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Assessment of Biomass Energy Resources: A Discussion on its Need and Methodology

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ASSESSMENT OF BIOMASS ENERGY RESOURCES:

A DISCUSSION ON ITS NEED AND METHODOLOGY

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ABSTRACT

This paper points out the importance of woody and non-woody biomass from an energy perspective in developing countries. It then considers the dearth of reliable data on the standing stock and sustainable yield of woody biomass and on the quantities of crop residues and other non-woody biomass that could potentially be used for fuel within the woodfuel catchments of both urban and rural areas. The paper emphasises the need for sufficently reliable data so as to be able to carry out meaningful energy planning as well as for the development and management of woodfuel resources. It points out that biomass assessment should not be an end in itself, but should be used as a planning and management tool and that it should be used as cost efficently as possible, with the scope and intensity of the assessment being dictated by planning and management needs. Woody and non-woody biomass is defined and the various parameters that may be used to assess woody biomass are described. The paper deals largely with the assessment of woody biomass and after discussing the general principles involved with such assessment, it then covers in some detail the methodologies that may be employed, including the appropriate use of satellite imagery and aerial photography; resource mapping; the establishment of tree-weight functions; and the design and execution of field inventories for both forest and non-forest areas. Variations in the methodologies are discussed. The difficult question of determining growth rates and yield potential is also discussed. Methods for estimating non-woody biomass are dealt with, particularly as they relate to crop residues. Finally, the paper demonstrates the type of data that can result from biomass assessments and the use to which it can be put.

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ABBREVIATIONS AND ACRONYMS

AVHRR	Advanced very high resolution radiometer
db	dry weight basis (moisture content)
dbh	diameter at breast height (1.3m)
ESMAP	Joint UNDP/World Bank Energy Sector Management Assistance Program
FAO	Food and Agricultural Organization of the UN
GIS	Geographic Information System
GPS	Global Positioning System
MSS	Multi-spectoral scanner (Landsat)
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NRSA	National Remote Sensing Agency (India)
NDVI	Normalized Difference Vegetation Index
SADCC	Southern African Development Cooperation Council
TM	Thematic Mapper (Landsat)

ASSESSMENT OF BIOMASS ENERGY RESOURCES: A DISCUSSION ON ITS NEED AND METHODOLOGY

I. INTRODUCTION

Background

1.1 Biomass provides about 14% of the world's primary energy, equivalent to 25 million barrels of oil per day and is the major fuel in most developing countries, providing on the average 35% of the energy to 75% of the world's population (Hall, 1990). This rises to between 60 to 90% of the energy requirements for most Sub-Saharan African countries and many Asian countries. The principal consumers are households both urban and rural with 85 to 99% of their energy needs being met by biomass in these same countries, although small scale (rural) industries and some service sector industries (restaurants, bakeries) also rely on biomass as fuel.

1.2 Little attention has been paid by planners or countries to the supply or demand of this energy, but now it is being realized that biomass is meeting and can continue to meet the energy demands of a large section of the community. However, biomass is a conditionally renewable resource; it is renewable on condition that it is managed properly and is not mined. In order to manage the resource, it is necessary to determine how much biomass is available on a sustained basis. For woody biomass this entails measuring growing stock and annual yield whereas for plants and animals estimates of annual residue production have to be undertaken. Unless and until supply statistics are accurate, strategy planning and forecasting become a matter of guesswork and faith. Hence the importance of undertaking sound biomass assessment work.

1.3 In the context in which it is used here, biomass is defined as plant material that is used for energy generation through direct combustion. Biomass fuels may be categorized into three types: (a) woody biomass; (b) non-woody biomass; and (c) animal residue (dung). Woody biomass may be burnt directly as fuelwood or first converted into charcoal before being used. Both woody and non-woody biomass may be converted into liquid fuels such as ethanol and methanol or may be used as feedstock for thermal power generation. Woody biomass comes from any ligneous plant such as trees, bushes or bamboos. Non-woody biomass includes leaves, herbaceous plants and crop residues, although some of the latter, such as cotton and rapeseed stalks are quite woody. For convenience they are usually classified under "non-woody biomass". Animal residues may come from the excrement of any animal but cattle dung is the most common form. Not considered here is city waste and sewage.

1.4 Fuelwood or charcoal are the principal forms of biomass fuels and are not only used by households, but by many small industries both rural and urban such as agricultural processing (tea, tobacco, parboiled rice, cassava production) brick and tile manufacture, alcoholic beverage production, wood processing, bakeries, restaurants/canteens/food stalls etc. Some industries burn their own agricultural residues, the principal one being sugar manufacturing where bagasse is used.

1.5 Rural households tend to consume firewood, although in Sudan, as woodfuel resources become scarce, charcoal is being purchased and used more widely in the rural areas. Generally, the tendency in rural areas with ample supplies of woody biomass is to burn branches and even small or split stem wood. However, in countries where prices for fuelwood and charcoal are reasonably high, such as Ethiopia and India, villagers may cut and sell the larger wood, and they themselves use small branches, twigs and leaves. However, in areas where woodfuel resources overall diminish within an accessible radius the rural household becomes more dependent on twigs and leaves as well as non-woody biomass such as crop residues, and animal dung. However, if too great a proportional of crop residues and dung is burnt and not returned to the field this can have a detrimental effect on soil fertility and conservation.

1.6 Urban households and small industries are both fuelwood and charcoal consumers depending on tradition and income. For those urban areas that use charcoal e.g. in Sudan, Kenya, Ethiopia, Uganda and Tanzania, the drain on the woodfuel resources has been increasing substantially with increasing urbanization and the fact that between four and seven tonnes of air dry wood are needed to make a tonne of charcoal, although one should bear in mind that charcoal has twice the energy value of wood per unit weight.

Current State of Biomass Assessment

1.7 Estimates of woody biomass and, to a lesser extent, of non-woody biomass consumption have been made for urban and rural areas, at both a micro and macro basis in many countries using household energy consumption surveys. These have been compared to usually very rough estimates of the biomass resource: typically defined as the woody biomass standing in specific areas of forest or woodland and its sustainable yield as determined by estimates of its growth rate. Unfortunately the statistics for biomass resources in most, if not all, developing countries, and in several developed countries lack any degree of statistical accuracy. The Beijer Institute (1982) compiled statistics on biomass for all areas of Kenya, both forest and agricultural land, but few other African countries have done the same. Much work has been done in the United States, Canada and in several European countries on woody biomass from trees and shrubs, particularly since the mid 1970's when the energy potential of biomass was recognized to a greater degree following the OPEC oil price increases. 1/

1.8 FAO has been one of the principal agencies involved in compiling data on woody biomass resources and yield potential for developing countries. However, most of the data have

1/ Cost and McClure (1982); Saucier, Phillips and Williams; Keays (1971); Stanek and State (1978); Cost and Tansey; et al.

been derived from country reports, many of which refer only to (commercial) stem wood, and the data present in the reports usually lacks accuracy as regards woody biomass growing stock and yield. Even data for state forest areas are generally lacking in accuracy. This is because the forest mensuration methods used have generally tended to concentrate on the commercial (industrial) wood extraction possibilities. Consequently, the ensuing mensuration data has consisted mainly of stem volumes of potentially commercial species and within potentially commercial size limits net of defects. Such estimates neglect the tops, branches, non-commercial species, woody undergrowth and dead wood, all of which are often major sources of fuel.

1.9 Most importantly, these mensuration estimates give little if any indication of the woody biomass stocking and productivity in forest areas outside high forests because such areas were often not considered to have much industrial wood value. However, these areas, particularly the woodlands, are a principal source of woodfuels in much of Africa. Assessments by Openshaw (1986) and Chidumayo (1990) are notable exceptions. The other important source of woodfuels that has had very little attention is the woody biomass that occurs in non-forest areas, in villages, around farms and alongside roads. Much of the supply for rural households comes from such sources. Yield data for these are only crudely estimated. Hammermaster's study of village trees in Bangladesh (1982) is an exception as are surveys that have been carried out in India. One was carried out in Andhra Pradesh from 1987 to 1989 under the CIDA - funded Social Forestry Project (Forestal/Sandwell Swan Wooster, 1989). Another was carried out recently in two villages in Haryana State under the auspices of the FAO Regional Wood Energy Development Programme in Asia (FAO, 1990). Brown and Lugo (1984) give very broad estimates of the biomass in tropical forests, as shown in Table 1.1, but their basic volume and area data are based on FAO reports. 2/ They used studies of various life zones/forest types to determine a factor for converting stemwood biomass to total biomass (above and below ground). However, understorey biomass was not included as very few studies measured this. In general it was considered to account for less than 2 percent of the total biomass.

2/ FAO, Los Recursos Forestales de la America Tropical (1981); Forest Resources of Tropical Asia (1981), Forest Resources of Tropical Africa (1981).

