in a position to manage larger herds more productively and with lesser impact on grassland and tree regeneration because they have access to more and better grazing lands, and have full control over them. They are also in a position to supplement or substitute for grazing with purchased or own fodder. Paddy-only cultivators own significant livestock but have little control over grazing lands, which prompts them to encroach so-called forest lands and convert them into grasslands wherever possible. Landless or marginal households attempt to take advantage of the only land to which they have access, viz., MF/RF land, in the only way they can, viz., through utilization for grazing. They are, however, hampered by the limited labour-time they can spare, and the absence of some fodder source like paddy to tide them through the summer. If the impact of grazing on tree regeneration and grassland productivity were linearly related to the animal-months of free grazing,[37] it might be reasonable to suggest that the paddy-only cultivators have a somewhat higher impact than other groups, as a result of their lop-sided resource situation.

Discussions with livestock-owners about traditional "ideal" grazing practices indicated that, given the resources, their preferred grazing/feeding regime might be the following: Graze the animals lightly in grasslands during the first couple of months of the monsoon, then graze them under the tree canopy till the end of the growing season, moving them onto the stubble grass in early winter, followed by light grazing on paddy field stubble and stream beds in the dry season. Simultaneously, they would feed them with green grass and paddy straw in the wet season, and dry grass, paddy straw and other agricultural wastes in the dry season. The clipping studies have shown that light early grazing is not likely to have a negative effect on grassland productivity. I would also hypothesize, based upon my impressions, that grazing under the tree canopy during

[37] Two alternate models are possible. Firstly, the effects may be non-linear (but monotonic), with an animal-month of grazing during the monsoon having lesser effect on tree regeneration than an animal-month during the dry season, when the animals are more likely to browse on tree seedlings. Weighting the wet and dry season grazing differently did not, however, change the above results significantly. The second possibility is that the effects may be non-monotonic, since the grass clipping experiments show stimulation of grass production by grazing early in the growing season, but reduction if grazed later. More research on the relationship between grazing locations, intensities, and effects will be needed to answer the question.

the wet season is unlikely to have a major negative effect on tree regeneration because the presence of green grass entices animals away from browsing on tree seedlings.

The traditional idealized system of grazing management may indeed be quite sustainable. However, substantial deviations from this system occur. On the basis of the results presented above, they appear to be mostly related to the lack of access to the different complementary resources that the system requires.

6. Trees versus grass: The endogenous logic of land use in uncultivated lands

In analyzing the relationship between biomass resource use and household land assets and access, the absolute and relative distribution of tree and grass land across households was taken as given, as independent variables determining resource availability and influencing resource management. One may ask, however, whether manipulating the ratio between tree and grass vegetation might not itself be a part of the household's resource management strategy?[38] Indeed, discussions with cultivators continually hinted at this possibility. During discussions about the condition of their *soppinabettas*, many areca cultivators indicated that they had converted some part of their legally designated *betta* land to *bena* (grassland), as they needed fodder for their livestock.[39]

The general logic may be spelt out as follows: Households need both tree and

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[38] One could raise the same possibility in the context of other household variables. For instance, instead of taking the endowments of cultivated lands as given, one could think of crop choice and even extent of cultivated land assets as the outcome of household livelihood strategies. However, as pointed out at the beginning of this chapter, these decisions are likely to be more influenced by exogenous variables such as market prices than endogenous ones, and these dynamics (arguably slower in the Malnaad region, particularly in the traditionally areca-cultivating villages, than in frontier forest settlements) are outside the scope of this dissertation.

[39] They would often be defensive about this, probably because, as one of them told me, they believed that we "environmentalists" frowned upon any "deforestation".

grass biomass as inputs to their domestic, livestock and agricultural sectors. They would prefer to obtain most of the biomass from the lands they control. But there is a clear tradeoff between the production of these two biomass types (as seen in Chapter V). Therefore the household would try to manipulate their distribution to best fit their needs and endowments. Moreover, the *soppinabetta* privileges allow considerable *de jure* latitude in the distribution of vegetation types in betta lands[40]; the *de facto* latitude is even greater, and extends to MF lands.

If this general logic is valid, and in view of the uses to which the different biomass types may be put by an areca-cultivating household, one could hypothesize that the area of grass land in the total betta land held by the household would be

(a) both positively and negatively related to the household's areca holding, because areca requires both leafy matter for manure/mulch and fodder-based dung for manure,

(b) more positively than negatively related to household size, since the household directly needs fuelwood but indirectly also needs grass for milk-producing livestock, and,

(c) negatively related to the household's endowment of alternative fodder resources, viz., paddy land and private grassland, and to the household's ability to purchase fodder substitutes.

A less complicated logic could be outlined for paddy-only cultivators, but their lack of control on most of the MF/RF vegetation they use makes it unlikely that the

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[40] The legal barriers to modification of vegetation in the bettas are quite limited. The Kanara Forest Privileges, which govern the use of the bettas, only stipulate that the density of trees should be greater than 100 per hectare. They do not even stipulate the minimum size for all the trees, only that "at least 50 trees .... of the reserved kind of not less than 30 to 45 centimetres diameter at breast height should be maintained evenly spaced in the Betta area" (KFD, 1976, para.131(F)(xi-c)). Moreover, even this stipulation has apparently never been implemented in practice, not least because of the split responsibility for the bettas between the Forest Department and the Revenue Department.

hypotheses can be meaningfully tested for such households.[41] I therefore tested the above hypotheses only for betta-holder households, using step-wise linear regression with the household data, supplemented by an examination of aggregate village-level data.

6.1 Grasslands in bettas: Trends at the household-level

The variables and variable codes used in the regression analysis are as follows:

Dependent variable : grassy[42] area in *soppinabetta* or MF/RF under the household's control (NONPVTGR);

Independent variables : total areca holding (ARECATOT), total paddy holding (PADDYTOT), private grassland, usually in dry land (PVT_GRAS), number of individuals in household (HH_SIZE), total livestock (TOTANIMALS), and ratio of total betta land to total areca land (B_ARATIO).

B_ARATIO was used instead of betta land under trees (TREELAND) because the latter was highly correlated with ARECATOT. Private grasslands (which are in dry lands) were included as an independent variable rather than a dependent variable, because they are almost never under tree vegetation. Livestock holding was not included as an independent variable because it was strongly related to household land assets. The results presented are robust to the inclusion of the herd size variable. Purchases of fodder were not included as independent variables because they are significantly correlated with land

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[41] In any case, MF/RF lands constitute a small fraction of the uncultivated lands in six of the seven villages for which full land-use information was available (see Table 1).

[42] As mentioned earlier, "grassy" area is defined as the area of "pure" grassland plus treeland with tree density < 100 trees/ha and having grass growth.

assets. Households owning bio-gas are likely to have different preferences, since they need less fuelwood and possibly more grass for their livestock; such households were therefore excluded from the analysis unless otherwise mentioned. The analysis was conducted initially with households from all clusters pooled together, and then for each cluster separately, rather than using location as a dummy variable, because the effect of location on the distribution of paddy and dry lands was not systematic.

The results obtained when all areca-cultivating households were pooled together, and for each cluster separately are summarized in Table 7. In all cases, the values of the partial correlation coefficients were very close to the ß values, and hence have been omitted from the table.

It appears that area of grassy land in bettas does correlate negatively with area of private grassland owned after areca area is controlled for, in the pooled sample and in the Tattikai cluster. In the Sirsimakki cluster, paddy landholding replaces private grassland as the significant variable, while neither paddy land nor grassland account for any variation in the grassy betta area of the households in the Malenalli cluster. The consistently significant correlation with total areca holding is to be expected, since size of betta-holding generally increases in direct proportion to areca-holding. Even if grasslands were randomly distributed across bettas, those with more areca land (and therefore more betta land) would naturally own more absolute grassy betta area. What is interesting is that paddy or private grassland area do come out to be highly significant in two clusters *even after controlling for areca area.*

Further, in a subset of households in the Tattikai cluster that did have significant paddy holdings (i.e., those in the villages of Tattikai, Bilekal, Baddemane or Kelagina

Table 7 Results of step-wise linear regression of grass vegetation in betta land controlled by household (NPVTGRAS) against household assets (F-to-enter = 1.0).

Cluster	Significant independent variable	Beta	Std. Error of Beta	p-level	Multiple r^2	N
ALL CLUSTERS	PVT_GRAS	-0.27	0.08	<0.001	0.11	146
	ARECATOT	+0.26	0.08	<0.001		
TK	ARECATOT	+0.46	0.13	<0.001	0.23	52*
	PVT_GRAS	-0.27	0.13	<0.04		
SM	ARECATOT	+0.41	0.15	<0.008	0.23	45**
	PADDYTOT	-0.46	0.15	<0.004		
MH	ARECATOT	+0.60	0.30	<0.07	0.31	17+
	PADDYTOT	+0.21	0.24	<0.40		
	PVT_GRAS	-0.24	0.30	<0.40		

* : Includes all households. If households in Melina Sarakuli hamlet, where the betta area is owned communally and is not demarcated properly, are excluded, or if bio-gas owning households are excluded, r^2 improves to ~0.3.

**: Excludes 22 households that either hold areca and betta land outside the village cluster (because the vegetation condition of the betta land could not be verified) or own bio-gas.

+ : Excludes 15 households with bio-gas, but includes households with land outside village cluster, because none of this was areca/betta land, and much of it was verifiable since it was in the neighbouring Belale village. Inclusion of bio-gas owning households results in no variable entering the regression.

Sarakuli), PADDYTOT was found to replace PVT_GRAS as the second significant variable after ARECATOT. Conversely, a subset from the same cluster that consisted of households owning little paddy cultivation (hamlets Keregadde and Bitgod) indicated a stronger correlation between NONPVTGR and PVT_GRAS (partial correlation coefficient of -0.69, $p<0.02$). In the Malenalli cluster, the absence of any significance of PVT_GRAS after controlling for ARECATOT is explained by the significant correlation ($r=0.5$) between PVT_GRAS and ARECATOT.

The low values of the multiple-r^2 need some explanation. Much of the scatter is likely to be a consequence of the large uncertainties in farmers' area estimates and in their notion of what constitutes "grassy" land. Village-level totals from questionnaire data were found to be within +/- 20% of those obtained from the mapping, but individual errors could be much higher. Significant scatter is also inherent to the problem, since there are so many other fairly random factors that affect betta condition. These factors include eco-climatic factors such as soil, locational variables such as distance of betta from household, etc. And some of the grassy areas may indeed represent a process of degradation from treeland to barren land.

The higher β value for private grassland as compared to paddy land when both are present (as in the TK cluster) may be understood as follows. Firstly, paddy straw is not as nutritious a source of fodder as fresh grass or even dry grass (Narayanan and Dabadghao, 1972, pp.280-281). Secondly, during paddy cultivation, no fodder is available from that land (although some is available from the edges of the fields), whereas grasslands can be partially grazed during the growing season. Thirdly, paddy cultivation creates its own demand for draught power, and hence for fodder for the draught animals (as long as tractors are not used, which is generally the case in the villages). It is therefore less effective in reducing the pressure on betta lands for fodder. This might also explain the positive correlation of grassland in bettas with paddy lands seen in the case of the MH cluster (Golikoppa and Arasapura villages).

It is useful to consider the obvious alternative explanation for the presence of grassy patches in betta lands, viz., that these patches represent degraded forest, not a conscious change in land-use. If so, one would expect the extent of degradation to correlate with the variables representing the extent of pressure, viz., betta land per capita (since fuelwood and timber use is likely to increase in proportion to the population), or betta land per unit of areca. This was not found to be the case; average betta per capita values are not lower for the SM cluster than elsewhere (see Table 1). Also, observation indicates that many of these grassy patches in betta lands are regularly fenced during the monsoon season, indicating the active interest in promoting grass growth.

Table 8: Village-level aggregates of betta condition and uncultivated land endowments.

Village (Cluster)	Barren Fraction in Betta	Grassy Fraction in Betta	Treeland Fraction in Betta	Ratio of Official Betta to "Orchard" land	Actual uncultivated Betta/ Actual areca	Actual treeland/ Actual areca	Private Grassland / Actual Areca (*)	Paddy/ Actual Areca (*)
Mundagesara (SM)	16%	30%	51%	8.26	7.7	4.0	0.0	0.2 (0.6)
Sirsimakki (SM)	7%	30%	60%	6.32**	6.0	3.6	0.0	0.4
K.Sarakuli (TK)	0%	16%	79%	7.82	7.7	6.1	0.2	0.6
Tattikai (TK)	3%	18%	78%	7.00	6.7	5.3	0.3	0.1
Keregadde (TK)+	NA	9%	91%	7.06	7.3	6.7	0.8	0.5
Golikoppa (MH)	1%	9%	88%	7.17	5.6	5.0	0.2 (0.3)	0.3 (1.4)
Arasapura (MH)	6%	7%	86%	7.43	6.9	5.9	1.3 (1.7)	1.5 (1.8)

* : Figures in parentheses indicate the ratios if grass/paddy land owned by the areca cultivating household in neighbouring villages is included. E.g., paddy lands of many household in Golikoppa lie within the boundary of neighbouring Belale village.

+ : Values for Keregadde village exclude land in Melina Sarakuli hamlet because the exact area of betta land used by the households there is not known, although it is likely to be less than 20% of the total area in the TK cluster. Barren land fraction is not calculated because only part of Keregadde revenue village has been included in this sample.

**: Low value of betta/areca ratio for SM village may be due to certain betta areas being missed in the mapping.

6.2 Grasslands in bettas: Aggregate variations across village-clusters

The village-level aggregate information was compiled on the basis of village land records and mapping (see Appendix D). The results are summarized in Table 8 in the form of the fractions of betta land under grassy and barren condition, and ratios of betta, paddy and private grassland to areca land in these villages. The fraction of tree savannahs (land with tree density < 100/hectare) and "pure" grasslands in betta lands appears to be higher in the SM cluster than the other two. One notices a distinct decrease in the grassy land (~30% to 7%) and almost corresponding increases in the paddy/areca or private grassland/areca ratios across the village clusters, particularly if one includes lands held in neighbouring villages. These variations in the endowments of land resources fit the hypotheses that private grassland and paddy land endowments can reduce the need to convert the vegetation in betta land from trees to grass. Note how areca cultivators in the SM cluster have little paddy land and no private grassland, while those in the TK cluster often have a significant amounts of both, and those in the MH cluster appear to have substantial amounts of both (Arasapura) or at least paddy (Golikoppa).[43] Not surprisingly, therefore, it is only in TK that both private grassland and paddy land endowment appeared as significant explanatory variables in the regression analysis, and only paddy land holding was significant in SM.