Table 1.1: RATIO OF TOTAL BIOMASS TO STEM, WOOD BIOMASS FOR A VARIETY OF TROPICAL FORESTS

Life Zone	Biomass (ton/ha)		Ratio of Total biomass to stemwood biomass
	Stemwood	Total[a]	
Tropical premontane wet forest	416.1	689.7	1.7
	272.8	475.3	1.7
Tropical lower montane rain forest	385.0	552.8	1.4
Tropical montane west forest	269.7	415.8	1.5
	269.7	374.0	1.4
Tropical wet forest	229.5	415.2	1.8
	201.3	348.0	1.7
	110.5	171.7	1.6
	297.0	501.3	1.7
Tropical moist forest	346.0	473.7	1.4
	297.5	394.3	1.3
	298.9	473.1	1.6
	206.0	324.2	1.6
	230.0	361.8	1.6
Tropical premontane moist forest	63.5	170.3	2.7 b/
Subtropical wet forest	153.3	271.8	1.8
Subtropical moist forest	133.0	230.4	1.7
	209.0	290.8	1.4
	112.0	157.0	1.4
Subtropical dry forest	55.0	78.1	1.4
	29.0	89.8	3.1 c/
Mean (standard error)			1.6 (0.04)

a/ Includes stemwood, branches, leaves and roots.
b/ Not included in the calculation of the mean because these two forests are not typical of open forest formations.
c/ Trees in this formation tend to branch more and have a larger proportion of their biomass in branches and below ground.

Source: Brown & Lugo (1984)

1.10 The data situation is equally deficient for non-woody biomass supplies. Where crop residues are an important energy source some studies have been made to measure the production of residues from certain crops such as sugar cane/bagasse. However, for the most part estimates are derived from crop production, and livestock figures as has been done in Kenya (Openshaw, 1986). Reduction factors have been applied to allow for accessibility and the use of such biomass for fodder, manure, compost and as a construction material.

Why Do Biomass Assessments?

1.11 If statistics exist for biomass fuels they are usually at a national level. What is needed, particularly for household energy resources, are reliable statistics at a more micro level, within woodfuel catchments for population concentrations. This applies particularly to those catchments for people in urban areas. For these, woodfuel extraction may have a more marked effect on woody biomass resources and the environment, and the catchment may extent for a radius of 700 km or more along transport routes.

1.12 The biomass supply statistics that exist indicate that in specific areas there are current or potential deficit situations between sustainable biomass supply - i.e. supply met from annual growth - and consumption, although care needs to be taken in extrapolating the current demand and supply situations to project a future scenario as both the sustainability per se of the resource is difficult to predict as are woodfuel consumption patterns. If there are such deficits then solutions need to be found, preferably before a crisis situation develops. But first it is necessary to determine, using sufficiently reliable data, the nature and magnitude of the problem. Solutions may take the form of fuel conservation, fuel substitution and/or enhancement and management of the resource. However, to plan and implement those solutions requires data on the woodfuel resource as well as on energy consumption patterns. The former includes reliable data on the standing stock of the biomass resource, its sustainable yield, the trends in its depletion and the causes for the depletion, including the extent to which exogenous factors such as agricultural and livestock expansion have contributed to the depletion. It is only after data on both the energy resource situation and its cost as well as consumption patterns are obtained for the areas in question (with an acceptable level of statistical accuracy) that meaningful strategies to solve any biomass deficit can be made.

1.13 It must be stressed that biomass assessment should not be an end in itself simply to compile data on biomass resources. An assessment is a necessary planning and management tool and the scope and intensity of the assessment as well as the cost thereof should be dictated by these planning and management needs. If little or nothing is known about the extent, nature and sustainability of the supply of woodfuels for rural and urban households and industries within important urban woodfuel catchments, then sufficient data should be obtained so that plans can be made and interventions programmed to overcome any woodfuel shortfall. Should improved multiple-use management of the said woodfuel resource (e.g. large tracts of woodland) be proposed then sufficient data on the resource and its dynamics needs to be at hand to enable reasonable management to be undertaken. Periodic Assessments will be required to enable adjustments to be made in management or silvicultural practices so as to optimize sustainable yield on a sound economic and environmental basis.

1.14 This paper sets out the type of biomass data that are required and some of the methodologies that may be used to obtain the data, including the use of satellite imagery and aerial photography to delineate biomass resource types. The practice of biomass assessment, the methods used and the type of biomass that needs to be assessed varies from country to country, but there are significant differences between developed and developing countries, based to a large extent on the type of resource available and the use of the biomass for the energy generation. In developed countries biomass energy forms only a small percentage of total energy consumption - less than 5% in many cases, and a high percentage of this is produced by and used in industry. Collection and harvesting methods are often sophisticated and mechanized, meaning that the biomass resource needs to be concentrated and of a distinct type. In developing countries biomass is often the major energy source, particularly for households. Harvesting methods are usually basic and manual, with all types of biomass being used, depending upon scarcity of wood. The biomass concentration ranges from individual trees or small patches of crop residues to plantations or large tracts of forest/woodland. This paper concentrates on the biomass assessment in developing countries, but makes reference to biomass assessment methodologies that have been used in developed countries where such are relevant to developing countries.

II. WHAT TO MEASURE

General

2.1 The objective of a biomass assessment is to obtain estimates of the biomass available for fuel and other potential uses within accessible distances of demand centers so as to provide data with the necessary degree of scope and accuracy to enable meaningful energy planning and biomass resource management decisions to be made.

2.2 Although total country assessment of all woody and non-woody biomass available for energy would provide useful data for long range planning, it is better to limit detailed assessment to specific biomass fuels and to particular areas of a country that provide or could potentially provide biomass for energy to large demand centers. Such demand centers are cities, towns, groups of villages, or even a single village and biomass-using industries such as tea estates, fish smoking and brick kilns if these are distinct from the villages or urban areas.

2.3 The woodfuel catchment for most villages and rural industries is usually small (a radius of 1 to 5 km); however, for larger towns and cities the catchment may extend to between 200 and 400 km with considerable quantities of charcoal and/or fuelwood being extracted for the urban area, but with fuelwood also being extracted for local villages and rural industries within that same catchment. Financial and manpower resources to carry out effective biomass assessments are scarce, therefore they should be targeted to high demand areas, particularly if the indications from existing information suggest a current or near term shortfall in biomass supplies in relation to demand.

2.4 The type of biomass used for energy varies from country to country and sometimes from region to region within a country. It can also vary from season to season. In some countries with scarce woody biomass resources such as most of Ethiopia, Afghanistan and parts of China, there is very little waste. All the above ground tree material that is not used for more valuable products such as timber, poles or farm implements is used for fuel, including the leaves. In addition large quantities of agricultural residues, livestock dung and even grass are often used for energy production. In other countries with more abundant woody biomass only dead wood or cord wood (greater than 7 cm diameter) of specific species are used. Thus it is more cost effective to concentrate the assessment on biomass that is at present consumed or likely to be used in the near future while only making subsidiary measurements of the quantity and nature of the remaining biomass.

2.5 While endeavouring to be cost efficient in carrying out assessments of woody biomass, it would still be very useful if information could be obtained on the general flora and fauna situation as well as on any existing or potential soil degradation factors. This may take the form of comments at each sampling point and would assist in determining the environmental feasibility of extracting woodfuels on a sustained yield management basis or, alternatively, indicate the economic cost of environmental degradation that may be occurring or could occur with the extractionof woody biomass.

Woody Biomass

What Constitutes Woody Biomass

2.6 Woody biomass comes from trees, shrubs, bushes and clumps of bamboo. Woody biomass occurs in closed forests or open woodlands and wooded grasslands and all the gradations in between; it may be even aged, uneven aged, mixed species, single species, natural, plantation grown, managed or unmanaged. Besides being in large tracts or blocks, woody biomass can occur along roads or waterways or around villages and in fields as single trees, hedges or wind breaks. It may also be scattered throughout the farmers fields, between houses and on grasslands; in fact in hundreds of variations. Thus what constitutes woody biomass is site specific and this should be determined before attempts are made to measure it.

2.7 Wood that has a higher value use than fuel should not be categorized in the assessment as woody biomass for energy. Such wood may be used for lumber, plywood, reconstituted wood pulp or poles, the former three being referred to as "industrial wood". Determination of the wood end-use is often a site-specific judgement, based on species, tree form and size, and access to conversion facilities. The woody biomass remaining after determining the higher value use may then be used for fuel. Some "industrial wood" may eventually end up as fuel. For example sawmill residues could constitute 50% of the wood raw material and are potentially burnable. Likewise packing case material, house or fence poles, once they have served their purpose, may be burnt as fuel. In any event, assessments should not have the narrow objective of determining only the extent, quantity and nature of wood for energy, but the determination should cover wood for other uses and, possibly, other non-woody forest products. Investigations should be undertaken to determine the importance of industrial roundwood and wood products as potential fuel.

2.8 In isolated cases, tree, shrub or bush roots may be used as fuel, generally out of necessity and the lack of sufficient alternative biomass. These roots should then be quantified if they are important sources of fuel, especially if land is being cleared for other uses such as agriculture. However, in most situations where such roots are so used they should not be considered as fuel in an unqualified way. Roots are often the source of future wood supplies through coppicing or sprouting especially if good cutting practices are observed. It makes little sense to remove the source of such future supplies, particularly as the use of roots often occurs in areas of poor vegetation and arid or semi-arid conditions where regeneration potential is otherwise very difficult. The roots also act as soil retainers or stabilizers, helping to curtail erosion. They do this even when dead, though less effectively over time. Roots also facilitate water infiltration and improve ground water supplies while helping to curtail runoff. For these reasons roots, particularly in poorly vegetated and erosion-prone sites, should not be regarded as fuel. This role of soil and water conservation may also apply to some species in erosion-sensitive areas and these should also be excluded from the final estimates of woody biomass for the area concerned.

Accessibility

2.9 One has to also consider the accessibility of woody biomass for use as fuel. This involves economic, financial and environmental factors. Thus the distance a villager will go to collect subsistence fuelwood depends to a large extent on how he/she values their time and consequently how far he/she is prepared to travel to collect the fuel while at the same time considering the need for the fuelwood and the presence or absence of alternative fuels.

2.10 Harvesters of urban woodfuels will consider the market price of either fuelwood or charcoal and demand elasticity in relation to price when considering the radius of the urban woodfuel catchment. Of course the condition of road and rail access play a part here. The market or end-use price will be affected by the end-use concerned. Thus woodfuels used solely for household cooking may not command as high a price as woodfuels used for relatively fuel-efficient commercial operations or for generation of electric power.

2.11 Another factor affecting the economic accessibility of woodfuels that should be taken into account is the cost and availability of competing fuels such as kerosene, liquid propane gas, and electricity. This applies particularly to urban woodfuel catchments where woodfuels are more commonly traded. Should the cost of transporting woodfuels cause the urban price to approach or surpass the price of alternative fuels that are readily available, then the woodfuel economic accessibility has been reached. Finally, but not least, the accessibility of woodfuels may be determined by environmental considerations. Preservation of soil and flora resources as well as water catchment safeguards are factors to be considered here.

Moisture and Ash Content

2.12 When weighing the quantity of woody biomass, it is important to determine the moisture content as this affects the heating value of the wood. This should be done when the samples are weighed green or wet, and also when the wood is air dry. Oven dry weights are also often made. Water in the wood reduces the effective heating value of the wood in two ways. Firstly, in any piece of wood it is only the wood fibers that have energy, thus if half the weight of a piece of wood is water then only half of the mass has burnable energy. Secondly, energy is used to drive off the water as steam; for every kilogram (kg) of water 2.4 megajoules (MJ) of energy (133 grams of bone dry wood) are required to expel it. Thus, the dryer the wood the more energy is available as heat, although at best wood is burnt air dry with between 10 to 20% moisture 3/. Table 2.1 shows the variation in energy values with different moisture contents.

2.13 Ash content will also affect energy values. The proportion of non-combustible materials such as silica that form ash affects the amount of combustible material present and thus the energy value. For most woods the ash content is approximately 1%, but it may be as high as 20% for crop residues.

Table 2.1: Variations in wood energy values with moisture content (MJ/KG)

	Moisture Content %							
db 1/ wb	100 50	80 44	60 38	40 29	20 17	15 13	10 9	0 0
Energy value 2/	8.2	9.4	10.7	12.6	15.1	16.0	16.8	18.7

1/ The formula for converting dry basis (db) to wet basis (wb) is:

$$\frac{D}{1+D/100} = W \text{ and vice versa } \frac{W}{1-W/100} = D$$

where D = Moisture content as % on dry weight basis
W = Moisture content as % on wet weight basis

2/ This is the low heat value or the heat that is practically available. It excludes the heat of condensation - approximately 1.3 MJ/KG.

2.14 One point that should be clarified is the question as to whether some woods have higher energy values than others. This is only true if the energy content is measured on a volume to volume basis and/or at different moisture contents. On a weight for weight basis at the same moisture content the energy value of wood will be the same + or - 5%. This is because all woody cellulose consists of about 50% carbon, 44% oxygen and 6% hydrogen on an ash free basis, and the ash content of most woods is about 1%. Resin in some woods such as that from many conifers give slightly higher energy values than the average.

2.15 Even though the energy value of all wood is similar on a weight for weight basis and at the same moisture content, some species of wood are more favored than others when it comes

3/ Air dry moisture content of the wood will vary with the ambient relative humidity, being higher in wetter climates and lower in arid or semi-arid areas. It is also a function of the heartwood/sapwood ratio with sapwood containing considerably more moisture when green (wet) than heartwood. Hitchcock and McDonald (1979) quote figures of 50% of heartwood and 100% of sapwood on an oven-dry weight basis. Thus moisture content is inversely proportional to increasing stem diameter.

to burning. Generally speaking, the household cook prefers dead wood from species with a high density because they are slower burning; small diameter wood is used for lighting the fire and larger diameter wood is preferred once the fire is lit because the fire needs less tending. This is the one great advantage wood has over crop residues. Some species of wood give off obnoxious odors or spark vigorously where as others add flavour to the food especially when grilling meat or smoking fish. Therefore it is important to know which species are preferred, but of course, if there is an acute shortage of wood any species will be considered.

2.16 Industry also has its preferences when it comes to choice of species. Charcoal manufacturers and end users prefer dense species because they produce dense (slow burning) charcoal, thus there is sometimes resistance to plantation grown wood such as eucalyptus or softwoods being used for charcoal because it burns more quickly than "open woodland species" charcoal. Fire cured tobacco, and fish smoking requires the use of specific species to prevent tainting the product. So again it is important to know the desired species so they may be categorized during the assessment to assist planning.

2.17 Though the energy value of wood is constant, that of charcoal can vary depending on the percentage of carbon left in the charcoal. Charred wood has about 52% carbon and an energy value of 20 MJ/kg whereas fully carbonized charcoal has about 93% charcoal with an energy value of 33 MJ/kg. The conversion percentage of wood to "charcoal" also varies inversely with the energy value. Therefore if charcoal is a principal end product of the forest or woodlands, measurements may have to be taken at the production process site to determine the energy content of the finished product.

Parameters to be Determined

2.18 Several methods have been devised to measure biomass, but all require field data. If woody biomass is measured standing then height, stem diameter/girth (at specific heights), mean crown diameter and depth, stem taper, and unit basal area are important variables. For felled trees, the weight and moisture content of logs, cordwood, twigs, and leaves need to be measured as well as the proportions of stem wood and branch wood 4/ by utilization category - veneer logs, sawlogs, poles, pulpwood, fuelwood and other wood products.

4/ This will enable correlations to be established between stem volume/weight and branch volume/weight or total above ground volume/weight. If necessary correlations may also be established between tree volume/weight and the volume or weight of leaves. For frequent fodder harvests from a tree, annual leaf production may be determined.

Areas of Biomass Classes

2.19 Different classes of biomass should be identified or stratified and the area of each determined. Woody biomass may be divided into various vegetation/ecological classes, while crop residues are divided according to the crops or mixtures of crops grown. Stratification improves the accuracy of the final estimates by reducing the variance within the strata population, however, the strata or classes should be identifiable on the medium used for stratification. This refers principally to woody biomass strata where satellite imagery, aerial photography or existing vegetation/forest-type maps are used. Crop residue data is based on statistics of crops grown in a given area, though satellite imagery or aerial photography may also be used to obtain estimates of crop type areas and sometimes of yields, particularly on a regional or sub-regional basis where area statistics may be lacking, or simply to verify printed statistics of crop areas where they exist. Obviously the higher the resolution of the imagery and the larger the scale of the photography the more detailed the biomass classes or strata may be.

Volume/Weight of Biomass

2.20 For woody biomass the standing volume or weight should be determined within each biomass strata or class. This represents the total quantity of above-ground woody biomass present at a given point in time. From this it is necessary to deduct undesirable species (e.g. very low density wood) or protected species and trees. Those used for non-woody purposes such as fruit, latex, resin or green mulch production should be categorized because, although their primary products are non-woody, they usually can contribute wood for fuel and other purposes over time. A similar situation exists in protection forests where dead wood may be collected and used for fuel. If the principal purpose of the assessment is to estimate woody biomass for energy then account must be taken of the volume that would be used for other products while making allowance for any logging and sawmilling residues that may be used as fuel. The standing biomass estimation should only include wood to the accepted biomass fuel utilization limit, which will vary from region to region depending upon the local fuel deficit situation. As mentioned previously, it should only include those species and sizes 5/ that are acceptable as biomass fuel.

2.21 Although most measurements of wood are based on volume, weight measurements are preferred when biomass is considered as fuel. This is because the heating value, or amount of heat that can be provided, is correlated to weight, and biomass assessments aim to determine the amount of heat available for use. To obtain weight estimates, a sample of trees has to be felled to determine the green, air dry and possibly bone dry density (weight/unit volume). While wood loses weight when it dries, there is very little shrinkage until the wood gets down to about 10% moisture

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5/ Some desirable species may be too large to fell with available tools thus only dead wood may be collected from them or small branches lopped off them.

content 6/, therefore knowing volume and average density, the weight (air dry/bone dry) can be determined with sufficient accuracy.