[43] Golikoppa shows a low ratio of private grassland to areca land because more than half of the private dry land has been converted into coconut or other orchards. In fact, coconut orchards often have exotic grasses cultivated in the area between the palms using the irrigation water provided for coconut. To the extent that this is so, the orchards would continue to be a source of fodder, and hence should be included in the area of private grassland.

6.3 Trees versus grass: Summary

I hypothesized that areca cultivators would modify betta vegetation to suit their needs of tree and grass biomass. I also assumed that households would choose to produce some biomass from their own lands before they purchase it in the market or obtain it from MF/RF lands. I therefore hypothesized that households with relatively lower endowments of paddy lands or private grasslands would end up with higher areas of grasslands in their *soppinabettas*. The empirical evidence appears to confirm the essence of the proposition. My model is of course limited by assumptions of linear relationships between variables (e.g., the relationships between tree density, tree production and grass production). It is also limited to the extent that the distribution of tree and grass vegetation changes slowly, and so is likely to lag behind changes in cropping patterns initiated by the household.[44] Nevertheless, its fit with the available data indicates that the mosaic of vegetation types observed in village forest lands may relate at least partly to long-term purposeful manipulations of the "uncultivated" vegetation by village households to suit their individual needs and abilities.

[44] These changes are, however, small in comparison with the total cultivated area. Net additions to cropped area in these villages occurred through the expansion of areca into betta lands along the edges of the areca orchards or through the conversion of uncultivated dry land to coconut or areca. Based on data from the mapping of village land-use, the former was estimated to be 3-9% of the total area under areca, while the latter was between 0-8% of the total cultivated area except in one case which was 20%. Increases in areca at the expense of paddy cultivation ranged from 0% to 9% of total areca area. These changes are spread out over varying time periods, from a decade to several decades.

7. Barren forest lands: internal use or external pressures?

Table 8 indicated that the fraction of barren land or scrub vegetation in the bettas is significant in Mundagesara village (34.4 ha, or 15% of total betta land) and to a lesser extent in Sirsimakki (8.1 ha, or 7%) and Arasapura (5.4 ha or 6%) villages. If the distribution of vegetation types across village betta lands follows a "rational" household logic of optimizing the combination of biomass resources at its disposal, and if the evidence of degrading pressure is as limited as shown in Chapter III, how does one explain the presence of barren lands in the village clusters?

First of all, are these lands evidence of human-induced degradation, or have they always been barren? In the absence of a reliable time series of vegetative condition (such as through aerial photography), one has to rely on oral histories to provide some idea of the historical situation. Villagers in Arasapura said that the barren area there has been so for a long time (more than a few decades) observation suggested that stony soil might be the driving factor. But the majority opinion in the SM cluster was that the barren patches had appeared over the last two decades.

It could be argued that since the situation regarding woody biomass extraction appeared to be most precarious in the SM cluster, the fact that the highest fraction of barren area in betta land is in this cluster is a reflection of historical unsustainable use. In the absence of hard evidence, this argument cannot be rejected out of hand. But many pieces of contextual information would appear to support an alternative hypothesis, viz., that this betta degradation is a result of *urban pressure* for fuelwood, not internal pressure from the villagers. Firstly, there is the variation across the three clusters itself: the cluster with the largest absolute and fractional area of barren land in bettas is the SM

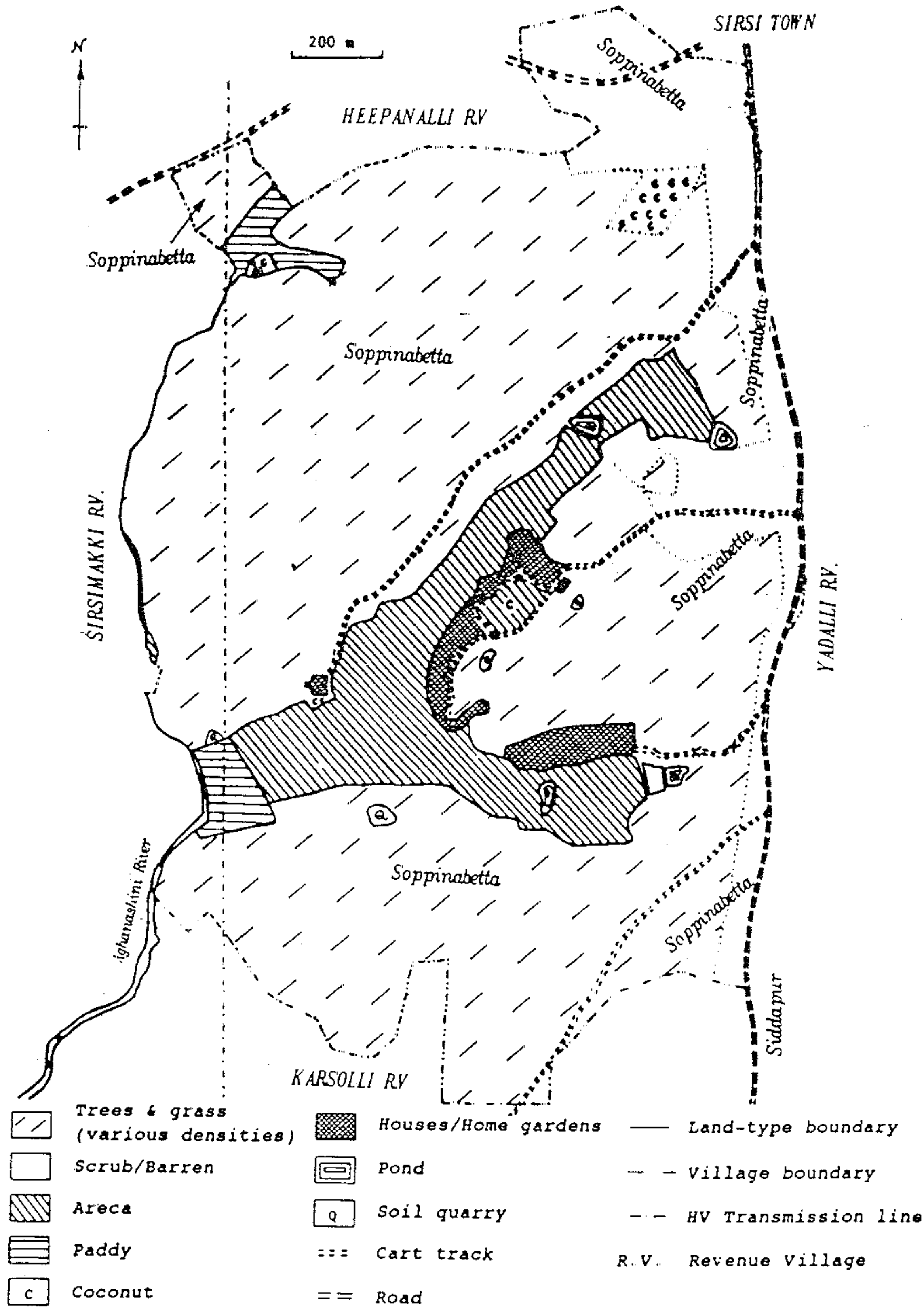

Figure 1: Location of vegetated and barren patches of *soppinabetta* lands in Mundagesara village

cluster, which is also the only cluster close to a town. Secondly, all the barren patches are located along the edges of the village-cluster that adjoin the two main roads from Sirsi town. For instance, strips of barren land occur on the eastern edge of Mudagesara village, which is the Sirsi-Siddapur road (Figure 1). The barren land in Sirsimakki village occurs along its north-western boundary, which is the Sirsi-Kumta road. And the biggest patch of barren betta land occurs at the north-eastern corner of MG village, which borders the nominal boundary of Sirsi town. Thirdly, there is ample evidence of heavy headloading of fuelwood into Sirsi town. Prasad *et al.* (1987b) estimated that only 40% or 13000 tonnes of their estimate of annual fuelwood requirement of Sirsi town was being met by fuelwood supplied by the forest department. Reddy *et al.* (1986) reported counting 700 headloads of fuelwood entering Sirsi town on a typical day from all directions. My own observations confirmed the essential picture of daily streams of women headloaders and men "cycle-loaders" bringing in large quantities of fuelwood gathered from MF, RF and betta lands bordering the many main roads that converge onto Sirsi town. Fourthly, personal observation suggested that MFs and bettas in other directions out of Sirsi town are also similarly affected.[45]

This is not to paint any romantic picture of rural households as being somehow "wiser" than urban households. (Indeed many of the urban headloaders are recent migrants from villages to the towns.) It is just that rapidly expanding towns create high concentrations of human beings without having inbuilt mechanisms to internalize the resource costs of such concentrations. The combination of this high demand, scarcity of

[45] No wonder then that one of the major demands made by the betta-holders in the SM cluster during the design and implementation of pilot ecodevelopment projects in that cluster was for the provision of a deep trench around the periphery of the betta lands.

other livelihood opportunities, and the general absence or decline of villagers' control on village common lands has created situations where the urban poor (or rural poor in villages in peri-urban areas) have incentives to rapidly exploit these lands, but little ability to ensure resource sustainability, resulting in "circles of degradation" around many urban centres (CSE, 1985; B. Bowonder et al., 1985). That even betta lands, which are under private control, have not escaped the effects speaks to the magnitude of the problem.[46]

8. Concluding remarks

To summarize the main argument of this chapter, it is useful to contrast the archetypes of the two broad social groups in the Malnaad villages: the traditional areca-cultivating betta-holder households, and the paddy-cultivating or landless non-betta-holders. Betta-holders appear to exert the greater demand for forest biomass: whether fuelwood, leafy matter or fodder. But their concomitant access to betta lands in approximate proportion to their total needs and the control they have on the use and condition of these lands creates a capacity for sustainable management of the biomass resources. This capacity is enhanced by the complementarity of other land assets that they often own. It is enhanced even more by the productivity of their main asset, the areca-spice orchard, that gives them the ability to use or purchase substitutes, to obtain more efficient technologies, and to hire labour for or invest in resource management activities. Equally important, they have strong incentives to sustain the productivity of the uncultivated

[46] No wonder then that one of the major demands expressed by the betta-holders of Sirsimakki-Mundagesara during CES' pilot project on rural eco-development was the need for a trench and fence around the periphery of the remaining vegetated betta lands.

vegetation, because although they cannot sell any forest produce directly, the productivity of their main asset depends critically upon the application of leafy matter and dung, with no real substitute for either.

Non-betta-holders, on the other hand, have somewhat lower needs of uncultivated biomass. But their access to uncultivated biomass resources is much more uncertain and generally lower, and they exert no *de jure*, and limited *de facto*, control over them, reducing their capacity to provide for their needs in a sustainable manner. They usually do not have the resources to adopt the more efficient technologies, and only limited ability to purchase substitutes. And the marginal benefits obtained by them from the use of the biomass in their agriculture/livestock production system, though high in survival value, are low in terms of creating a surplus that can be re-invested in long-term resource management.

This balance of needs, capacities, and incentives, in combination with the productive ecology of the moist tropical ecosystem, is what shapes the outcome on the land. Any attempt to modify the outcome, or to understand how it might be influenced by larger economic and political forces, must contend with the complexity of this balance.

Chapter VII. Conclusions

Villagers in the rural Malnaad region of Uttara Kannada district use forest lands in a variety of ways. This variety reflects not only the complexity of individual biomass use practices and the diversity of occupational niches that have evolved over centuries, but also the diversity of interests and abilities in a society that is differentiated in terms of quality and quantity of productive assets and access to forests. To judge the outcome of their use on the basis of notions of forest degradation or sustainability that are born out of concern for the positive externalities generated by natural forests for others would be to hold the villagers to an unfair standard. Defining forest degradation in terms of declining production of each biomass type used by the villagers is not merely a subjective choice being made explicit before applying a socially constructed concept. It is also a first step towards understanding why villagers' actions might sometimes result in the loss of future benefits for themselves. The purpose of this dissertation was to examine whether (and under what ecological conditions) such unsustainable use is occurring, and to understand the relationship between these patterns of use, the characteristics of the user households, and property rights regimes governing the use. In conclusion, I shall summarize the main results and discuss their implications in light of the ongoing demographic, agrarian and political dynamic.

Even within our narrow definition of sustainable use, the empirical task of assessing it was difficult, not the least because of the enormous complexity of the region's moist forest ecosystem that has co-evolved with human use. Lack of a reliable time series of vegetation condition means that one has to either compare current condition with some benchmark (theoretical or empirical), or use the notion of sustainability as a balance of inputs and outputs provided the underlying assumptions of stock-dependent production and homogeneity of product appear to be reasonable.

I applied the input-output balance criterion to the woody biomass of trees in village forest lands. I showed that the annual increment in the above-ground woody biomass of trees in these forests is consistently higher than an earlier estimate of 1 cu.m./ha/yr (Reddy *et al.*, 1986), and that the total useful production is significantly higher than annual increment, as the latter excludes the deadwood litter that is used by villagers for fuelwood. The extent of tree vegetation across village lands contradicts notions of rampant denudation.[1] This vegetation produces substantial woody biomass in each village as a whole. Comparing this production with estimates of woody biomass consumption for users of those lands, we found that an excess of harvest over production may have existed in at most one of the three village clusters studied prior to the recent introduction of fuelwood-conserving technologies.

The sustainability of tree biomass production was also assessed by examining the shape of the tree girth-class distribution, and through sapling and seedling density measurements. A deficit of young trees or saplings was seen to exist in some of the sampled plots, but the data were insufficient to explicate any clear-cut patterns, except to suggest that such deficits may not be ubiquitous.

Analysis of soil texture and nutrient status, when compared with analyses in

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[1] Such as the statement that "nearly 70% of Betta lands .... have become grass lands instead of being covered by useful trees" (Reddy *et al.*, 1986).

natural forest hinted that some depletion of soil organic matter and phosphorus due to heavy extraction of tree biomass may be occurring.

Grass production in historically maintained "pure" grasslands across the Malnaad was found to range from 3 to 6 t/ha/yr. Within-year production dropped by ~40% under simulated heavy grazing, but was not sensitive to light grazing early in the growing season. Most of the privately-owned grassland, many parts of betta lands, and even some areas in open-access Minor Forest or Reserve Forest lands were found to be protected during most of the growing season by village households. Grass production is of course highly sensitive to tree canopy cover, creating a trade-off between tree and grass biomass that is substantially responsible for the mosaic of vegetation types one observes in village forest lands.