Growth Rates

2.22 Although the estimates of standing woody biomass show what is present at a given point in time, the woody biomass is in a dynamic state and is renewable, with or without assistance, but with varying growth rates. To obtain an estimate of the annual (periodic) sustainable yield it is necessary to gather data on the annual increment, and in older stands, the quantity of overaged trees. The annual sustainable yield or annual allowable cut (AAC) is usually calculated as the average annual increment of the stand, 7/ but in older stands with over-aged or moribund trees, the weight of biomass fuel in these older trees is amortized over a period of time, usually a cutting cycle or rotation, and the AAC would then include this annual amortized quantity as per the following formula:

AAC (over-aged stands) = annual increment + over-aged biomass/rotation

Regeneration Capability

2.23 Considering the sustainability of woody biomass resources, an important aspect to take into account is the regenerative capability of the trees or other plants comprising the resource. If the trees or plants do not regenerate after harvest, 8/ as is the case with agricultural field crops, then we are dealing with a finite resource that will decline by the amount that is cut in a given time. To maintain a sustainable resource in such cases it is necessary to carry out artificial regeneration by planting seedlings or sowing seed, often at considerable cost; this has to be reflected in the value of the resource.

2.24 Natural regeneration occurs via natural seed distribution, germination and growth, and via the sprouting of coppice shoots or root suckers after cutting of the trunk. Natural seedling regeneration and growth is dependent on seed supply (number of seed bearing trees in vicinity and annual seed production) and seed viability, ground conditions, the presence of seed gathering animals and birds, weather conditions, and interference from livestock and man. The production of coppice or suckers is dependent upon the species; some species do not coppice or sucker, but

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6/ Bryce (1967) has radial shrinkages for Tanzanian species that range from 1.2 to 3.5%, but average 2%.

7/ The annual allowable cut (annual increment) varies over time. The rotation of maximum volume production is where current annual increment is equal to mean annual increment. However, this is not necessarily the rotation of maximum financial or weight yield.

8/ Most plants in their natural habitat will grow from seed and this is very true for trees. However, natural regeneration may be patchy or not be desirable from a management/cost viewpoint.

most fuelwood species do at least coppice. It is also dependent to some extent on the method used to cut the tree and the season in which the cutting is done. The age of the tree may also be a factor, as some species coppice poorly or not at all from older, large stumps. There is usually a limit to the number of coppice rotations that can be achieved with satisfactory yields per unit area. With each cutting the viability of the stock usually declines and a percentage of stems fails to produce another crop. Species and the method of cutting play a role here, and careful felling with saws at the correct height (usually 10-20 cm) can prolong the coppicing ability of stumps. For many eucalypt plantations a maximum of four coppice crops plus the original seedling crop is generally the limit before yields become unsatisfactory, although short coppice rotations over 50 to 100 years have proved satisfactory with Eucalyptus globulus in India, E. camaldulensis in Israel (FAO, 1981) and E. globulus in Ethiopia (personal observation). In forests and woodlands there is little data on the longevity of the coppicing ability of trees. It is known that many desirable species coppice, particularly in the African woodlands, and with rotations being relatively long (20 years or more) it can be assumed that 75 to 100 years of sustained growth may be possible. Unfortunately, in some areas not all the desirable woodfuel species coppice so that either natural seedling regeneration or enrichment planting has to be considered in order to maintain a sustainable yield. Pollarding, or cutting the (outer) branches of a tree, is a harvesting system that can give high sustained fuelwood yields over a long period of time. This is practiced by farmers throughout the world. However, only a few detailed studies have been done on the productivity of such practices.

Non-Woody Biomass

2.25 Crop residues are the principal non-woody biomass. In areas acutely short of fuel, leaves may be used for fuel (Ethiopia and China) and, in some instances, grass (China). Crop residues come from annual crops such as rice or rape-seed, or are the residues from the fruit of perennial cropping plants such as coffee and coconuts. Perennial crops such as tea, coffee, rubber and cacao are pruned as well as removed from time to time and, on these occasions they may be important biomass supply sources and, therefore, need to be factored into any assessment. Similarly, coconut grounds, which have woody-textured mid ribs, are an important fuel in coconut producing areas and should not be neglected. Yields of crop residue may be based on crop production statistics using correlations between these yields and the quantity of biomass available for fuel for a given crop type. Consideration should be given to what proportion of these residues should remain on site to maintain long-term soil fertility and what may be needed for animal feed. Some residues, such as sorghum stalks may find short term uses for fencing or wall building materials, but within a year or two they could be available as fuel, less that portion lost to decay and insects.

2.26 Grass, where it is used, is a fuel of last resort or a "filler" to be used with crop residues, leaves and small branches. Estimating its sustainability as a fuel is difficult, given its other

uses such as for fodder and thatching as well as its environmental protection capabilities. It must be remembered to avoid double counting. One should not measure grass biomass and the dung from animals grazing in the same area. It is one or the other not both. Given its dual role in many instances and the fact that it is not a common fuel it is not considered in the following biomass assessment methodology.

<u>Animal Dung</u>

2.27 In estimating the quantity of animal dung available for energy conversion, one considers the production per unit animal type and the numbers of each animal type. The dung production per animal depends in turn on the type and quality of the feed and the body weight of the animal. During some dry seasons, the quantity and quality of the feed may decrease, resulting in reduction of the amount of dung.

2.28 Accessibility of the dung is an important factor to take into account, particularly where livestock are range fed, and, consequently the dung not easily accessible. The quantity or fraction of dung required for fertilizer also needs to be taken into consideration; although, where fuel is scarce the tendency seems to be to satisfy the short-term energy demand rather than be overly considerate of the affect on future food production. Apart from its use as fuel and fertilizer, dung may be an important building material in some countries.

III. WOODY BIOMASS ASSESSMENT METHODOLOGY

General Principles

3.1 In approaching a woody biomass assessment for a given country or region of a country the first step, obviously, would be to define the objectives of the assessment. It would then be beneficial to collect, review and evaluate any existing data on woody biomass for the areas concerned. This, together with the planning and management objectives for the assessment, enables one to decide the extent and intensity of any assessment. The following steps may then be followed in undertaking an assessment:

(a) defining what constitutes biomass for purposes of the assessment;

(b) defining the area to be covered in relation to a demand center;

(c) mapping and stratification of the catchment area;

(d) field survey methods to be used, including the need for destructive sampling to establish tree-weight equations;

(e) compilation of data from surveys; and

(f) presentation of data in a format that conforms with the assessment objective.

3.2 Generally the approach would be a multi-staged one. Detailed biomass inventories, though not excessively expensive per unit area, are a costly proposition when very large areas are involved. From a cost/benefit point of view it is preferable to concentrate more intensive biomass assessment in areas with indications of sustainable biomass supply problems, either currently or projected. To ascertain the location of such areas, low unit cost assessment methods may be used.

3.3 One of the lowest cost approaches is to use advanced very high resolution radiometry (AVHRR) with 1, 4 or 8 km resolution, limited ground verification, and a literature-sourced biomass data base. Such a method may be used to cover continents, regions thereof or large countries as ESMAP 9/ has done in Sub-Saharan Africa and Pakistan, and ETC in the SADCC countries. Subsequently, as low accuracy supply data in association demographically related woodfuel consumption data indicates areas with supply problems, more intensive assessments may be made in these areas using lower resolution satellite imagery supported in turn by medium to low

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9/ Joint world Bank/UNDP/Bilateral Energy Sector Management Assistance Program.

level aerial photography, and perhaps video remote sensing (Schade, 1987) Finally ground inventories may be undertaken. Each of the successively more intense assessment procedures may be used as sub-samples of the preceding type to obtain a more cost efficient assessment for a large area. The multistage assessment concept is illustrated in Table 3.1. It may not be necessary or desirable to go through all stages or to start with the top, least accurate stage. Planning and management objectives will indicate the stages to be used. The following sections deal in more detail with the methodologies involved in each stage.

3.4 ESMAP's Household Energy Strategy Study (HESS) in Pakistan is using multi-temporal land cover analysis of AVHRR data with 5.5 km spatial resolution as the joint stage in a multi-level sampling program. Data were obtained for each month from July 1981 to December 1987. The analysis of the AVHRR data also provides an important ecological based zonation of Pakistan and it will provide as important temporal context to the results obtained from the HESS project in the light of concerns about environmental change and their impact on the environment.

3.5 The primary zonation of Pakistan into a series of land cover classes is effected by the analysis of AVHRR data and the resulting land cover and land cover stability maps. Other, more detailed, levels of sampling, such as the more detailed land cover analysis based on earth observation satellite imagery, and ground survey will be done within the land cover classes identified and mapped from AVHRR data. The identification of relatively stable areas over the period 1981 to 1987 for each land cover class will enable the location of sites for more detailed sampling in the knowledge that these sites are representative of contemporary, and recent, land cover types in Pakistan and are not subject to environmental fluctuations. This is an important consideration because of the great variability of land cover in arid and semi-arid environments in response to changes in climate and anthropogenic factors (Saull and Millington, 1991).

3.6 In Ethiopia, Helliden (1987) used a three level monitoring and planning approach for natural resources, including woody biomass. The three levels are:

(a) National. 1:500,000 - 1:250,000 using Landsat MSS data, every one to five years.

(b) Regional. 1:250,000 - 1:10,000 using Landsat MSS and possibly TM. Areas selected from regional data based on priorities for the investigation.

(c) Local 1:50,000 - 10,000 using Landsat TM and SPOT data, air photos and field work to the degree required for information. This is usually a one time survey or monitoring during a defined period with areas selected from the regional data based on priorities for the investigation.

3.7 The method of biomass assessment will also depend upon the type of woodfuel catchment that is involved, once those catchments have been identified and the sampling accuracy required has been determined.