The direct sale of timber and other valuable forest products is controlled by the state. This means that villagers use biomass from uncultivated lands largely to satisfy their domestic needs or as inputs into their agricultural or livestock production. The presence or absence of sustainable management in uncultivated lands is therefore related directly to (a) the nature of the household's domestic, agricultural and livestock-related needs, (b) the household's access to uncultivated land to satisfy them, (c) its capacity to control those lands and to invest in their maintenance, and (d) the regime of property rights that enables and allocates this access and control. The absence of substantial degradation in the villages studied is mostly explained by the fact that in most of the villages, the forest lands were betta lands, i.e., lands controlled by households for whom this balance between needs, capacities and access/control is the least precarious. In other villages, initial sufficiency of the resource may imply a current excess of availability over demand, but the long-term productivity cannot be predicted. On the other hand, the creation of *de facto* control by many households over small patches of uncultivated lands are expressions of a felt need for modifications in the *de jure* regime of forest rights.

In this analysis, the needs, assets, and endowments of a household are taken as a given. This was necessary for the analysis, and justified to the extent that the region is not a "frontier" region with rapid changes in population, land-use and the political economy of forest rights.[2] I now speculate on the likely impact of ongoing changes in these variables on the outcome, viz., the distribution of vegetation types, and the sustainability of their use. I shall also consider the implications of current and future outcomes for regional beneficiaries of the forest lands.

1. Trends in cultivation, demographics, and forest rights

Land assets are the most important determinant of uncultivated biomass use in these villages, and hence changes in them will be critical to changes in outcomes on uncultivated lands. Typical changes observed in the region are discussed in terms of the factors driving them, estimated trends, and implications for biomass use.

[2] For instance, the Cardamom Hills of Kerala experienced a population growth rate of 14% per annum (compounded) during the period 1951 to 1971, during which vast areas of forested lands and cardamom plantations were converted to pepper and home garden cultivation, transforming not only the landscape, but also the extent and distribution of resource access across households (Moench, 1990). In contrast, the population in the rural Malnaad region of Uttara Kannada grew at 3% per annum during the same time, no significant changes took place in the crop types, cultivation may have expanded by about 10-20%, and loosening of state control of forests occurred only on such lands.

Expansion of areca cultivation

Although areca has been the dominant crop of the region, its cultivation has historically contracted and expanded in response to prices, labour costs, forest rights and living conditions (see, e.g., Masur, 1918). The trend over the past few decades has been mostly one of expansion. Farmers have responded to stable or increasing prices[3], improved market control for the cultivators through their cooperatives (Gajanana, 1985), state support, governmental credit support for areca cultivation through its Areca Development Scheme (Mruthyunjaya, 1972) and general schemes for soft credit to farmers.

Areca has stringent requirements of irrigation, drainage, micro-climate (high humidity and relatively cool temperatures) and agricultural knowledge (mostly intangible local knowledge that has evolved over centuries) on the one hand and long maturation period (9-13 years) and heavy investment (Krishnaraja, 1981) on the other. Consequently, its expansion in the Malnaad appears to have been largely at the cost of conversion of paddy adjoining the orchards, usually by those who already hold areca land.[4] Between 1960 and 1989, areca cultivation in the Malnaad talukas expanded by

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[3] The difference between nominal inflation in arecanut prices as quoted by the leading farmers' cooperative in the region (which tracks the net price obtained by the farmer fairly accurately), and the general rate of inflation between 1951 and 1989 is between 0 and 5 percent points, depending upon the period chosen and the method for calculating general inflation.

[4] The other form of expansion, much commented upon by Mani (1985, p.16), is into betta lands along the edges of the areca orchards, as a by-product of the practice of applying freshly dug soil to the areca palms every 5-10 years. The amount of betta land lost and areca land created in this process is rarely recorded or incorporated into official statistics. My estimates of such expansion, based on interviews and mapping, amount to between 3% and 11% of total areca area in the villages sampled; note that this expansion has occurred over the 100 years since land survey and settlement. This proportion is similar to that reported by Nadkarni *et al.* (1989, p.129). It appears that future opportunities for such expansion are limited, since the location of houses or the steepness of the resultant "cliff" in the betta land is already preventing expansion in many cases. Contrary to the impression given by Mani (1985) and prevalent even amongst some betta-holders, such conversion has official sanction in the Kanara Forest Privileges Rules, the idea at the time of the formulation being that such increases would be recorded and the farmers taxed on it.

between 3% and 28%, mostly in the *hoblis* (sub-divisions of taluka) that had the most cultivation to begin with. In the villages sampled, the extent and rate of this increase was hard to determine but definitely positive.[5]

The immediate implications of this expansion are three-fold: increased demand for leaf mulch, for dung+leaf manure, and decreased availability of paddy straw fodder. Initial heavier extraction from own bettas in some plots or nearby RF/MF lands may gradually be replaced by purchases from the market when the new orchards begin to yield cash income. Given that the sellers of manure are local landless or marginal households who produce manure by lopping and grazing animals in MF/RF lands over which they have little control, the ecological impacts will be negative in most cases.[6] It is not clear at this stage whether the externalities of expansion might be reduced through the inter-cropping of areca with cocoa, which yields leaflitter and twigs in significant amounts and is being experimented with by some farmers. At the same time, the expansion of areca is likely to increase the long-term demand for labour, which could lead to increased pressures from seasonal migrant labourer households.

[5] Comparing legal land category with current crop, I found that 24%, 16% and 3% of the wet lands in Tattikai, Golikoppa and Arasapura villages respectively were under areca. Since wet lands correspond to paddy/sugarcane cultivation at the time of land survey settlement by the British (1890-1910), this provides a lower limit on the estimate of such conversion during this period.

[6] Fodder is now being imported through trucks/tractors from the cropland-dominated parts of Yellapur and Mundgod talukas. The impact of such exports on those regions is unclear.

Expansion of coconut and cashew cultivation

Governmental credit support for areca expansion has now ceased and has been replaced by support for coconut expansion (V.S.Hegde, Hulgol, pers.comm.). Although coconut is less remunerative than an areca-spice orchard, its agronomic requirements appear to be less stringent too, enabling its establishment in locations where areca cultivation is not possible, if coupled with irrigation using modern pump-sets. Cashew trees are even easier to grow, and their planting *in forest lands* is being actively encouraged by the state through its modification of forest rights (KFD, 1976, para.131(E)(v)).

This trend is clearly visible in the sampled villages. Coconut plantations had been established in 0.8-5 ha of the private *khushki* (dry) lands, amounting to between 5%-67% of the total dry land area. In the SM cluster, coinciding with the relative scarcity of dry lands, coconut plantations amounting to ~6 ha had been established in betta lands. These betta lands also had 5 ha of cashew plantations. The owners of these plantations were predominantly from the better-off households.

Planting coconut in dry lands, usually maintained as grass lands, would appear to reduce the availability of fodder, while increasing the demand for dung/leafy manure. However, as coconut cultivation appears to be tied with the provision of irrigation facilities, it simultaneously creates the possibility of inter-cropping with exotic hybrid grasses, which are highly productive if irrigated. It is not clear to what extent the externality is simply being shifted from biomass resources to groundwater resources. On the other hand, cashew trees cannot be lopped if they are to yield nuts, and once fully grown, their dense canopy will reduce grass growth significantly.

Expansion of paddy cultivation

Increases in the population, and the lack of access to other income-generating opportunities, coupled with the displacements created by large hydropower projects in Uttara Kannada and neighbouring Shimoga district, have led to an increasing pressure for cultivated land. Responding to these pressures, and despite protests from the forest department, the state government implemented a land grant program during the "Grow more Food" campaign of the 1960s that involved the granting of plots in state-owned "forest" lands for cultivation. In addition, the state government has essentially turned a blind eye to "encroachments" in forest lands, although more recently, with support from the central Forest Conservation Act of 1980, the forest department appears to have been more successful in evicting encroachers (D.Sarmah, pers.comm.).

"Illegal" paddy (and sugarcane or cotton) cultivation is present on a significant scale (13 ha) in the one village (Malenalli) that has large areas of RF and MF lands. The area of such conversion as a fraction of total RF/MF lands is of course small: 1% of MF land and 8% of RF land in that village. Most of these fields were located along water courses, on lands originally with slopes of less than 5 degrees, and were terraced. The lion's share (11.9 ha) in this cultivation is of paddy, and the distribution across households is fairly even: 0.75-1.5 ha plots encroached by a total of 14 households. Of these, 9 households own no legal land. But generalization on the basis of data from a single village is dangerous. Nadkarni *et al.*'s data for four other villages show that better-off households too may augment their productive assets by converting MF/RF lands into paddy cultivation or other orchards, and that the total area encroached by them could be as much or greater than that encroached by the poorer households.

This process of "encroachment for cultivation" in forest lands illustrates the idea of a dual relationship of dependence and antagonism between "forests" (in the vegetational sense of the term) and rural people. The antagonistic component increases as one goes down the socio-economic ladder, as the household's ability to use forest products as supporting lands to major sources of food or income (paddy or areca) decreases. Thus, for the landless households, forests are hardly a source of benefits, and their interest is always in getting toe-hold on some small patch somewhere, so as to begin cultivation.[7] Unfortunately, these households are also the most dis-enfranchised with respect to a share in the power to make land-use decisions over forest lands: while conversion of betta land into areca by the areca cultivator has official sanction, that of RF/MF lands into paddy by the landless labourer does not.

It should also be pointed out that many of these so-called encroached cultivation patches might in fact be previously cultivated lands that were abandoned during the general de-population of the region that occurred during the 1900-1930 period from a combination of malaria, influenza and possibly restrictive forest-access policies (Masur, 1918). Evidence for this is circumstantial but, to my mind, quite compelling: at least three patches of paddy land "encroached" in Malenalli village alone coincide exactly to peculiarly shaped small RF plots ("survey numbers") marked *within* a much larger RF plot. Given that a cardinal rule of the land survey and settlement procedure was to avoid such "doughnut-shaped" configurations, the only explanation for such a configuration is

[7] No doubt this reflects the abundance of forests themselves. But one might also ask whether this abundance is not at least somewhat artificial, i.e., resulting from the sequential exclusion of shifting cultivators, paddy cultivators (as well graziers and artisans) from the forests that began during the colonial period and has continued till today?

that the small "RF" plots were in fact cultivated plots abandoned for some reason, but perhaps cultivated in the last century. Conversations with the cultivators of these plots elicited one case where an old cultivator remembered encroaching what was simply fallow terraced land. A senior forest official confirmed the existence of substantial areas of fallow land under the RF classification, and said that these lands were the first to be released for cultivation under the Grow-more-Food campaign (S. Parameshwarappa, pers. comm.).

Even if the forest land had been forested land before it was encroached, the implications of converting 13 ha out of 280 ha of forest into paddy cultivation may not seem significant. Its direct impact on availability of forest biomass would be negligible. It would only add a little pressure for grazing by the animals maintained to provide the dung manure for cultivation, since paddy straw from the cultivation cannot supply all the fodder needs.[8]

But in the long term, these encroachments add up to a significant amount,[9] especially as perceived laxity in preventing current encroachment attracts more encroachers. This increases the total population in a particular region, and therefore their pressure for at least fuelwood and timber. Under the current situation, given that the encroachers do not even get tenure to the land they cultivate and that the land available for the satisfaction of their biomass needs is mostly under a *de facto* open-access regime, such immigration may lead to unsustainable biomass use in many cases.

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[8] Area of MF/RF land enclosed by paddy cultivators in Malenalli village (legal or illegal) correlated only weakly with their area of paddy land ($r=0.56$, $p<0.01$).

[9] Reddy *et al.* (1986) reported that the total "forest" land released or lost to cultivation in the district was ~54,000 ha, amounting to 6.5% of the total legal forest area in the district.

Demographic change

The annual compounded rate of growth of the rural Malnaad population in the past few years has been over 2% over the past three decades. Part of this dynamic is being played out in the encroachment for cultivation discussed above. But the overall dynamic may be more complicated than this gross figure indicates.

Examining the population trend in each village in the sample, I found that for four villages that were dominated by historical areca cultivation (K. Sarakuli, Mundagesara, Golikoppa and Arasapura), the population showed a consistently downward trend between 1971 and 1989[10]. Even on a longer time-frame of 1891-1989, obtained using data from revenue settlement reports (Mathrani, 1942), the population in three of these villages has increased by about 10%-35%, during a period when the rural population in the Malnaad as a whole more than doubled.[11] In responding to the questions on household composition, many of the areca-cultivating households indicated that a number of household "members" of the younger generation were actually living and working in various cities, usually in white-collar jobs. It appears therefore that the better-off and better-educated areca-cultivators have been able to externalize at least part of the natural growth in their population onto the cities. It also appeared from the composition of the youngest generation that these households were now in a second demographic transition of rapidly reducing family sizes.

The situation in villages with significant fractions of paddy-only cultivators or

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[10] Three data points are available: two census years, 1971 and 1981, and my survey data.

[11] Population in Golikoppa village increased by 108%, probably due to the permanent settling of erstwhile seasonally migrant labourers.

landless households is distinctly different. Two villages (SM and KG) with a mixture of paddy and areca cultivators showed increases of 57%-62% between 1891-1981. Malenalli, the village inhabited mostly by paddy-only cultivators, shows an increase of 247%. The period of fastest growth appears to be after 1951 or so, suggesting that part of the growth is through immigration of encroachers, but the current household composition also indicates high fertility rates in the current generation.

Caution is required in generalizing from these few data points. But I would argue that this dichotomy represents a dichotomy in rural Malnaad society at large: While those who own old areca cultivation and have the cultural ability to make use of modern education and white-collar opportunities have managed to externalize their initial population growth and are now in a position to make a demographic transition, those without such historical access and skills have remained mired in a poverty-population growth loop from which simple grants of forest lands or the land reform of the 1970s have failed to release them.

2. Regional "environmental" implications

While it is heartening to learn that biomass use in the Malnaad may be sustainable from the villagers' point of view, the question of regional implications of their activities remains. Indeed, this concern has become the major justification for having a "state forest policy", viz., that state intervention or governance is required to strike a balance between local interests and regional and national interests. As Shyam Sunder and Reddy put it, "the distress of the individual evokes sympathy; the repercussions on the unsuspecting *millions* living elsewhere concerns none" (Shyam Sunder and Reddy, 1986 my emphasis).

Referring to the tables depicting the distribution of different benefits from different vegetative forms across different scales presented in Chapter I, it would appear that rural use and transformation of forest lands may have negative implications from the point of view of regional beneficiaries *if compared with those from "natural" forests*. But the loss of regional environmental benefits, viz., soil conservation, hydrological control, bio-diversity, carbon sequestration, might be much lower in practice, for a number of reasons.

Firstly, to use untouched natural forest as the benchmark would be unrealistic. Virtually none of the forest in the Malnaad is untouched natural forest, nor has it been so for the past few centuries (Madhav Gadgil, pers.comm.). In the historically settled areca-cultivating villages, lopping of surrounding forests is a very old practice (Cleghorn, 1861, p.16), as has been the burning of forest strips for grass growth and protection in all villages. More important, the remaining (larger) forest area has been heavily exploited by the state, (Gadgil and Chandran, 1989; Gadgil *et al.*, 1983; Buchy, 1990). Large areas of the RF lands in the Malnaad have been converted to teak and eucalyptus plantations, species that have not produced the timber they were expected to anyway (Prasad, 1986).

Secondly, the feared increases in soil erosion and decrease in groundwater flows due to the conversion of natural forest vegetation to some other use may not occur in every case. In particular, groundwater flows might be enhanced (Hamilton, 1983) and soil erosion may not be significantly different under well-maintained, lightly grazed grasslands[12], particularly those located on the lower slopes of the rolling Malnaad hills. Similarly, encroached paddy cultivation, even when at the expense of fores*ted* land, occurs in mildly sloping lands, with terracing, and puddled cultivation. The soil erosion implications of such conversion are not likely to be very negative. Conversion of tree land to grass land certainly has negative carbon sequestration benefits; but such conversion will probably occur willy-nilly until villagers are provided with sufficient productive and supplementary assets to get them out of their poverty traps.

Finally, the implications of human use for biodiversity (plant and animal) are too complex and poorly understood to allow the simple equation of increased use with reduced biodiversity (Gadgil, 1991, and references therein).

It is not clear, therefore, that the villagers' current use or transformation of historically used and transformed forest lands will cause dramatic declines in regional environmental benefits.

3. Implications for rural eco-development policy

The makers of forest policy in India and in Karnataka are showing welcome signs of openness to new thinking on the issue of rural use of and control over forest lands. The idea of Joint Forest Management (JFM), i.e., management involving villagers and the forest department, has been approved in principle by many state governments (Khare, 1992). For the Malnaad region, the Karnataka Forest Department has launched a "forestry and environment" plan that includes a significant JFM component (KFD, 1990).

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[12] Erosion rates are primarily determined by the extent and quality of ground cover, not tree canopy cover (see, e.g., Moench, 1990).

It also includes many components of earlier "eco-development" plans attempted in the region, such as subsidies for bio-gas plants, modern animal husbandry packages, etc.

This research has two major implications for such policy initiatives that are located at the nexus of rural development (i.e., alleviation of rural poverty) and environmental management (i.e., promotion of resource use so as to sustain the flow of benefits to the local and regional users). Firstly, it suggests that, when villagers have multiple needs and require multiple vegetation types to satisfy them, an obsession with "forests as trees" is to miss the trees for the wood. Forest department officials have attempted to restrict the scope of JFM-type initiatives, and the modifications in tenure and access following from them, to "degraded" forest lands, defined by forest officials in a meeting on this subject as lands with less than 30% tree canopy. The sole objective thus appears to be to somehow get tree cover back on the land.[13] This single objective is likely to be at variance with the interests of users'. Imposing it is likely to lead to the failure of the programme, or to benefit only those who have the ability to satisfy their forest needs in other ways; it is therefore impractical and arguably regressive.

Secondly, this research suggests a need for greater attention to the differences in resource rights, incentives, capabilities and needs that exist within rural communities, and equal caution in interpreting the implications of such differences for resource degradation. In a previous analysis of the same region, Nadkarni *et al.* (1989) argued that stratified ownership of agricultural resources and the concomitant stratification of

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[13] The same has been the case in KFD's programme for the reforestation of Minor Forest lands, implemented with commendable zeal in Uttara Kannada. Fencing off the planted patch for three years produces high yields of fodder to begin with, but the *Acacia auriculiformis* saplings grow rapidly and, at the density planted, soon suppress all grass growth subsequently.

access to forest land resources have resulted in the degradation of the forest lands because the "unequal benefits from the forests, and the lack of any communitarian institution" causes "apathy" towards the regeneration of the forests, in spite of the "substantial dependence [on] and [hence] stake in" the forests [p.153]. They claimed to have "shown that private and exclusive access to forests, as in the case of *bettas*, has not ensured their sustainable use" because "what was scarce from the point of the society as a whole and from a long-term perspective, was not equally scarce in the eyes of the richer sections of society who enjoyed the lion's share of the benefits from the forests".

My research shows that lack of communitarian institutions of managements would explain degradation, if any, only in the open-access MF/RF lands. Given the combination of capacities, incentives and control that betta-holder households are endowed with, degradation in fully privatized bettas would be a counter-intuitive result. Wholesale degradation does not appear to be empirically substantiated.[14] This is not to understate the importance of stratification in rural communities. Indeed, the relationships shown between bio-gas, stall-feeding and land asset ownership in this research illustrate that many of the technological packages recommended in the name of eco-development may result in a regressive allocation of state resources because of attributes that make them viable options only for wealthier households.

In the Malnaad, the problem is not so much inadequacy of biomass resources in general, or simply one of "alienation of the village community *at large* from the management of the resource", but that of a *combination* of inadequate incentives,

[14] Nadkarni *et al.*'s conclusions may be the consequence of equating "heavy use" with "degradation" (see Chapter IV), or of interpreting tree-less grassland as degraded forest.

capabilities and control for productive and sustainable use amongst *certain communities*. It would be tempting to put all the blame for resource degradation on the inequitable allocation of access to forest lands or on the open-access nature of the lands accessible to the poor. Certainly, a modification of the system of forest rights in the Malnaad in particular and in general in India is more than overdue. Whether such changes lead to sustainable use or degradation of the forests will, however, depend upon the extent to which they incorporate the complex and location-specific relationships among social groups and between them and the land.

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Appendix A: Climate, soils and tree vegetation of the Malnaad

A.1 Climate

Across Uttara Kannada district, the total annual rainfall shows a distinct relationship with the topography, increasing from the coast to the crest of the Western Ghats, and dropping rapidly as one proceeds east-north-east across the Malnaad (see Fig.1(a)), while being relatively similar in the direction parallel to the coastline. Within the year, the rainfall is unimodal. The rains, provided by the south-west monsoon, occur between June-November, with June, July and August being the rainiest. December to mid-May is an almost completely dry period, with December-February being relatively cool, and March-May being the summer season. Figure 1(b) gives the mean monthly rainfall and temperature recorded at Sirsi town, which is the commercial hub of the arecanut economy and the headquarters of Sirsi taluka.

A.2 Soils

The geology of Uttara Kannada district consists mainly of "Dharwar" (chlorite-) schists, granitic gneisses and charnockites, rocks of one of the oldest rock formations in the earth's crust known as the Archaen complex (Kamath, 1985, pp.22-24; Bourgeon, 1989a). Schists underlie most of the Malnaad region. The soils of the Malnaad are broadly categorised as red sandy (or sandy-clayey) loams (Kamath, 1985, p.304). More formally, Bourgeon (1989a) has identified the "natural" (i.e., forest) soils of the Malnaad region as mainly ferrallitics (as per the French system of soil classification), or the orders Alfisols and Inceptisols (as per the U.S.D.A. Soil Taxonomy system).[1]

[1] Hapl*ust*alfs occur in the drier (ustic) regimes under deciduous forest and savannahs, and Hapl*ud*alfs in moister (udic) ones under evergreen forests; some Eutrodoxes and Eutropepts are also reported.

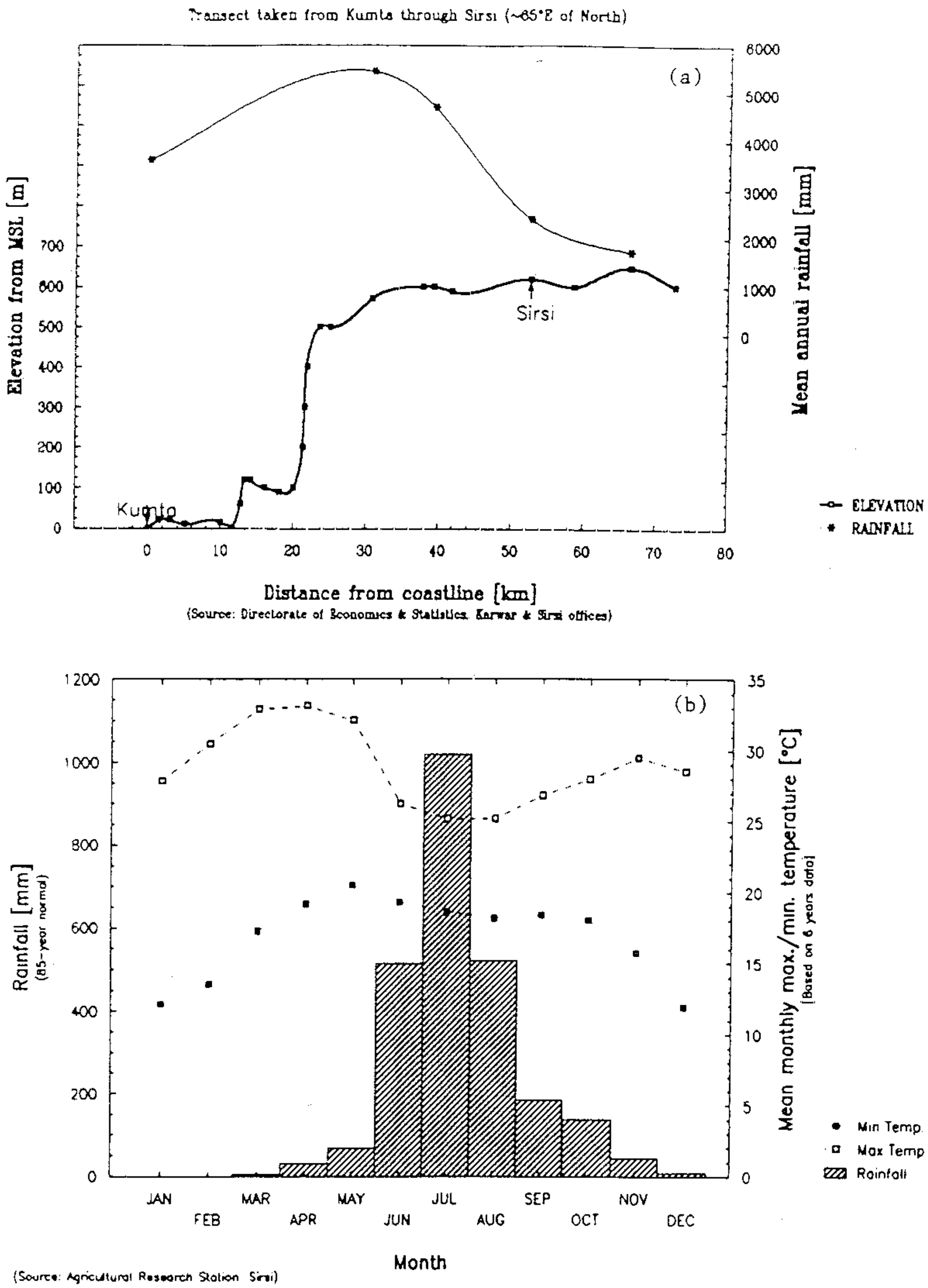

Figure 1: (a) Topographic and rainfall gradient across Uttara Kannada district.
(b) Seasonal variation in rainfall and temperature at Sirsi town in the Malnaad.

A.3 Tree vegetation in the sampled villages

The tree vegetation in the forests of the Malnaad region has been described as consisting of moist-evergreen, semi-evergreen (or moist-deciduous) and dry-deciduous types in various successional stages from fully "degraded" to "climax"[2] (Pascal, 1986; KFD, 1990, Annex III). The typical associations of tree species corresponding to these vegetation types in this region are:

Evergreen: *Ervatamia heyneana-Hopea wightiana-Terminalia paniculata-Lophopetalum wightianum-Garcinia sp.-Aporosa lindleyana-Calophyllum inophyllum* associations;

Semi-evergreen: *Terminalia tomentosa-Syzigium cumini-Terminalia paniculata-Aporosa lindleyana-Buchanania lanzan-Xylia xylocarpa* associations; and

Deciduous: *Tectona grandis-Anogeissus latifolia-Terminalia tomentosa-Terminalia paniculata-Dalbergia latifolia-Xylia xylocarpa-Lagerstroemia microcarpa* associations.

The actual species composition and canopy structure encountered in the forests around villages differs from these climax associations in proportion to the degree of human manipulation. The tree, shrub and herblayer species encountered at twelve forest locations (nine natural forests and three plantations) in Uttara Kannada district have been reported by Bhat *et al.* (1986?). These include five locations in the Malnaad region

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[2] Note that the term "degraded" here applies in a successional sense, wherein it is assumed that any site left "undisturbed" would reach a certain climax stage determined by eco-climatic conditions. Therefore, any vegetation that does not correspond to the climax vegetation type that appears to be applicable to that location is considered to be "degraded" from climax.

(marked as BH-BE, BH-MF, SONDA, BIDR and SUGAV on the map in Figure 1, Chapter II), hereinafter termed "time-series sites", as they were monitored over time for estimating tree girth increment rates. The tree species composition of most of the forest lands in the villages of interest in this study differed from that in these five samples because (a) the latter did not include samples in the evergreen belt in which the Tattikai cluster is located, and (b) the vegetation in the village forest lands was much more "disturbed" or modified by human activities. Data on tree vegetation in the villages of interest were therefore compiled from ten samples in *soppinabetta* lands, three (SM-BETTA, SM-TRANS and BK-LOP) sampled earlier by researchers at the Centre for Ecological Sciences (CES), and seven (AP-AVH, AP-GMH, GK-GBHAT, BH-KMH, BK-DVH, TK-GGH, TK-RTH) sampled during the field work for this study. The tree species encountered in these samples are listed in Table A.1.