Low Resolution Satellite Imagery

3.8 Satellite imagery with a resolution of one to eight km, such as that produced by the Advanced Very High Resolution Radiometer (AVHRR) on the NOAA Weather Satellites 10/ may serve as a first stage in woody biomass assessment or provide a general overview that has a low level of accuracy as regards around cover typing and type borders. It is relatively inexpensive ($15,000 for imagery covering Africa south of the Sahara over a 12 month period), and, as with most satellite imagery, is repeatable so that time sequential data are available. These factors make AVHRR a valuable tool, not only as the first stage in woody biomass assessment, but also for monitoring macro and seasonal changes in the woody biomass resource base.

3.9 As with data from the earth resources satellites (e.g. LANDSAT series and SPOT), the data from weather satellites are provided either as optical or digital products, the latter coming in the form of computer compatible tapes (CCT's). These tapes, in many cases, are more useful than optical products, particularly for low spatial resolution imagery, as they can be processed digitally to maximize the amount of information extracted from them. This, however, requires digital image processing systems or access to them.

10/ AVHRR may actually be programmed for either local areas coverage (LAC) at one km resolution or global area coverage (GAC) at 4 km resolution. 8 km resolution data may then be derived from these for very wide area coverage.

<u>Table 3.1</u>: MULTI-STAGE APPROACH TO WOODY BIOMASS ASSESSMENT

REVIEW OF EXISTING DATA/MAPS FOR AREA

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LOW SPATIAL RESOLUTION IMAGERY - AVHRR (Resolution 1 to 8 km)
- Large country or multi-country region
- Supported by limited ground truthing and existing biomass data
- Gives maps with (1:5,000,000) broad vegetation types and rough biomass estimates

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SPATIAL WOODFUEL CONSUMPTION PATTERNS

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HIGHER SPATIAL RESOLUTION SATELLITE IMAGERY
- LANDSAT TM and MSS (Resolution 30 to 80 m)
- Small country or part of country
- Supported by ground truthing, aerial photos, airborne video plus existing data on biomass estimates
- Gives maps or overlays (1:250,000 to 1:1,000,000) with more reliable vegetation types and rough biomass estimates

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BIOMASS RECONNAISSANCE INVENTORY
- SPOT Imagery and/or Aerial Photos
- Low intensity inventory perhaps with sub-plots for smaller vegetation
- Supported by cartographic or imagery maps and established regressions and correlations between measurable parameters and biomass
- Destructive sampling to establish regressions
- May include non-forest as well as forest areas

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BIOMASS MANAGEMENT INVENTORY
- Higher intensity with sub plots supported by maps in forest and non-forest areas

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CONVERSION OF INDUSTRIAL WOOD VOLUMES TO TOTAL ABOVE GROUND BIOMASS
- Supported by maps and/or aerial photography, and established regressions and correlations between industrial wood volume and total biomass

3.10 The AVHRR data is used to identify and map vegetation/biomass classes by means of a Global Vegetation Index. The NOAA satellites six through ten that have the AVHRR sensor on board pass a given point on the earth's surface every 12 hours. Although the data collected is mainly for the meteorological community, useful ecological information can be obtained from cloud-free ground resolution elements (pixels) 11/ using the wavelengths of the sensors on channels 1 and 2. (0.58-0.68 and 0.725-1.10 micrometers respectively), representing the red and near-infra red parts of the spectrum. By manipulating the data an index of vegetation status can be calculated for each ground resolution element. Called the Normalized Difference Vegetation Index (NDVI) it is calculated as follows:

$$NDVI = \frac{DN(\text{channel } 2) - DN(\text{channel } 1)}{DN(\text{channel } 2) + DN(\text{channel } 1)}$$

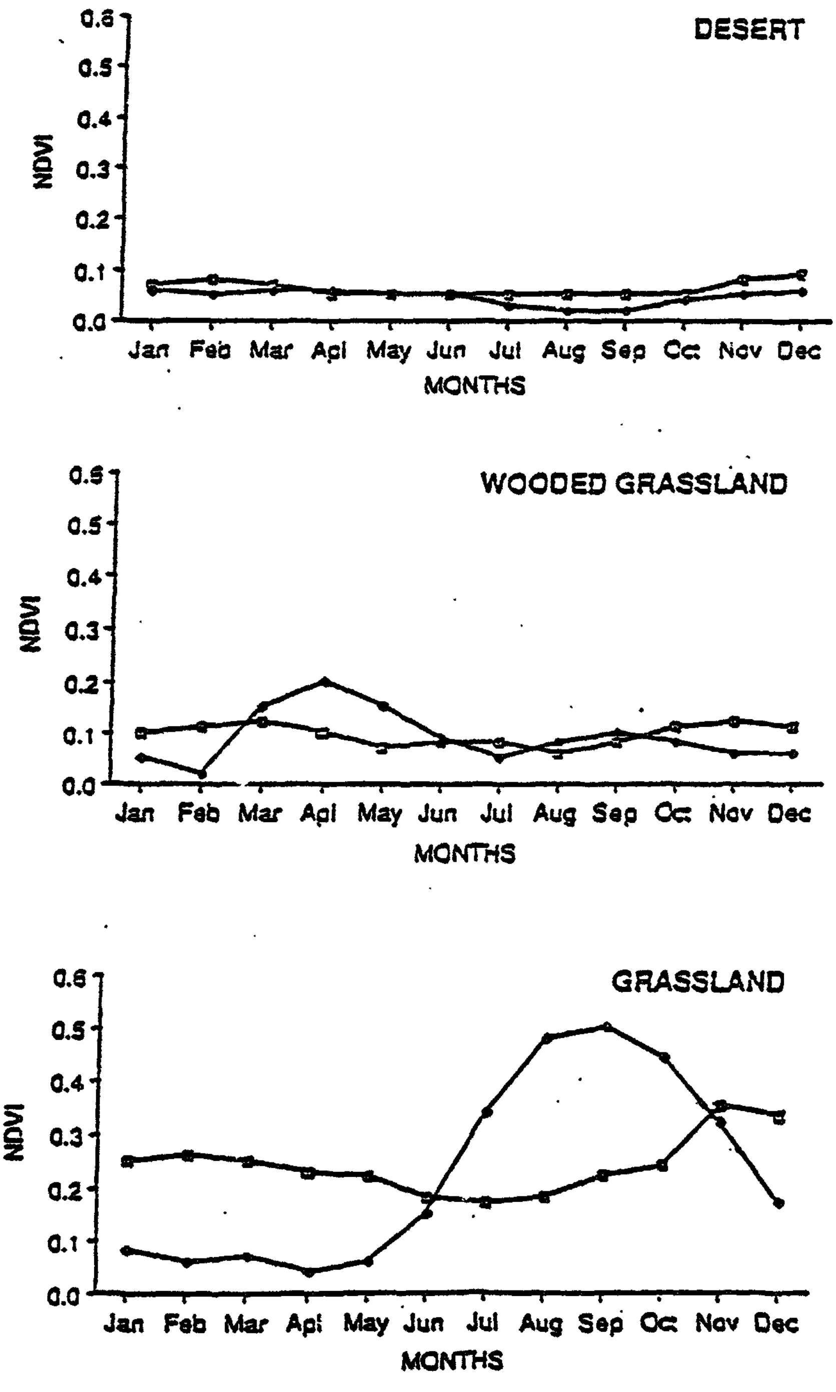
DN is the digital number representing the reflectance from channel n for a given panel.

3.11 Such data have been used for large area vegetation mapping (Gathin et al. 1983, Norwine and Greegor, 1983; Townsend and Tucker, 1984; Tucker et al. 1984, 1985). It was used to map vegetation/biomass types for the SADCC countries (ETC 1987). The resulting maps have only limited accuracy even on a regional basis, let alone on a national basis.

3.12 More recent use of AVHRR 8 km imagery has been to map vegetation/biomass types for African countries south of the Sahara, (ESMAP and ETC(UK)). Eight km resolution imagery was used and temporal NDVI curves, based on the best available monthly NDVI values, were established for each major ground cover/vegetation type. Samples of these are shown in Figures 3.1 and 3.2. To assist with the identification of vegetation types that had been determined by the NDVI curves, field visits were made to the various regions involved. However, the ground truthing carried out was very limited in relation to the overall area concerned and the number of identified vegetation types (9 single digit types sub-divided into 44 double digit types). The principal purpose of the ground truthing was to resolve identification of transition zones.