Table A.1 Names of all sixty-four tree species encountered in *soppinabetta* samples in the villages studied

Species	Family	Leaves	Vernacular Names
Ailanthus malabarica	Simarubiaceae	E	Maddi Dhupa
Albizzia odoratissima	Fabaceae	E	Bilkambi
Alseodaphne semicarpifolia	Lauraceae	E	Masé
Aporosa lindleyana	Euphorbiaceae	E	Sallé
Artocarpus gomezianus	Urticaceae	D	Vaataambi
Artocarpus hirsutus	Urticaceae	E	
Bassia latifolia	Sapotaceae	D	Hippé
Bauhinia racemosa	Fabaceae	D	
Bombax malabaricum	Malvaceae	D	Booralu
Bridelia sp.	Euphorbiaceae	D	
Buchanania lanzan	Anacardiaceae	D	Chaar, Nurukalu
Carallia brachiata	Rhizophoraceae	E	Andi, Anaadmurugalu
Careya arborea	Lecythidaceae	D	Kowlu, Kaaval (M)
Caryota urens	Palmae	E	Baini, Belmaad (M)
Cassia fistula	Fabaceae	D	Kakkai, Amaltaash (M)
Cinnamomum sp.	Lauraceae	E	Chappé lavanga
Dalbergia latifolia	Fabaceae	D	Beete
Dalbergia paniculata	Fabaceae	D	Belgaa, Kusraani
Dillenia pentagyna	Dilleniaceae	D	Kanagalu
Diospyros candoleana	Ebenaceae	E	Kari mara
Diospyros melanoxylon	Ebenaceae	D	Beedi-ele

Table A.1 Names of all sixty-four tree species encountered in *soppinabetta* samples villages studied

Species	Family	Leaves	Vernacular Names
Diospyros montana	Ebenaceae	D	Balagane
Ervatamia heyneana	Apocynaceae	D	Maddarasa
Ficus asperrima	Urticaceae	D	Garagatti
Ficus benghalensis	Moraceae	D	Aala
Ficus infectoria	Urticaceae	D	Bilebasari
Ficus sp.	Moraceae	D	
Flacourtia montana	Flacourtiaceae	E	Hannu sampigé
Garcinia indica	Clusiaceae	E	Murugalu
Heterophragma dalzelli	Bignoniaceae	D	
Holarrhena antidysenterica	Apocynaceae	D	Kudaa
Holigarna arnottiana	Anacardiaceae	E	Holigéré
Hopea wightiana	Dipterocarpaceae	E	Haiga
Ixora brachiata	Rubiaceae	E	Gorabaalé, Gandu surugi
Lagerstroemia microcarpa	Lythraceae	D	Nandi
Lannea coromandelica	Anacardiaceae	D	Gojjalu; Goda aamaté?
Litsea sp.	Lauraceae	E	
Lophopetalum wightianum	Celastraceae	E	Banaaté
Mangifera indica	Anacardiaceae	E	Maavina-mara
Mimusops elengi	Sapotaceae	E	Ranjalu
Mitragyna parviflora	Rubiaceae	D	Kalam
Nothopegia colebrookiana	Anacardiaceae	E	Gandu holigéré
Olea dioica	Oleaceae	E	Acharakalu
Phyllanthus emblica	Euphorbiaceae	D	Nélli
Plectronia didyma	Rubiaceae	E	Hanagaré
Pterocarpus marsupium	Fabaceae	D	Honné, bettahonné
SAPOTACEAE member	Sapotaceae		
Sapindus laurifolia	Sapindaceae	D	Atlakaai, Antwaala
Schleichera oleosa	Sapindaceae	D	Bilijambé mara, Kallusagadi
Semecarpus anacardium	Anacardiaceae	D	Kyaara gida? [M:Bibbaa]
Shorea talura	Dipterocarpaceae	E	Jaala
Stereospermum personatum	Bignoniaceae	D	Nukarti, Padli
Strychnos nuxvomica	Loganiaceae	D	Kaasaraka
Syzigium caryophyllatum	Myrtaceae	E	Pillé
Syzigium cumini	Myrtaceae	E	Néralu
Terminalia alata	Combretaceae	D	Matti
Terminalia bellirica	Combretaceae	D	Taaré
Terminalia chebula	Combretaceae	D	Aialé, Analé
Terminalia paniculata	Combretaceae	D	Honaalu
Vitex altissima	Verbenaceae	D	Banagé, Bharanigi
Xantolis tomentosa	Sapotaceae	E	Gomblé
Xylia xylocarpa	Fabaceae	D	Jambé
Zanthoxylum rhetsa	Rutaceae	D	Jummana

* : E = Evergreen, D= Deciduous; ** : Kannada name (default) or Marathi name (M)

The tree species composition was also found to differ significantly across clusters, as can be seen from Table A.2, which lists the ten most dominant tree species in each cluster (based upon aggregate data for all the tree vegetation samples in a cluster).

Table A.2 Variation in ten most dominant tree species in *soppinabettas* across the Malnaad. Percentage Importance Value Index (%IVI) is calculated as fraction by number * fraction by basal area) *100. See Table A.1 for full names of species.

Malenalli cluster		Sirsimakki cluster		Tattikai cluster	
Species	**%IVI**	**Species**	**%IVI**	**Species**	**%IVI**
Terminalia p.	32.0%	Aporosa lindleyana	25.4%	Lophopetalum w.	15.0%
Terminalia alata	36.0%	Terminalia p.	13.5%	Hopea wightiana	11.7%
Careya arborea	14.8%	Syzigium cumini	12.1%	Aporosa lindleyana	10.7%
Shorea talura	15.9%	Terminalia alata	14.2%	Olea dioica	7.5%
Xylia xylocarpa	6.8%	Careya arborea	9.3%	Ficus sp.	5.4%
Strychnos n.	5.7%	Buchanania lanzan	8.7%	Mangifera indica	7.1%
Buchanania lanzan	2.3%	Syzigium cary.	2.2%	Terminalia alata	4.0%
Syzigium cumini	2.2%	Phyllanthus e.	2.2%	Holigarna a.	4.4%
Dillenia pentagyna	2.4%	Alseodaphne s.	2.2%	Carallia brachiata	3.3%
Stereospermum p.	2.3%	Bassia latifolia	2.9%	Syzigium cumini	2.4%

Appendix B. Field methods and calculations pertaining to tree vegetation data

Methods described here are those followed in time-series monitoring of tree girth carried out by staff at the Centre for Ecological Sciences (CES), and in sampling of tree vegetation carried out as a part of this study. (Differences in the two methods are mentioned where relevant.)

B.1 Tree basal area

Tree girth (GBH) was measured at breast height, defined as 1.30m above ground level. The precision of girth measurements was 0.5cm. Basal area (BA) was taken as $(GBH)^2/(4\pi)$, without corrections for non-circular cross-sections. Multiple stems in a forked tree were marked as A, B, C, etc., their girths measured separately, the BA values of all forks added to obtain BA for the tree, and an "equivalent" GBH ($=(4*\pi*BA)^{1/2}$) calculated to determine the tree's girth class and to use in any girth-based regressions.

B.2 Basal area increment

CES researchers monitored the girth of trees in the "time-series" sites starting in 1983-1984 (the calendar used being a monsoonal one, i.e., June-May), and BK-LOP starting in 1986-87. Tree girth data were collected annually at about the same time (± one month) as the previous measurement *for all the trees present at the time of the initial enumeration*, with measurements being made at the same point on the tree stem every time (the point being marked with paint). Notes were made as to whether the tree appeared to have been lopped that year. Trees that were dead or cut were noted. Data for the period 1983-1989 (1986-1989 for BK-LOP) were available at the time the field work for this research was completed. These data included a number of confusing entries, e.g., trees which were missed for some years, mix-ups between girth entries across trees, etc. They were corrected to the extent possible.

Given that the girth increment in a year is often not much greater than the measurement error of 0.5cm, I used only the difference between the 1989-90 and 1983-84 measurement to estimate increment. Basal area increment (BAI) was calculated as the difference in basal areas between the first and the final year. It was converted to a *percentage annual* increment (%BAI) by dividing by the number of years and by the *average* basal area across the time period, i.e.,

$$\% \; Annual \; BAI = \frac{(BA_{final} - BA_{initial})}{\left[\frac{BA_{initial} + BA_{final}}{2}\right]} * (t_{final} - t_{initial}) * 100\% \quad . . . \quad (1)$$

where (t_{final}-$t_{initial}$) is the difference between the dates of the first and final GBH measurement (in years). The average %BAI for each 20cm girth-class (beginning at 20cm[3]) was then calculated for each site using all the individuals whose average equivalent GBH was within that particular girth-class (i.e., 20cm ≤ average GBH <

[3] CES's cutoff girth value varied, with 10cm being the cutoff for the 1-ha plots, but 20cm being the cutoff for the BK-LOP experiment. For the sake of consistency, and considering that 5cm *diameter* is the more common cutoff in the literature, I have used a 20cm GBH (≈ 6cm diameter) cutoff throughout.

40cm, and so on) for whatever site-species combination desired.[4]

B.3 Estimation of tree woody above-ground biomass (TWAGB)

In order to estimate TWAGB production, which includes survivor increment and additions through recruitment, it is necessary to have or develop relations between tree dimensions and woody AGB, where the former may include GBH, height, crown height, diameter at base of crown, branch diameters, etc. (Satoo and Madgwick, 1982, pp. 15-30). These relationships can be obtained in three ways: (1) through "destructive sampling", wherein a sample of trees similar to those being monitored is cut down and its woody biomass and dimensions measured, (2) through "non-destructive" sampling, wherein the volume of each tree is estimated by taking carefully measuring the dimensions and shapes of all the woody components of the tree, and (3) from the literature. Considering the number of trees required to develop new relationships for the village forests of Malnaad region, destructive sampling was socially unacceptable and legally impossible (given the ban on tree-felling), while non-destructive measurements were prohibitively time-consuming. I was therefore forced to adopt some relationship from the existing literature.

Generally speaking, the literature on relationships between AGB or tree volume and tree dimensions is much scarcer for tropical natural broad-leaf forests than for

[4] A more accurate method of estimating girth-specific growth rates would be to use the transition matrix or two-way frequency table approach, wherein the number of transitions into and out of a much smaller girth class (typically 3cm wide) are recorded. This method was, e.g., used by Rai (1980a) with girth increment data for 35 years (i.e., 7 five-year periods). Since CES data spanned six years or less, i.e., just one measurable growth period, I used the simpler approach described above so as to obtain sufficient number of samples in each girth-class.

temperate ones. As such, only two sets of destructive sampling studies were found for the Western Ghats region in which Uttara Kannada is located. The first is a set of "Regional Volume Tables" developed from tree samples taken from Goa state, which is immediately to the north of Uttara Kannada district (Sharma *et al.*, 1979a-1979e). The second is a set of studies published by S.N.Rai based on data from old-growth evergreen forest sites that were clear-felled as they were being submerged under a hydropower dam project (Rai, 1980b; Rai, 1984; Rai and Proctor, 1986a). The relevant information from these studies is summarized in Table B.1, and some of the relationships are plotted in Figure 2 for comparison, along with the one I adopted.

I chose to adopt the functional form of $V = a + b*(D^2H)$ as it allows for a form factor (ratio of V to (BA*H)) that varies inversely with tree size, while being simpler to use and compare than a log-log relationship such as that used by Rai and Proctor. Note that the lower limit on the value of the form factor is $b*4/\pi$ (since for very large trees, $b*(D^2H) >> a$, hence $V \approx b*(D^2H)$, and $D^2H = 4*BA*H/\pi$), and the highest value reached by the form factor corresponds to the lowest value of D^2H in one's sample.

Table B.1 Woody volume and tree dimensions: Available relationships for the Western Ghats region, and relationship adopted for this study.

Reference	Site location and characteristics	Species	Regression for Woody volume (V) (Units= m for D and H; cu.m. for V, unless mentioned otherwise)
Rai (1980b)	Karnataka Western Ghats, south of Uttara Kannada; Evergreen old-growth	20 species, only 1 of which (*Syzigium cumini*) occurs commonly in my sample	*S. cumini*: Stemwood $V = 0.024 + 0.417*(D^2H)$ All overstorey species: Stemwood $V = 0.055 + 0.417*(D^2H)$ All understorey species: Stemwood $V = 0.230 + 0.381*(D^2H)$
Rai & Proctor (1986a)	Same as above	43 species combined, only 4 of which occur in my sample	All species combined: $\ln(\text{Total AGB}) = -0.435 + 2.12*\ln(D)$ [AGB in kg; D in cm; density = ~0.7]
Sharma *et al.* (1979d)	From the Western Ghats in Goa (north of Uttara Kannada); site characteristics unknown	*Terminalia paniculata*	Total $V = 0.023 + 0.352*(D^2H)$
Sharma *et al.* (1979a)		*Careya arborea*	Total $V = 0.156 + 0.250*(D^2H)$
Sharma *et al.* (1979e)		*Xylia xylocarpa*	Total $V = 0.062 + 0.332*(D^2H)$
Sharma *et al.* (1979c)		*Terminalia bellirica*	Total $V = 0.115 + 0.306*(D^2H)$
Sharma *et al.* (1979b)		*Lagerstroemia microcarpa* (syn. *L. lanceolata)*	Total $V = 0.261 + 0.315*(D^2H)$
Chosen for this study	Uttara Kannada above-ghat hilly region, mostly lopped forests	All species	Total $V = 0.025 + 0.39*(D^2H)$ $= 0.025 + 0.5 * (BA * H)$

The choice of values for a and b is critical, and the two sets of studies appear to differ significantly in them. Rai's values for b are distinctly higher than those in Sharma *et al.*'s Regional Volume tables, particularly if one notes that his regression is for *stemwood only*, and so inclusion of branchwood would be expected to increase further the slope of the V-D^2H curve. Taking the latter into consideration, I chose a value for

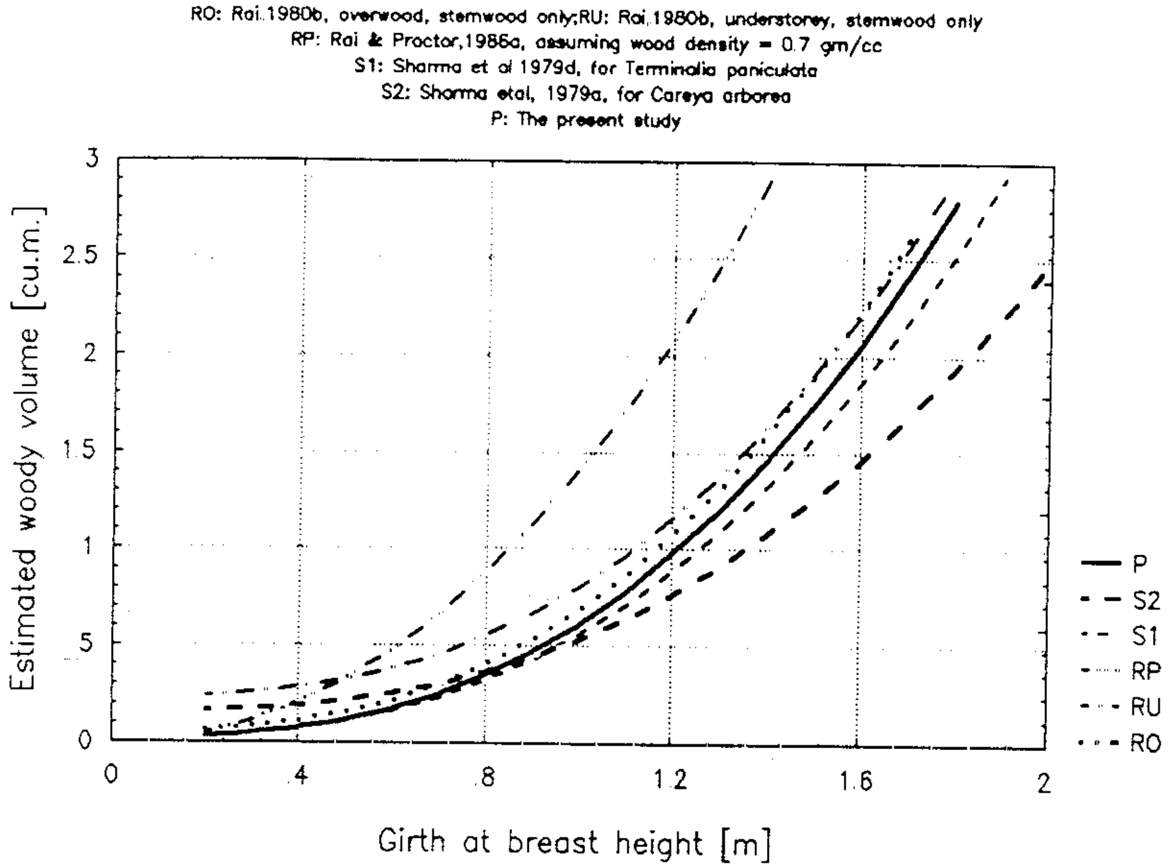

Figure 2. Volume-GBH relationships implied by different regressions (using the height-GBH relationship derived for BH-BE in Figure 1, Chapter III)

b of 0.39, which is at the higher end of the b-values in the volume tables, but much lower than what Rai's values would be for total woody volume. In choosing 0.025 as the value of a, in addition to the fact that it is a conservative (i.e., low) value compared to those in the literature, I took into consideration the fact that 'a' contributes significantly to the total volume of smaller trees, and should therefore yield meaningful values of tree volume at low GBH.[5] As can be seen from Figure 2, the values I chose lead to a volume-girth relationship that is very much in the middle of the range reported in the literature.