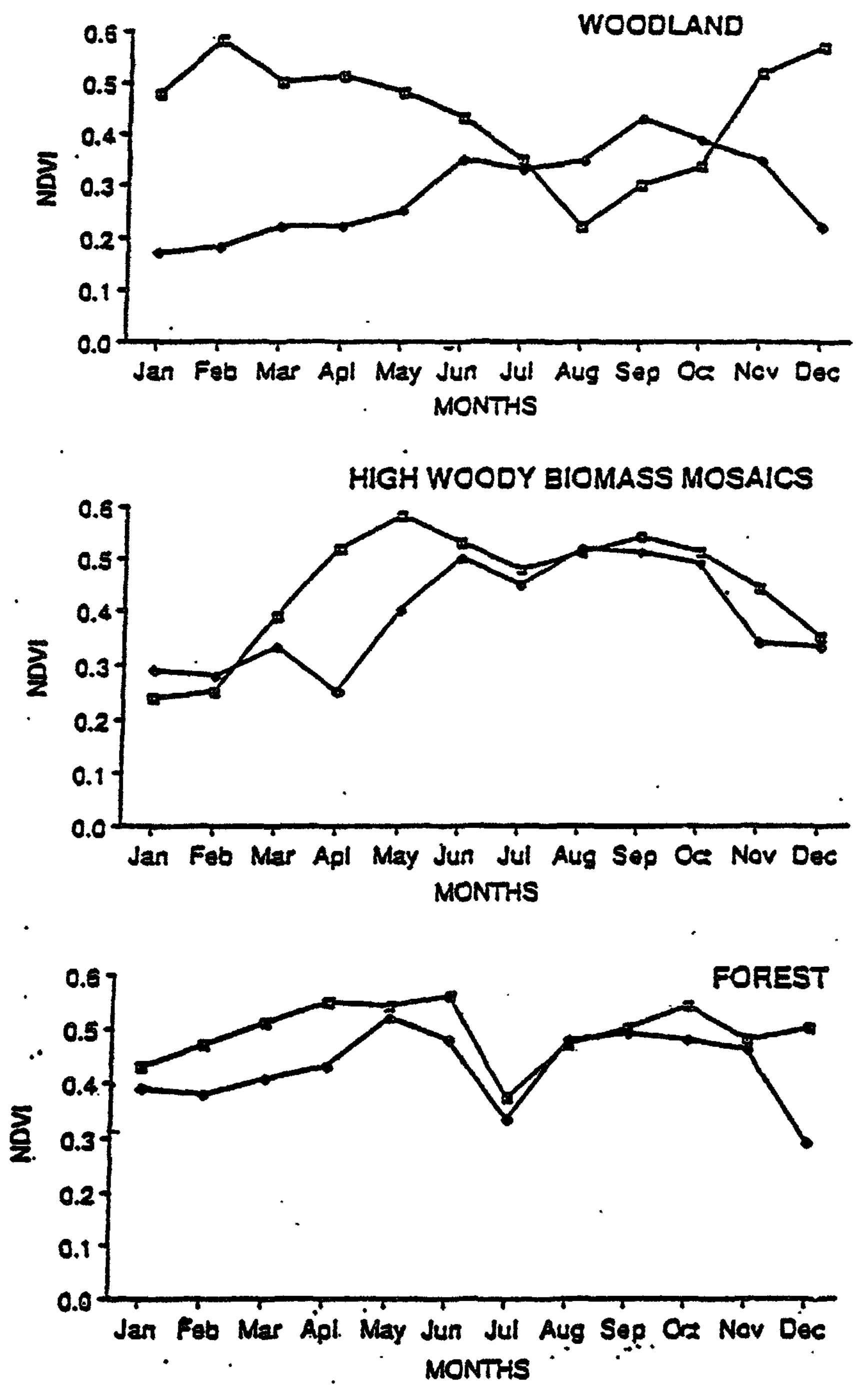
11/ The smallest area that can be resolved on the imagery.

Fig. 3.1: NDVI Temporal Profiles 1/



1/ Double profiles refer to different rainfall regimes.
Source: Millington et al (1991)

Figure 3.2: NDVI Temporal Profiles



1/ Double profiles refer to different rainfall regimes.
Source: Millington et al (1991)

3.13 A detailed literature review provided some limited data on the standing quantity of biomass and annual increments that could be expected, thus giving an indication of biomass yield potential for vegetation types. This was done by interlinking the biomass data base and a geographic information system (GIS) that was established from the satellite mapping data. Unfortunately, the data base, as was expected, was seriously lacking. Limited information was available for types that are commercially exploited for timber, but here the data often only referred to merchantable (stem) volumes. Little, if any, information was available for the remainder of the woody biomass, either in the merchantable trees or in the non-merchantable trees and undergrowth. For the bushland and woodland types there was a real paucity of data, with only a limited amount coming from research work. 12/ 13/ There were also inconsistences in the presentation of the woody biomass data and often a lack of information on the parameter limits which made compilation of a standardized data base difficult.

Higher Resolution Satellite Imagery

3.14 The next, more intensive, stage of woody biomass assessment is to use satellite imagery with relatively higher spatial resolution for limited areas e.g. a large country or selected vegetation types in a region such as the Sahel. Landsat Multi-Spectral Scanner (MSS) imagery has a resolution of 80m and Landsat Thematic Mapper (TM) a resolution of 30m, while SPOT has a resolution of 20 m for multispectral (XS) imagery and 10 m for panchromatic (XP). A greater degree of ground truthing would be required to identify vegetation/ground cover types discernable through the lower resolution imagery. This may take the form of ground field work, aerial reconnaissances or aerial photo or video sampling.

3.15 A further staged approach may be desirable, increasing accuracy with increasing resolution and ground verification while at the same time narrowing the area of investigation from a regional or national to a local level. Hellden (1987) proposes a 3-level concept to assess woody biomass, community forests, land use and soil erosion in Ethiopia, with data from the different information layers stored and analyzed in a GIS.

3.16 Maps of 1:500,000 to 1:1,000,000 would be drawn for the regional or national level or possibly even a larger scale for small countries such as Liberia or Rwanda. AVHRR 1 km imagery 14/

12/ Results of biomass surveys done by Chidumayo in Zambia, 1989, are an example of such work.

13/ The Kenya Rangeland Ecological Monitoring Unit has permanent sample plots in the rangeland areas of Kenya and systematically collects production data.

14/ Special programming orders need to be placed and stock imagery at this scale is not generally available.

or Landsat MSS data could be used at this level. Hellden used Landsat MSS data to develop 1:250,000 scale maps. However, as he points out the scale chosen must be one that considers both the practical and economic point of view. Large scale mapping of large areas requires considerable cartographic capability and time e.g. it takes more than 1,700 map sheets at 1:50,000 to cover Ethiopia (1.2 million km²). The annual production of the Ethiopian Mapping Agency, employing 350 people, was about 30 sheets in 1985 (Anderson and Ekelund 1985) and at this rate it would take over 50 years to map the whole country. A cost efficient alternative is the production of imagery maps that may be registered to existing national map grids. ESMAP, through SATIMAGE, Sweden, used Spot imagery to produce imagery maps for approximately 140,000 km² of woodfuel catchment areas in Tanzania (1990).

3.17 Kent et al (1980) discuss the application of three-phase sampling for stratification to multi-resource inventories. In phase 1 a random sample of 1.1 ac high altitude photo plots were selected, interpreted and placed into one of three phase 1 strata (land-use classes). Phase 2 sampling fractions were set and random samples of high altitude plots taken of each phase 1 stratum. These photo plots were then located on low altitude photo plots and stratified into six phase 2 strata (forest/vegetation types). Phase 3 sampling fractions were set and random samples taken of the low altitude photo plots. These plots were then located on the ground and the characteristics of interest were measured.

3.18 The general principle of this multi-stage concept is to go from the generalized, low accuracy, national or possible regional level to the detailed, more accurate local level. The investments in data collection and analysis would be directed by the overall objectives of the assessment and priorities established from information obtained at the less intensive level. The objective of each stage needs to be set and methodology established to achieve the objective, including type of imagery, scale of mapping, and intensity of ground verification.

3.19 In some instances, however, there may be sufficient information or need to go directly to a relatively intensive data collection level such as a woody biomass/forestry inventory using maps developed from imagery. Such was the case in Tanzania where woodfuel catchment areas around several major urban centers had been roughly defined, but reliable information was needed on the actual extent and sustainable yield of woodlands in these areas in order to implement a management program (ESMAP, 1990).

3.20 There is also the need, that should be catered to, for repeat up-to-date information at a more generalized level to monitor woody biomass resource changes and use such monitoring to assist with the development of national strategies and priorities. There may be a reliability problem, however, in using a repeat series of images to monitor changes over a given area unless an accurate base case has been established. This is particularly so with lower spatial resolution AVHRR imagery. The variations in NDVI values for a given site can be quite significant due to rainfall/moisture regimes that affect the vigor and growth of vegetation. However, such values could be interpreted as change in ground cover/vegetation types as well as in biomass productivity unless a clear pattern of several years has been used to establish a base case situation.

3.21 The use of higher resolution imagery such as Landsat TM or SPOT may be valid for annual monitoring, as more reliable interpretation of ground cover/vegetation types is possible with the visible spectrum. Care should be taken that the imagery used is for the same season, as leafless periods, or periods when both crops and trees have green leaves could confuse interpretation. Aerial photography would be the best means for annual monitoring, but the cost would limit it to selected areas. For very large areas a cost efficient method of monitoring ground cover changes could be to stratify the area on a broad climatic/ecological basis and randomly select a sample of imagery frame locations for which imagery would be obtained over the same period.

3.22 Before higher resolution imagery is used over a broad geographic area it is useful to carry out a pilot study to determine the amount of ground verification required; the interpretation methodology - visual, digital or a combination of both; the optimum period(s) for registration of imagery data to distinguish ground cover types 15/; and the degree of stratification of ground cover types possible.