B.4 Estimating annual increment in TWAGB

Given the above regression, the increment in WAGB of a tree between two time periods t and t+1 would be given by

$$\Delta(TWAGB)=SG_{t+1}*(a + b*D_{t+1}^2*H_{t+1}) - SG_t*(a + b*D_t^2*H_t) \quad \ldots \quad (2)$$

where SG stands for mean specific gravity of woody matter. Assuming that wood density for a tree does not change significantly over its lifetime, and remembering that $D^2=4*BA/\pi$, we get,

$$\Delta(TWAGB) \approx SG*\frac{4b}{\pi}*[BA_{t+1}*H_{t+1} - BAsubt*H_t] \quad \ldots \quad (3)$$

The increment in height can be estimated from the regression of height on girth (Figure 1, Chapter III) as follows:

[5] Another way to test for the meaningfulness of a is to calculate the Stand Form Factor, i.e., the ratio of total volume of trees in the stand to the product of their total basal area and average height (Cannell, 1984). This factor is highly sensitive to the value of a used, and for a=0.025, one gets stand form factor values ranging from 0.6 to 0.9, which is the range reported by Rai and Proctor (1986a); see also Brown *et al.* (1989).

$$\ln(H) = c + d*\ln(G),$$
$$i.e.,\quad H = c'(BA)^{d'}, \qquad \ldots\ldots (4)$$
$$where\quad c' = \exp(a*\frac{\sigma^2}{2})*(4\pi)^{d/2}\ ,\quad d' = d/2$$

$$\Delta H = c'*d'*(BA)^{d'-1}*(\Delta BA)$$
$$i.e.,\quad \frac{\Delta H}{H} = d'\left(\frac{\Delta BA}{BA}\right) \qquad \ldots\ldots (5)$$

Thus, total change in tree volume is given by,

$$\Delta V = b'*H*BA\left(\frac{\Delta BA}{BA}\right)(1 + d') \qquad \ldots\ldots (6)$$
$$where\quad b' = \frac{4b}{\pi}.$$

This when multiplied by the specific gravity of wood for that tree species, gives the increment in tree WAGB.

The fractional error associated with this estimate of WAGB increment is the sume of the fractional errors in estimating each of BA, H, b', ΔBA/BA, and (1+d'). The error in b' is unquantifiable, since b has been arrived through hand-waving arguments. That in d' corresponds to the standard error of d in the height-girth regression, which turns out to be between 3%-11% of d; the term is therefore negligible, since the consequent error in (1+d') gets attenuated by a factor of 3 or more. The greater uncertainty about the validity of the regressions across different sites is, of course, unquantifiable. To estimate the error involved in estimating H from the log-log regression of H againts GBH, one would need to incorporate the asymmetry of the errors resulting from such a regression that has been pointed out by many (Baskerville, 1972; Mountford and Bunce, 1973). However, I simply used the anti-logarithm of the standard error of the estimate for ln(H) (=1.0m), since it turns out that there is hardly any variation in the standard error associated with different H values, and using the anti-logarithm of the standard error of the estimate for ln(H) gives conservative errors. Finally, the error in $\Delta BA/BA$ is the standard error associated with the particular rate of %BAI chosen for that girth-class. The uncertainties associated with using %BAI rates measured at one site in estimating ΔBA at another (and sometimes quite a different) site are not quantifiable. The possible uncertainty in the use of specific gravity values could also not be quantified; however, the default value of 0.6gm/cc, used for all the species whose specific gravity was not known, is quite conservative.

B.5 Estimating addition to TWAGB through annual "recruitment"

Recruitment or "ingrowth" is the amount of basal area or AGB that is added through *new* individuals that cross the minimum girth cutoff after the initial sample of trees is enumerated (as against increment, which is the net *increase* in basal area or AGB of individuals that were already above this cutoff). As explained in section 1.3 of Chapter III, the addition to stand basal area due to recruitment was estimated to be ~10% of the increment in stand basal area due to survivor growth. To convert this "recruitment basal area" to "recruitment WAGB", I adopted the following approximate procedure. I calculated the ratio of total WAGB: total BA for the trees that formed the recruitment in the five time-series sites in which recruitment was monitored.[6] This ratio was found

[6] The recruitment basal area was easily computed because I used a GBH cutoff of 20cm, while CES's cutoff for the five time-series sites was 10cm. Thus, it was possible to count the number of individuals initially in the 10-20cm girth class that crossed the 20cm mark at the end of the six-year period, and to convert their basal area into an annual value. Note that this leads to a slight underestimate of "natural" recruitment, because some trees in this girth-class were cut down before they grew beyond 20cm GBH.

to be between 4.9 and 6.8 tonnes/m^2. Since the overall WAGB:BA ratios for the time-series sites were similar to those observed in the vegetation sampled in the Malenalli cluster, but almost twice as much as those observed for the vegetation in the Sirsimakki and Tattikai clusters, I decided to use a value of 5 for sites in the MH cluster and 3 for those in the SM and TK clusters. These ratios, when multiplied by the corresponding estimates of recruitment basal area, yield the recruitment WAGB estimates. The error in this estimate was not quantifiable; a guesstimate value of 30% has been adopted.

Appendix C. Differences in rates of basal area increment

It is important to understand the factors responsible for the variation in %BAI rates observed across sites in Table 1 of Chapter III, to help decide the %BAI rates to be adopted in the calculation of TWAGB production in the village forests of interests. This section describes the analyses carried out for this purpose. The effect of three factors on girth-specific %BAI was examined: species, lopping and "site effects" other than due to species or lopping.

C.1 Differences in %BAI across species

A visual examination of the girth-specific %BAI rates for each time-series site suggests that different species do exhibit systematic differences[7]. Table C.1 illustrates this phenomenon for the BK-LOP site. Testing for statistical significance was highly constrained by the lack of sufficient samples within each site-girth-species combination and the concommittant unbalanced design. Nevertheless, the tests indicated that many of the apparent differences in average %BAI were significant for smaller girth classes. For instance, in BK-LOP, %BAI for *Careya arborea* and *T.alata* was lower than that for *Aporosa l.*, *Buchanania l.*, *Syzigium cumini*, and *T.paniculata* for the 20-40cm girth class at $p < 0.05$ or better in a multiple-comparison test ("honest-significant difference" (HSD) test for unequal sample sizes; Spjotvoll and Stoline, 1973). Similarly, %BAI was lower

[7] In the absence of clear ring formation in the stems of trees in tropical broadleaf evergreen and semi-evergreen forests (Mathauda, 1953), it is not possible to determine the age of the trees with any accuracy. Thus, it is not clear whether the difference in girth-specific growth rates is actually a difference in age-specific growth rates or whether it is the result of individuals of different species in one girth-class being of different age.

for *T. alata* than for *Aporosa l.*, *Buchanania l.*, and *Syzigium c.* for the 40-60cm girth class at $p<0.05$ or better. *T. alata* and *Careya arborea* are also lower in %BAI than *T. paniculata* and *Syzigium c.* at $p<0.05$ for the 80-100cm girth class if pair-wise comparisons (parametric or non-parametric) are carried out. The absence of significance at higher girth classes is most likely due to the absence of sufficient trees of each species for the comparison. (Only unlopped trees were used in these comparisons.)

Table C.1 Species-wise %BAI rates for BK-LOP site [sample of 928 trees]

Girth-class [cm]	Aporosa lindleyana	Buchanania lanzan	Careya arborea	Syzigium cumini	T. pani-culata	T. alata
20-40	9.7%	12.6%	4.3%	11.3%	4.3%	8.8%
40-60	4.0%	6.9%	2.8%	9.1%	0.6%	3.6%
60-80	2.3%	3.1%	2.6%	5.2%	2.0%	2.7%
80-100	2.9%	2.0%	0.7%	2.2%	0.9%	3.2%
100-120	1.0%	4.8%	3.2%	2.7%	0.7%	1.7%
120-140	2.4%	0.0%	0.0%	2.4%	1.2%	1.5%
140-160	0.0%	0.0%	0.0%	1.7%	0.0%	0.2%
160-180	0.0%	0.0%	0.0%	0.0%	2.3%	3.2%

Similarly, upon combining the sample of unlopped trees from BH-BE and BH-MF (sites that are physically next to each other), *Strychnos n.* had higher %BAI than *T. paniculata*, *T. alata*, and *Xylia x.* for 20-40cm ($p<0.05$) and 60-80cm ($p<0.06$), and also higher than *Randia s.* and *Phyllanthus e.* ($p<0.05$ or better) in the 20-40cm girth class when tested using non-parametric pair-wise comparisons, and in some cases even with parametric multiple-comparison tests. (These results could not have been due to differences in the BH-BE and BH-MF sites.) Clearly then, some species are faster growing than others.

C.2 Effect of lopping

The growth rate of a tree depends not only on which species it belongs to, but also upon environmental and management variables. The management variable which is most obviously related to tree growth rates is lopping, since the removal of all tree foliage would result in the repartitioning of assimilate towards new foliage growth, rather than towards woody matter buildup (Cannell, 1983). Thus, e.g., it has been reported that the removal of the lower 80% of the crown in 12-year old trees of *Schima wallichi* resulted in a reduction in diameter increment by as much as 80% (Mohns, 1984).

Two of the time-series sites, BK-LOP and BH-BE included regularly lopped and unlopped trees. Of these, BK-LOP was in fact an experiment carried out by CES to test the effect of different intensities of lopping (i.e., percentage of crown removed) on girth increment. Three years of girth increment data[8] from 5 strips of 50mx100m, with about 30-40% of the trees in each strip being subjected to varying degrees (0% to 100%) of crown removal annually, were available for this analysis. Given the differences in growth rates across girth-classes and species for unlopped trees, it was necessary to disaggregate the lopped/unlopped comparisons by species and girth-class. This drastically reduced the available replicates. In order to increase the number of replicates, I combined trees subjected to "100%" or "75%" lopping into a single "lopped" category, and all the

[8] It appears that the site was a previously lopped one, so that the problem of the first three years corresponding to "transient" behaviour is not so serious.

unlopped in these strips into the "unlopped" category. The results, presented in Table C.2, show that, for the species that could be meaningfully tested, a lopping effect was apparent at only the the smallest girth-classes (20-40cm and perhaps 40-60cm).

Table C.2 Testing for the effect of 75% or 100% lopping on girth increment

Girth class [cm]	Site = BK-LOP		Site = BH-BE			
	Aporosa	T.pani.	T.pani.	Xylia	T.alata	Careya
20-40	$p<0.04$ (29:2)	$p<0.01$ (22:3)	n.s. (36:7)	NA	NA	NA
40-60	$p<0.07$ (13:19)	n.s.	n.s. (6:2)	NA	n.s. (3:2)	n.s.* (20:4)
60-80	n.s. (10:22)	n.s. (6:7)	n.s. (11:6)	NA	NA	n.s. (19:7)
80-100	NA	n.s. (7:4)	NA	NA	n.s. (3:4)	NA
100-120	NA	n.s. (2:11)	n.s. (10:2)	NA	NA	NA
120-140	NA	NA	NA	NA	n.s. (11:4)	NA
140-160	NA	NA	NA	NA	n.s. (6:2)	NA

1) NA = Test not conducted due to inadequate replicates in at least one of the categories.
2) Test used = non-parametric (Mann-Whitney U-test).
3) Dependent variable tested was average annual girth increment [cm/year]. In the case of BH-BE, the result for one cell (marked with *) became significant if the girth increment in the year immediately after lopping was used at the dependent variable.
4) Numbers in brackets correspond to the number of trees in unlopped and lopped categories respectively.
5) n.s. = difference not significant at even $p<0.10$.
6) The above species represent the dominant species in each plot that contained both lopped and unlopped trees. The share of each species in the total number trees at each site ranged between between 10-30%.

The BH-BE site was also a *soppinabetta* site, in which the betta-holder practiced a four-year lopping rotation. No specific control was exerted by CES researchers on the lopping, but each year that girth was monitored, a note was made as to whether it appeared to be lopped that year or not. I used this information to compare the girth increment for the trees that had been lopped at least once in the six years of girth monitoring with the other trees in each girth class-species combination. The results are given in Table C.2. No effect is apparent in any case.

In both cases, the highly inadequate number of replicates (as seen in the table) make generalization very hazardous. It would seem, however, that lopping has some effect at lower girth-classes, and not at higher ones. Interestingly, the lopping observations showed that the betta-holders tend to lop larger trees (GBH>60cm), suggesting the possiblity that they know the deleterious effect of lopping younger trees. Note also that the lopping in the BK-LOP site, where some negative effect was detected, is atypically severe, in the sense that betta-holders rarely lop every year; most bettas are lopped on a two-, three- or four-year cycle. Thus, it is possible that the direct effect of traditional lopping practices on girth increment itself is rather small. Other effects such as increased tree mortality, or reduced height increment, or reduced seed formation and therefore reduced regeneration need to be examined in the future.

C.3 The effect of "site" on girth increment

In order to examine whether the time-series sites were somehow different from each other, I chose trees of *Terminalia paniculata*, the only species that has sufficient replicates in each site-girth class combination. Significant site-wise differences were apparent when pair-wise Mann-Whitney U-tests (and t-tests) were conducted.[9] In particular, *T.paniculata* trees in BH-BE had lower %BAI than those in BK-LOP and SUGAV for girth classes 20-40, 100-120 and 120-140 at $p<0.05$ or better. Excluding lopped trees did not change the result (although it is possible that some of the trees in BH-BE classified as unlopped were actually lopped before monitoring of the site began). Although data on the soil fertility of the sites are not available, all signs (deeper soil, taller trees) point to BH-BE actually being more fertile than BK-LOP. A more likely explanation of the slower rate of tree growth at BH-BE would seem to be the difference in canopy closure: for similar tree densities (381 per hectare in BH-BE, 371 in BK-LOP), the basal area in BH-BE is $24m^2$ as against $13m^2$ in BK-LOP, and the trees are much taller, resulting in a much denser canopy than that in BK-LOP. This would result in reduced availability of light and slower rate of growth in the former.

On the other hand, no significant differences were found between trees in BH-BE and BH-MF for any girth class.[10] Neither did BH-BE and BH-MF differ with respect to any other common species (*Careya, Strychnos, or T.alata*), except for *T.alata* in the 60-80cm class ($p<0.07$) and *Careya* in the 40-60cm class ($p<0.01$), with BH-BE showing lower %BAI in both cases. Clearly then, the main cause of the difference between the *aggregate* average girth-specific %BAI between these two geographically adjacent sites (see Table 1, Chapter III) must be mainly a result of differences in *species*

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[9] A parametric multiple-comparison test (HSD for unequal N) showed a "site effect" for only the 80-100cm girth class. But given the highly unbalanced design and non-normality of the distribution (since the girth increment values are unlikely to be negative), I believe that the absence of an "effect in the multiple-comparison does not negate the pair-wise results.

[10] Other sites were also tested, but are not reported here.

composition, with BH-MF having a preponderance of faster-growing *Strychnos*, *Calycopteris* and *Alangium* genera.

C.4 Determining %BAI rates in the face of complexity

It appears therefore that tree girth increment rates depend not only on species type, but also on the structure of the tree stand. However, even such large datasets (250-450 trees monitored for six years at each of six sites) is completely inadequate to determine species-specific girth increment rates for many of the large variety of species occurring in the Malnaad village forest lands, let alone determining the relationship between these rates and stand structure! I therefore decided to adopt the *aggregate* (i.e., all species and lopped/unlopped combined) girth-specific %BAI rates from sites that appeared to most resemble the village forests of interest. Most of the betta plots I sampled in the Sirsimakki and Tattikai village clusters resembled the BK-LOP plot in basal area, canopy closure, tree heights, intensity of lopping and (in the case of samples from Sirsimakki) in species composition too. I therefore adopted BK-LOP as the representative site.

On the other hand, the BH-BE and BH-MF sites were not only geographically adjacent to the Malenalli cluster, but also very similar to the vegetation there in terms of canopy closure, tree height and basal area. Given that BH-MF contained a number of species (especially *Strychnos*) that commonly occurred in the vegetation sampled in the Malenalli cluster, and given the absence of any real difference between the growth rates for the two sites (as shown above), I decided to adopt the *aggregate* girth-specific %BAI rates for the *pooled* sample of trees from BH-MF and BH-BE. In cases where girth increment rates were not available (some of the higher girth-classe being unrepresented in BK-LOP), "guesstimates" were inserted. The set of mean %BAI values (and associated standard errors) used in the TWAGB increment calculations is given below in Table C.3.

Table C.3 Annual %BAI rates adopted

Girth Class	For tree vegetation samples in Sirsimakki and Tattikai village clusters (from BK-LOP: all treatments)		For tree vegetation samples in the Malenalli village cluster (from pooled sample for BH-BE & BH-MF)	
	Mean	Std.Error	Mean	Std.Error
20-40cm	9.13%	0.78%	5.98%	0.42%
40-60cm	3.99%	0.63%	2.32%	0.34%
60-80cm	2.58%	0.52%	1.11%	0.30%
80-100cm	2.10%	0.48%	0.51%	0.30%
100-120cm	1.84%	0.58%	0.77%	0.21%
120-140cm	1.95%	0.57%	0.64%	0.26%
140-160cm	0.97%	2.04%	0.23%	0.18%
160-180cm	2.83%	0.89%	0.72%	0.20%
180-200cm	1.41%*	0.39%*	1.89%	0.67%
200-220cm	1.48%*	0.59%*	1.99%	0.48%
220-240cm	0.95%*	0.50%**	1.50%**	0.50%**
240-260cm	0.97%*	0.34%*	1.50%**	0.50%**
260-280cm	1.25%*	0.50%**	1.50%**	0.50%**

*: Value is the average of values for that girth-class across all sites, where available.
**: Value is "guesstimate".

Appendix D. Land-use and vegetation condition: Classification, methods and inventories

Data on land area and vegetation condition (type, morphology, density etc.) were compiled at two levels, viz., household and village, for various purposes. At the houshold level, data on agricultural holdings and crop choice were essential to assess the household's asset position and relate it to biomass use. Data on the vegetation condition in uncultivated lands owned or controlled by the household provided information on the partitioning of its biomass resources into vegetation types. At the village scale, data on vegetation condition in uncultivated lands were used in (a) estimating the production of tree biomass in the village and area used by villagers, and (b) in conjunction with aggregate crop areas for comparing the allocation and condition of uncultivated lands across village clusters.

Information on the legal category of all the lands in the village allow some estimates of changes in land use over time. This is more reliable in private land, where the legal categories correspond very closely to crop type at the time of survey and settlement of the land. Its is trickier in "public lands" where "forest land" did not necessarily correspond to "forested" land even at the time of settlement. The existence of cultivation in forest lands may however in most cases correspond to a change in vegetation that occured after survey and settlement. Knowing the legal category also helps assess the influence of the forest rights regime (betta/MF/RF) on land-use and vegetation condition.

D.1 Classification of land-use and vegetation condition

I begin with the somewhat artificial but useful distinction between *cultivated* and *uncultivated* vegetation. Cultivated vegation is vegetation which is actively planted, irrigated, manured, and taken care of by the user of the land. It includes prenneial crops and annual crops. In the Malnaad these consist mainly of (a) areca, (b) coconut, (c) mulberry, (d) cashew, and (e) timber plantations, and *seasonal* crops consisting of (a) paddy, (b) sugarcane and (c) cotton.[1]

Uncultivated vegetaion was defined as vegetation that is not actively planted, irrigated and manured, or for which no land was ploughed or pits dug. It may however be manipulated and modified in many other ways, through lopping, cutting, firing, protecting, etc. It includes four broad categories of vegetation types and morphologies:

(a) unlopped "natural" treeland,

(b) lopped treeland, with varying combinations of tree densities and grass growth,

(c) grassland, and

(d) scrub or barren land.

Each of these categories corresponds to broad differences in the way the vegetaion is used. *Unlopped "natural" treeland* is closest to the conventional notion of a dense forest, and is characterized by a low-intensity extraction or disturbance regime, with biomass extraction being in the form of "minor" forest produce (including wild pepper, honey, fruits, seeds), leaflitter and deadwood collection, and limited cutting of shrubs or grazing. In other words, the tree vegetation is left largely intact, both in morphology and

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[1] These crops correspond to the vegetation seen in the wet season. Winter or summer crops of legumes, pulses, and vegetables may be taken in the land occupied by paddy during the wet season, but their extent is at most 10% of this area.

in species composition (at least in the short run).

Lopped treeland represents the traditional picture of a *soppinabetta*, where trees have a lopped morphology. The composition of tree species is usually somewhat different from that of a "natural" forest in the locality, as users manipulate the regeneration, and also create a drier regime through their lopping, thus favouring succession by species of moist-deciduous forests such as *Terminalia sp.* Undergrowth may consist of shrubs that are harvested annually, or may be fully grass. These forests are clearly being used for leaf manure, mulch and firewood from the trees, and manure or fodder from the undergrowth. Within this category, however, significant variation in tree densities (and inversely in grass growth) may exist, resulting in significantly different relative mixes of the products. I have classified lopped treeland into four sub-categories on the basis of tree density and basal area[2]:

(i) *High density*, i.e., tree density > 400/ha or basal area > $20m^2$/ha, mainly providing leafy matter, woody matter (including timber) and shrub biomass;

(ii) *Medium density*, i.e., tree density between 100-400/ha or basal area between <$20m^2$/ha, providing leafy matter, woody matter, and some grass;

(iii) *Low density*, i.e., tree density between 20-100/ha or basal area < $8m^2$/ha, providing mostly grass, and some leafy and woody matter.

Grasslands include "pure" grasslands and tree savannahs with trees in clumps or

[2] One would ideally like to distinguish between treeland of a particular density class with significant grass growth from that without. However, distinguishing between such conditions during the dry season, when a lot of the mapping was carried out, was not easy. Further, the complex interactions between management regime, particularly the use of fire, and edaphic conditions in determining the presence or absence of grass under an open canopy makes it hard to determine whether this presence or absence corresponds to purposeful modification or not.

along the edges of the patch. In most locations, they appear to be actively created and maintained for fodder production the use of fire, although in some cases the edaphic regime may also contribute in preventing tree growth. More important, in all but the most remote locations, the presence of high level of vegetative cover in the grass layer corresponds to the presence of some form of protection against or control of grazing (through fencing or trenching).

Scrub or barren land is that land which appears to produce little biomass of any kind but does not appear to be specifically maintained for non-vegetational use (see below). It was defined as land with tree densities of less than 20 per ha, with hacked or stunted morphologies, and little evidence of grass growth (using visual estimates of exposed soils versus vegetated soil). It is distinguished from grassland would correspond to equally low densities but visual evidence of high grass growth or growth potential.

In addition to cultivated and unclutivated land, land is used or occupied by a variety of *non-vegetational* uses, which include habitation areas, roads, ponds, stream channels, mud quarries, etc.

D.2 Legal classification of land

All the land in Indian villages is classified into private and public lands. In the Malnaad, private lands consist of three categories set up at the time of land survey and settlement:

(a) orchard land (*bagayati*),

(b) wet cropland (*tari*), and

(c) dry cropland (*khushki*).

Public lands in the Malnaad include "forest" lands and other lands that I call "public non-forest" lands. Forest lands consist of three categories (see Chapter I for details):

(d) *soppinabetta* (or betta),

(e) Minor Forest (MF), and

(f) Reserve Forest (RF),

corresponding to privately controlled, open-access, and state-controlled *public forest lands*. Finally, non-forest lands consist of land set aside for village houses (*gaavthaan*) or irrigation tanks, roads, etc.

D.3 Methods

Information on land-use and vegetation condition in the sample villages and households was obtained using a combination of official records, survey questionnaire data, key informant interviews, and mapping.

D.3.1 Aggregate land-use and vegetation at the village-scale

Information on the areal extent of the different legal categories of private and public lands was obtained from the village accountant (*talathi*). Forest land information was cross-checked with information in the copies of "Village Forest Registers" at the Divisional Office of the Forest Division.

Mapping of actual land-use and vegetation in the forest lands was carried out with the village "revenue" maps[3] as the base. Sampling of *soppinabetta* vegetation at select sites, described in Chapter III and Appendices A and B, provided estimates of typical tree densities and basal area. I then traversed all the village forest lands on foot, and assigned vegetation categories visually using experience from the sampled sites as a guide. In many cases, vegetation followed some natural boundaries (e.g., streams), fences, or legal boundaries (e.g., dry croplands were almost always grasslands or coconut/mulberry orchards). The totals for vegetation categories were then compared with those from individual responses to surveys, and found to match within $< \pm 20\%$.

Village-level totals of the extent of and cropping pattern in private lands were compiled from the information on individual holdings and compared with other sources of village-level information (e.g., Census,1981).

D.3.2 Household-level information

Information on individual landholdings of <u>cultivated</u> lands and the actual crops cultivated in them within each village had been initially obtained from questionnaire surveys by CES. This was then compared with information from the *talathi* and discrepancies were sorted out during my re-survey of the households. Field observations, noted on the village revenue maps, were also used in the re-survey.

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[3] These maps show the boundaries of legal plots ("revenue survey numbers") within a "revenue" village (see chapter I). They are drawn at 1:3960 or 1:7920 scale, and were prepared using chain surveys around 1890-1900. They have not been properly updated since, but still provide the best information at the village scale, and area estimates obtained from them were found to be remarkably accurate. Most of the marking stones and mounds corresponding to vertices on the revenue maps exist even today, and were invaluable in locating oneself in the field. In the case of Sirsimakki and Mundagesara villages (SM cluster), the Survey of India had prepared 1:5000 scale maps at CES' request. These maps include an overlay of revenue plot boundaries, and one containing broad vegetation categories, which I updated and modified in the field.

Information on the area of <u>forest land</u> controlled by the individual household and the condition of vegetation in it (including "illegal" or "semi-legal" use of these lands)[4] was based on the questionnaire survey and re-survey. Cross-checks were carried out by

(e) comparing the ratio of areca land to betta holding declared in the questionnaire with the official ratio (total official areca land to official betta land in the village, which is around 1:8);

(f) verifying the boundaries and measuring the area (either directly or after marking the boundaries on the map) for a sample of about 10% of the households; and

(g) using information provided by key individuals who were highly knowledgeable about the manner in which the *soppinabetta* lands had been actually divided up amongst households.

Information on land held by households in villages outside those in the sample villages was based only on responses to the questionnaire surveys, except in the case of many households in Golikoppa and Arasapura villages.

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[4] I use the term "semi-legal" to denote situations in which the law apparently allows conversion of public land for private use in principle, but seems to require bureaucratic permissions, the criteria for granting which are never spelt out, or where no permission may be required, but the procedures for official transfer of land title are not spelt out or completed. The extension of areca orchards into *soppinabettas* through the excavation of soil (KFD, 1976, 131(F)(ii-6) & (ix)), the construction of houses in *soppinabettas* (ibid., para. 131(F)(viii)), or the cultivation of cashew in Minor Forest lands (ibid., para. 131(E)(v)) are examples of such situations.