Aerial Photography

3.23 Aerial photography has been a tool commonly used for forest inventory, usually at a scale of 1:20,000 to 1:50,000, and over a limited area (300,000 ha). It is expensive per unit area (in East Africa 1989 costs were $10 or more per km^2 for 1:40,000 panchromatic photos), but it does provide a basis for more detailed delineation of vegetation types, and, in some instances, identification of individual tree species. The larger scale photography may be used to actually measure tree height and/or crown diameter in more open stands. This measurement is facilitated by using low level photography (100-200 m above-ground altitude), preferably with two cameras on a boom to obtain stereo sample shots, although vertical precision is essential.

3.24 For woody biomass assessment the use of aerial photography, flown specifically for the assessment would be limited, given the cost involved, the extensive areas that often need to be covered, the low value of woodfuels, and the need for less intensive management than for industrial wood products. However, existing photography could prove useful for limited areas, sub-sampling or for verification of ground cover/vegetation types in selected areas in conjunction with satellite imagery. In Zambia, existing aerial photography of two urban charcoal catchment areas, namely, the Copperbelt and Lusaka environs was interpreted for tree cover, woodland type and degree of

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15/ In Tanzania a pilot study, using three SPOT scenes determined that the optimal time to register imagery was at the end of the dry season when the trees were in leaf, but crops and grass dry (ESMAP, 1990).

disturbance. This was followed by a ground survey to determine growing stock and increment (Chidumayo, 1990).

3.25 Specially flown low level photography or videos may be used for aerial sampling or verification of types, particularly in areas that are not easily accessible on the ground. Low level aerial photography particularly that taken as boom stereo pa'-, 16/ is a useful tool in assessing woody biomass resources for villages. Whereas the woodfuel catchment area for a large town or city may extend over a wide area of woodland or forest from whence largely commercial woodfuel supplies are extracted and transported, the catchment area for a village is often a relatively small area, defined by the limits of collection on foot or sometimes using animal for transport. Included in the catchment area may be considerable woody biomass around the houses and fields in the form of trees (some may be fruit trees that can be pollarded) and bushes.

3.26 The low level photography or video could be used to take either aerial samples or transects in the village woodfuel catchment area. This would be supported by ground verification as well as by a household energy survey to ascertain where households obtain their woodfuels and what constitutes those woodfuels. Estimates may then be made of the woody biomass resource used for energy.

Mapping

3.27 Ground cover/biomass type paper maps may be produced from the range of imagery and photography discussed above. The objective is to use such imagery to produce maps both to determine the spatial extent of the various ground cover types and to enable the biomass types to be stratified so as to facilitate subsequent ground (or possible aerial) assessment of the woody biomass.

3.28 For AVHRR imagery with derived NDVI values, the identification and mapping of ground cover/wood biomass types is based on interpretation of digital data. For Landsat MSS and TM imagery, digital interpretation is also used, although visual interpretation may be used as for the broad forest classification done by the Indian National Remote Sensing Agency (NRSA) using MSS imagery for the period 1972 - 75 and TM imagery for the period 1980 - 82 (NRSA, 1983). With the higher resolution SPOT imagery, although digital interpretation may be used, it may be preferable to use visual interpretation, as was done for the Tanzania Remote Sensing and Mapping Project for peri-urban woodfuel catchment areas (Kikula et al, 1990). For all the satellite imagery the interpretation and mapping generally goes through three phases:

16/ Using 2 cameras fixed on a boom to an aircraft or helicopter.

(a) Data inspection and pre-processing; initial image interpretation; provisional biomass class mapping;

(b) Field verification of provisional biomass class/type maps;

(c) Final classification of woody biomass classes and production of woody biomass type maps.

Production of Provisional Type Maps.

3.29 The NDVI data provided by NASA comes for regular time periods (daily, 10 days or monthly). These data should be registered to each other and errors/omissions or cloud filtered out from the affected pixels where possible. Large areas of persistent cloud may not be entirely eliminated, however.

3.30 NDVI data for a given series of time periods, e.g. monthly, are then used for the initial interpretation in which provisional ground cover/woody biomass types are identified and mapped. An image with mean annual NDVI values may be created. This image provides a good indication of the amount and variation in annual vegetation productivity. Types or classes are made up of pixels with a statistically similar 17/ range of values grouped together.

3.31 The images formed from this provisional interpretation would be color coded and hard copies obtained at a scale suitable for field checking. This scale may range from 1:5,000,000 for regional maps from 8km AVHRR imagery to 1:1,000,000 for sub-regional or national maps using 1.1 km AVHRR imagery.

3.32 With Landsat or SPOT imagery the data acquired would be evaluated, particularly for the degree of cloud cover. Radiometric calibration would be applied to give a suitable range of colors for the data spectrum. Vegetation indices may also be set up on a temporal or one-shot basis using reflections in the infra-red and near infra-red spectrum. Paper copies of scenes at a scale of 1:100,000, (SPOT) 1:250,000, 1:500,000 and 1:1,000,000 (Landsat) may be produced for field verification. Provisional typing may be done using training sites for which information is known about the ground cover and overlays produced with such a classification. In many instances, however, the paper copies of scenes are used for field verification without provisional typing.

Field Verification.

3.33 Field verification is an essential element to the ground cover/biomass typing process, and, up to a point where sufficient sites have been observed to ensure reliable typing, the greater

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17/ NDVI values within an acceptable range of standard deviations are grouped together.

the amount of verification the more accurate would be the typing per se. In the case of broad continental or multi-regional mapping using AVHRR data, only limited verification is usually possible in relation to the area covered and the ground cover/wood biomass types involved. The approach adopted in the ESMAP project "Biomass Mapping for Sub-Saharan Africa" is indicative of the verification that can be done. Given limited funds and the area to be covered, the consultants, ETC (UK), concentrated on areas of transition between the main types as well as on types that were not clearly defined from literature and existing maps. Visits were made to selected sites in Senegal, Zaire, Zimbabwe, South Africa, Kenya, Somalia and Ethiopia with approximately 80 person-days being spent in the field. However, this was supplemented by draft type maps being critiqued at two regional workshops by delegates from many of the countries covered.

3.34 As the area involved decreases and greater interpretation accuracy is required more detailed verification is necessary. The intensity of the verification will also depend upon the number and complexity of the ground cover types. For the Remote Sensing and Mapping Project in Tanzania, where 1:50,000 scale maps were produced from SPOT imagery for urban woodfuel catchment areas, covering 140,000 km^2, fairly intensive ground verification was done for each area with each type being verified at several spots. Using 1:100,000 field image maps, a total of about 250 person days were spent in verification with no actual assessment of the woody biomass being undertaken.

3.35 The usual method of ground verification is to take provisional ground cover type maps or paper copies or quadrants of imagery scenes, possibly with provisional typing done on transparent overlays. Using local maps or the infrastructural information on the higher resolution imagery, field verification sites or transects would be identified that will assist in the verification of ground cover types. In the case of aerial photography less ground verification may be necessary than with imagery as stereoscopic examination may more easily identify types; this is particularly so as larger scale photograph is used, e.g. 1:10,000 to 1:20,000.

3.36 To accurately establish the coordinates of a ground verification site, use may be made of the Global Positioning System (GPS). With the use of a hand-held monitor and attached antenna the site can be located to within 25m, and in the case of a more expensive model to between 10 and 15m. The latter model also has a digital recording system that allows either points or lines such as roads or boundaries that have been traversed to be placed on a digitized mapping or GIS field. Unfortunately the system only works on line of sight and the U.S. Forest Service is currently carrying out experiments to determine how best to use the system under heavy tree cover or on adverse slope or aspect conditions. There is also a time limit, currently about 18 hours, during which it is possible to be in "sight" of two of the GPS satellites. However, when the planned 24 satellites are positioned a 24 hour service will be available with the added benefit that, if one can "sight" three satellites, it is possible to get a three dimensional reading that includes altitude.

3.37 Where ground access is difficult e.g. in very large tracts of woodlands with little or not road access, aerial verification may be used if helicopters or small fixed winged aircraft are available. Apart from visual observations, this could take the form of single or stereo-paired low-level photos 18/ at identified locations or a video taken over a pre-set course between two identifiable points. A photographic record is then available of the ground cover types for later comparative reference or possible use as training sites for confirming type identification. Photos may also be taken of various types during ground surveys, but being horizontal shots they are not as good as vertical shots for future comparative identification of ground cover types.

Final Type Classification and Map Production

3.38 Final ground cover/woody biomass type maps may be produced using the provisional maps or paper image scenes and the information obtained from the ground or aerial verification. Classification of the ground cover/woody biomass types may be done digitally (particularly with AVHRR and Landsat MSS imagery data) or manually (SPOT imagery or aerial photos). For digital classification the values of each pixel in each spectral channel are compared to various sets of pixel values (training statistics) for areas of known classification (training sites) from local knowledge or field verification and interpretation. Algorithms or formulas can be used to then assign pixels, and thereby areas on a map, to a given type. These types may then be color-coded, for easier visual interpretation on a digitally produced map.

3.39 The resultant ground cover/biomass types should be verified. This may be done by an expert knowledgeable of the types being mapped. It may also be done using ground information points that were reserved when the original interpretation had been done. Such points may be used to determine the accuracy of the interpretation as was done in Tanzania (ESMAP, 1990).