"Illegal" use, on the other hand, is use that is clearly (although perhaps arbitrarily) prohibited, particularly cultivation or house construction in RF lands. On the whole, I found that villagers were remarkably forthcoming about their illegal landholdings. While their confidence in CES' motives (and therefore in mine) may have made obtaining such information particularly easy for me, I was told that "encroachers" enjoy the sympathy and support of political parties, and are usually not worried about being "evicted" or prosecuted. Nadkarni *et al.* (1989) report experiencing similar frankness. In fact, it appeared that encroachers wanted to be identified and fined by the Forest Department, since such a fine provided "proof" that they had been cultivating that plot since that date; there were even cases where the encroacher himself informed the Forest Department of having encroached at so-and-so location and is willing to pay the requisite fine. Such proof of cultivation almost guarantees eventual "regularization" of the encroached land into a legal holding.

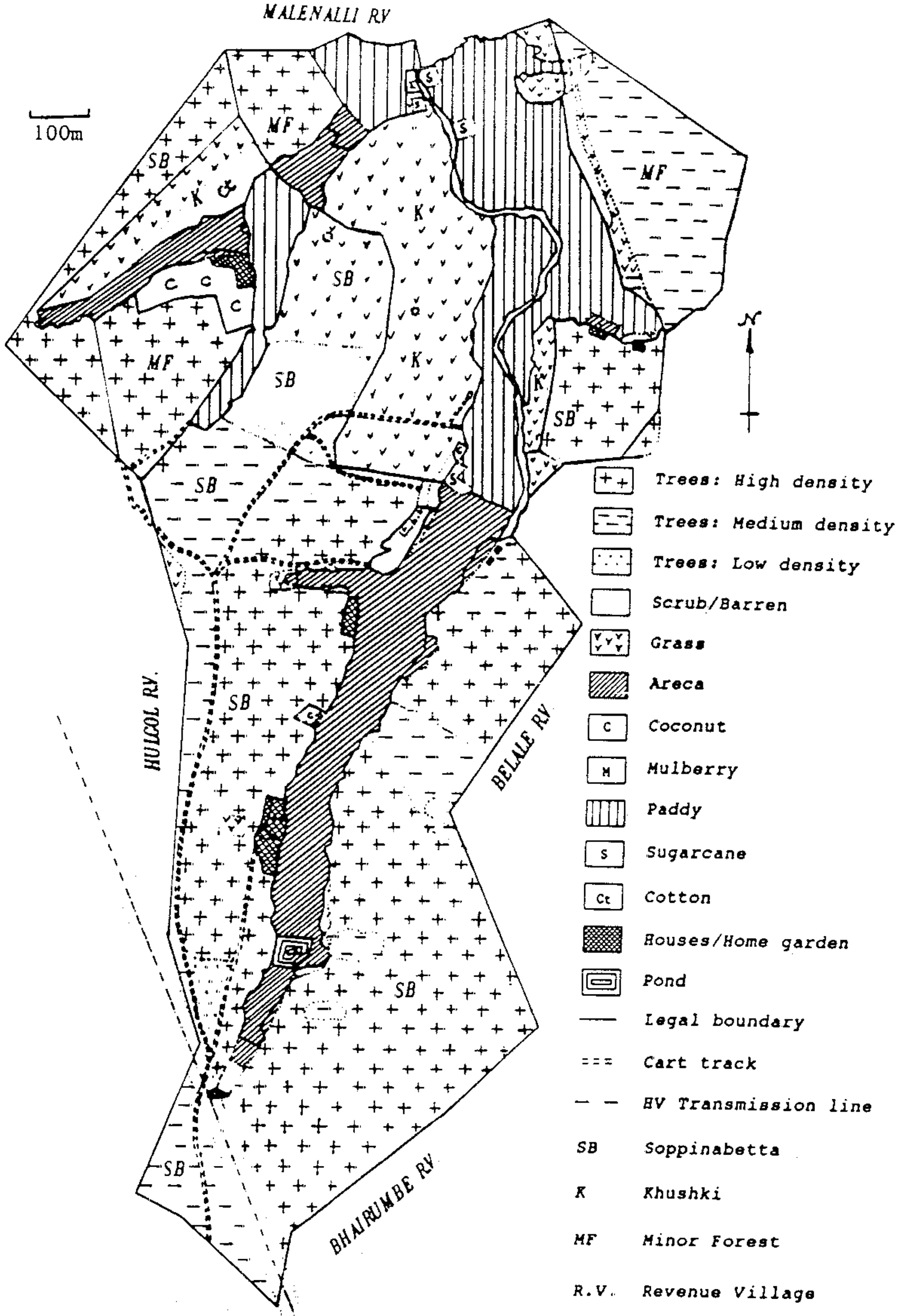

Figure 1 Vegetation in Arasapura village (Malenalli village-cluster)

D.4 Village-level inventories

In order to give the reader an idea of the spatial pattern and extent of land-use and vegetation types, a vegetaion map for Arasapura village is presented in Figure 1.

Detailed information on the total area under each legal category, and the extent of various vegetation types in it, for seven villages, two each in the TK & SM clusters, and three in the MH cluster,[5] is presented in Tables I-VII. In each table, the sequence of the legal categories is private, public forest, and then public non-forest land. Within each private land category, the "original" or "typical" use to which the category corresponds is given first. Within each forest land category, the sequence is from high density ("real") forest to grassland to barren land. All the information in the maps and tables pertains to the situation prior to the beginning of CES-initiated tree planting activities in the forest lands.

[5] The land-use tables for the unit denoted as Keregadde in the TK cluster and for the small hamlets of Vadagéri (SM cluster) and Mulakinakoppa (MH cluster) are not presented; the first because of some missing data, and the latter two because of their small size. The choice of unit boundaries is described in Chapter 1.

Table 1: Land-use in Kelagina Sarakuli village

Legal Type	Area [ha]	Vegetation Type	Area [ha]	% of Total
Bagayati	6.62	Areca	6.02	91%
Bagayati		O.Orchard	0.23	4%
Bagayati		Sugarcane	0.02	0%
Bagayati		Non-Agri	0.34	5%
Tari	8.75	Paddy	6.72	77%
Tari		Sugarcane	0.16	2%
Tari		O.Orchard	1.21	14%
Tari		Grass	0.64	7%
Tari		Non-Agri	0.02	0%
Khushki	1.76	Grass	0.78	44%
Khushki		Areca	0.01	1%
Khushki		O.Orchard	0.81	46%
Khushki		Sugarcane	0.04	2%
Khushki		Non-Agri	0.12	7%
Betta	51.76	HiDensity	20.44	39%
Betta		MedDensity	20.44	39%
Betta		LowDensity	3.84	7%
Betta		Scrub	0.16	0%
Betta		Grass	3.84	7%
Betta		Areca	0.32	1%
Betta		O.Orchard	0.04	0%
Betta		Non-Agri	2.67	5%
MF	0.00	No Minor Forest in this Village		
RF	0.00	No RF in this Village		
Uncultivable	0.22	River & other	0.22	

Table 2: Land-use in Tattikai hamlet

Legal Type	Area [ha]	Vegetation Type	Area [ha]	% of Total
Bagayati	19.28	Areca	18.23	95%
Bagayati		Non-Agri	1.05	5%
Tari	3.99	Paddy	2.13	53%
Tari		Sugarcane	0.65	16%
Tari		Areca	0.95	24%
Tari		Grass	0.22	6%
Tari		Non-Agri	0.04	1%
Khushki	12.24	Grass	4.92	40%
Khushki		Areca	0.04	0%
Khushki		O.Orchard	4.82	39%
Khushki		Paddy	0.30	2%
Khushki		Sugarcane	0.17	1%
Khushki		Forest	1.83	15%
Khushki		Non-Agri	0.16	1%
Betta	135.01	HiDensity	52.81	39%
Betta		MedDensity	52.81	39%
Betta		LowDensity	11.86	9%
Betta		Scrub	4.45	3%
Betta		Grass	11.86	9%
Betta		Areca	0.72	1%
Betta		O.Orchard	0.09	0%
Betta		Non-Agri	0.41	0%
MF	0.00	No Minor Forest in this Village		
RF	5.17	UnLopped HiDensity	3.96	77%
RF		Lopped HiDensity	0.81	16%
RF		Scrub	0.40	8%
Gaavthaan	0.00	No legal habitation area in this village		

Table 3: Land-use in Mundagesara village

Legal Type	Area [ha]	Vegetation Type	Area [ha]	% of Total
Bagayati	27.24	Areca	26.86	99%
Bagayati		O.Orchard	0.14	1%
Bagayati		Non-Agri	0.24	1%
Tari	5.12	Paddy	4.84	95%
Tari		Sugarcane	0.00	0%
Tari		Areca	0.10	2%
Tari		O.Orchard	0.00	0%
Tari		Grass	0.08	2%
Tari		Non-Agri	0.10	2%
Khushki	1.25	Grass	0.40	32%
Khushki		Areca	0.11	9%
Khushki		O.Orchard	0.61	48%
Khushki		Sugarcane	0.00	0%
Khushki		Non-Agri	0.13	10%
Betta	225.03	Hidensity	47.98	21%
Betta		MedDensity	67.91	30%
Betta		LowDensity	32.64	15%
Betta		Scrub/Barren	34.40	15%
Betta		Grass	32.64	15%
Betta		Areca	0.76	0%
Betta		O.Orchard	5.77	3%
Betta		Non-Agri	2.95	1%
MF	0.00	No Minor Forest in this Village		
RF	0.00	No RF in this Village		
Gaav-thaan	1.30	Houses	1.30	100%

Table 4: Land-use in Sirsimakki hamlet

Legal Type	Area [ha]	Landuse	Area [ha]	% of Total
Bagayati	19.48	Areca	18.70	96%
Bagayati		O.Orchard	0.63	3%
Bagayati		Non-Agri	0.15	1%
Tari	9.82	Paddy	8.68	88%
Tari		Sugarcane	0.55	6%
Tari		Areca	0.14	1%
Tari		O.Orchard	0.09	1%
Tari		Grass	0.14	1%
Tari		Non-Agri	0.22	2%
Khushki	0.34	Grass	0.00	0%
Khushki		Areca	0.00	0%
Khushki		O.Orchard	0.00	0%
Khushki		Sugarcane	0.13	38%
Khushki		Non-Agri	0.21	62%
Betta	123.12	Hidensity	16.19	13%
Betta		MedDensity	57.75	47%
Betta		LowDensity	17.91	15%
Betta		Scrub/Barren	8.09	7%
Betta		Grass	17.91	15%
Betta		Areca	0.75	1%
Betta		O.Orchard	3.78	3%
Betta		Non-Agri	0.74	1%
MF	0.00	No Minor Forest in this Village		
RF	5.26	HiDensity Unlopped	2.83	54%
RF		O.Orchard	2.43	46%
Gaavthaan	1.06	Houses	1.06	100%

Table 5: Land-use in Golikoppa village

Legal Type	Area [ha]	Vegetation Type	Area [ha]	% of Total
Bagayati	7.56	Areca	7.54	100%
Bagayati		Grass	0.02	0%
Tari	5.43	Paddy	3.25	60%
Tari		Areca	0.85	16%
Tari		O.Orchard	0.26	5%
Tari		Casuarina	0.72	13%
Tari		Uncultivable	0.35	6%
Khushki	4.12	Grass	1.36	33%
Khushki		O.Orchard	2.75	67%
Betta	53.95	HiDensity	45.25	84%
Betta		MedDensity	2.36	4%
Betta		LowDensity	4.72	9%
Betta		Scrub	0.40	1%
Betta		Grass	0.00	0%
Betta		Areca	0.81	2%
Betta		Non-Agri	0.40	1%
MF	0.00	No Minor Forest in this Village		
RF	7.68	HiDensity	7.10	92%
RF		LowDensity	0.58	8%
Gaavthaan	1.50	Non-Agri	1.50	

Table 6: Land-use in Arasapura village

Legal Type	Area [ha]	Land-use	Area [ha]	% of Total
Bagayati	11.55	Areca	11.49	100%
Bagayati		Grass	0.04	0%
Bagayati		Non-Agri	0.01	0%
Tari	19.56	Paddy	18.43	94%
Tari		Sugarcane	0.39	2%
Tari		Areca	0.55	3%
Tari		O.Orchard	0.10	1%
Tari		Grass	0.08	0%
Khushki	21.57	Grass	16.63	77%
Khushki		Areca	0.04	0%
Khushki		O.Orchard	1.90	9%
Khushki		Paddy	0.71	3%
Khushki		Sugarcane	0.01	0%
Khushki		Cotton	1.54	7%
Khushki		Non-Agri	0.74	3%
Betta	85.85	HiDensity	59.66	69%
Betta		MedDensity	14.24	17%
Betta		LowDensity	4.84	6%
Betta		Scrub	5.42	6%
Betta		Grass	1.11	1%
Betta		Areca	0.34	0%
Betta		Non-Agri	0.10	0%
MF	18.66	HiDensity	8.09	43%
MF		MedDensity	10.16	54%
MF		Paddy	0.40	2%
RF	0.00	No Reserve Forest in this Village		
Uncultivable	0.87	Pond+River +others	0.87	

Table 7: Land-use in Malenalli village

Legal Type	Area [ha]	Vegetation Type	Area [ha]	% of Total
Tari	40.19	Paddy	32.21	80%
Tari		Sugarcane	0.96	2%
Tari		Areca	0.70	2%
Tari		O.Orchard	5.62	14%
Tari		Teak	0.33	1%
Tari		Non-Agri	0.37	1%
Khushki	11.71	Grass	4.81	41%
Khushki		O.Orchard	1.52	13%
Khushki		Teak	2.23	19%
Khushki		Scrub	0.16	1%
Khushki		Non-Agri	2.99	26%
MF	76.10	HiDensity	46.91	62%
MF		MedDensity	2.02	3%
MF		LowDensity:No grass	4.05	5%
MF		Grass	14.57	19%
MF		Scrub	6.88	9%
MF		Areca	0.15	0%
MF		O.Orchard	0.05	0%
MF		Paddy	1.11	1%
MF		Sugarcane	0.25	0%
MF		Non-Agri	0.10	0%
RF	142.10	HiDensity	84.79	60%
RF		MedDensity	42.40	30%
RF		Grass	2.33	2%
RF		Areca	0.53	0%
RF		Paddy	10.74	8%
RF		Sugarcane	0.15	0%
RF		Cotton	0.76	1%
RF		Cult.Fallow	0.40	0%
Uncultivable	0.21	Pond	0.21	100%

Note: No Bagayati or Betta land in this village.