3.40 With coarse resolution imagery such as AVHRR there may be greater problems with interpretation that often are exacerbated by the low level of ground verification over wide areas. This is particularly so with variations in land use that may occur at a scale too fine for accurate interpretation as was found with forest, tree crops and agricultural crops in the West African Coastal Region(ESMAP, 1990). The ESMAP/ETC(UK) Sub-Saharan mapping experience illustrates how this problem can be accentuated in areas of steep slopes and high altitude. In the highlands of Ethiopia there exist small areas with different biomass levels and NDVI profiles. Altitude was introduced into the classification procedure and contour lines digitized and placed on the classified image. With the exception of the montane forest type all types occurring between 2000 and 3499 m in the area were merged to form a Highland Cultivation mosaic and those above 3400m were merged to form a Ethiopian Montane Steppe.

18/ Simultaneous photos taken from twin cameras attached to a boom that is fixed to the aircraft. Height above ground vary at 500 to 1000 feet.

3.41 Once the ground cover/biomass types have been satisfactorily established on a digital map this can be used directly to print paper copies of the map, generally at a very small scale for large areas. Enlargements may then be made from these maps and larger scale sub-divisions of the digital map inscribed with numbers or in color.

3.42 Classification done manually will also use training sites where ground cover/biomass types have been interpreted through local knowledge or field verification. Areas of similar tones and textures may then be interpreted allowing for any local knowledge that may alter the interpretation. Mapping of the various types and other ground features, such as towns and roads may be done on transparent overlays placed on the thematic maps produced from the imagery. These maps should be registered to local maps of the same scale e.g. 1:50,000 topographic map sheets, and a mosaic made to compensate for the deviation of the imagery flight path from the north-south axis as used by the local maps.

Field Surveys for Woody Biomass Assessment

General

3.43 At present there is a dearth of data on the standing stock and growth rates (potential annual sustainable yield) of woody biomass in the various vegetation/woody biomass types of Africa, Asia and Latin America. An extensive literature review carried out as part of the ESMAP Sub-Saharan Biomass Mapping Project confirms this as far as Sub-Saharan Africa is concerned (ESMAP, 1991). Reliable estimates of such standing stocks and growth rates are needed for determining the sustainability of woody biomass in a given area and also as an aid to resource management. The imagery and maps provide spatial information on the types, but for woodfuel resources planning, development and management it is essential to know the quantity, condition and growth rates of the resource within the types.

3.44 These woody biomass data are usually obtained using a ground inventory in forests and non-forest areas with woody vegetation, using the maps and/or imagery to stratify the sample so as to facilitate a cost efficient assessment to a desired level of accuracy. Regressions are established between measurable parameters and biomass to utilization limits with field and/or aerial sampling being undertaken to a specified intensity to achieve a given standard error. However, on occasions, particularly in commercial forests or plantations, inventories have been carried out to ascertain merchantable volumes of industrial wood. Rather than carry out another inventory for total tree biomass a correlation may be established between merchantable volume and total tree biomass to a given utilization limit. Considerable work has been done on this for relatively homogeneous coniferous stands in U.S.A. and Canada (Hitchcock, Saucier, Phillips and Williams, 1979). However, little if any work has been done on similar regression analysis for trees in more heterogeneous tropical and sub-tropical forests and woodlands, although Brown and Lugo (1984) have made some correlations between total wood and stemwood in tropical forests (Table 1.1).

3.45 An essential element in the woody biomass assessment is the definition of the various tree utilization limits for wood products, including fuelwood, for each assessment area, e.g. merchantable bole (for industrial roundwood) from a prescribed stump height to a prescribed diameter top or crown break; the woodfuel remaining above the stump, including branches, to a prescribed minimum diameter. As mentioned in Chapter I, for environmental reasons and to promote natural regeneration, one usually considers only above-ground woody biomass. However, where land clearing operations are concerned then total tree biomass to utilization limits should be assessed. Where charcoal for urban markets is the principal product and woodfuel is reasonably abundant the utilization limit of branches may be relatively high e.g. 3-4 cm diameter. However, in areas where woodfuels are scarce such as in Ethiopia and parts of China, even twigs and leaves are used as fuel, while in fuel starved areas, such as Afghanistan and Lesotho, plants are uprooted with obvious environmental consequences.

Establishing Tree-Weight Functions and Tables

3.46 Before a woody biomass assessment can be carried out it is necessary to establish the correlation between parameters such as diameter at breast height (dbh), stump diameter, total tree height or crown diameter, that may be measured during the sampling process, and the volume/weight of woody biomass to a utilization limit. In some instances, particularly for areas of the U.S.A. and Canada, and possibly parts of Europe, this correlation may already exist in the form of a regression equation or set of volume/weight tables. A limited number of such equations exist for African forests and woodlands, e.g. Chidumayo (1990) and Stromgard (1985) in Zambia and Bird and Shepherd (1989) in Somalia, but it is likely that most woody biomass assessments in Africa, Asia and Latin America will require the development of this correlation.

3.47 Development of appropriate tree-weight functions requires destructive sampling of trees, the number being related to the variation between and within species for a given size class. Much of the work in North America has been rather arbitrary in determination of sample size and has varied with the researcher involved (Hitchcock and McDonnell 1981) and Young (1976) demonstrated through a sampling study in Maine that approximately 30 sample trees, evenly distributed across the range of stem diameters, were sufficient to prepare a species weight table. The number used in practice, at least in North America, however, ranges from 10 (MacLean and Wein, 1976 and Schlaegel, 1975) to several hundred for a species (Burkhart et al., 1972 and Shtuble, 1969). The indications are that when developing weight tables in the 5-30 inch (12-75 cm) diameter range 20 to 40 trees are sufficient to give coefficients of determination of 0.95 or better on total tree weight (Clark and Taras 1976, King and Schnell 1972, Wiant et al, 1978, and Brown 1976). In a woodfuel inventory in Somalia, Bird and Shepherd (1989) used between 1 and 11 trees per 1m crown diameter class or 49 trees in total for the Acacia bussei population and between 2 and 6 trees per 4cm stem diameter class or a total of 34 trees for the A. senegal population.

3.48 In African woodlands with numerous species the task may seem formidable indeed. A sensible short cut may be to first consider only the more important woodfuel/pole/timber species. This could entail from 6 to 16 species. It should also be borne in mind that variations in edaphic and climatic site conditions could increase the coefficient of variance within a genus or species size class necessitating a larger sample to achieve a regression curve that has an acceptable correlation coefficient. In the end, manpower and money may decide the number of trees to be destructively sampled, although other determining factors are the relationship of local villagers to the trees e.g. low tree density around villages and farms would necessitate cutting as few trees as possible, and environmental considerations. In such circumstances ocular measurements of stem and branch sections with some sampling of small branches and leaves may be a less accvrate, but preferable alternative.

3.49 Generally, sample trees are selected quite subjectively or by some variation of stratified random sampling, with the objective being to obtain a reasonable distribution across diameter or height classes. To develop the tree volume/weight function, measurements of tree height, crown diameter and stem diameter at breast or butt height are taken prior to the tree being cut down and weighed. It is important to record whether trees are single stemmed, multiple stemmed, have buttress roots and are under story trees over story trees. Similar species should be grouped together. Regression equations by species types may then be developed using one or two independent variables (parameters) and analysis carried out to determine the parameter(s) that give the best correlation.

3.50 The general procedure to estimate air dry weight and/or volume of a tree to defined utilization limits is a variation of the following:

(a) Fell the tree at a good coppicing stump height, usually 20 to 30 cm above the ground, and separate the major components of pole/sawlog/peeler logs, firewood logs and large branches, small branches, twigs, and leaves. If a woodfuel utilization limit larger than 2.5 cm diameter exists then this should be used as the minimum for large branches.

(b) Measure the length and top plus bottom diameters/girths or mid diameter/girth of all utilizable logs by species. For cordwood (stacked fuelwood) and poles one may measure the stacked volume as well.

(c) Weigh the components by sections taking subsamples of leaves from the small branches to determine the weight of leaves per unit weight of branches or total above-ground wood by species and size class.

(d) Use a moisture meter to determine the moisture content of each component by species. Take a sub-sample of disks, preferably from each section to verify the moisture content readings and to determine the air dry and, possibly, the bone dry densities as well as specific gravity after measuring the volume and weights of the samples at various moisture contents. Ideally the bark should be separated and its moisture content, volume and weight measured separately from the wood. Measurements of bark thickness at several sample points should give a good estimate of the percentage of bark to wood.

(e) Finally, sum the volumes and weights of the sections and components by species within the one or more utilization limits.

3.51 If there is dead wood on the forest floor or dead trees still standing the above procedures should be followed as applicable and estimates of dead volume/weight by species (if possible) made.

3.52 A complete set of volume/weight tables may consist of all possible permutations of green weight, dry weight, wood, and bark for each of the major components. In some cases the stem or branch components may be sub-divided into size classes based on utilization standards. In practice, in order to simplify matters, total above-ground green and air dry weight to a utilization limit(s) may be used with notes made on the relationship between stem and branch wood, green moisture content, and specific gravity.

3.53 In the North American context with fairly well defined stems and branches, and often more homogeneous stands in terms of species and age classes than tropical forests, Young (1977) recommends the use of diameter for the independent variable in local tree-weight functions with the addition of height for regional tables because of a greater variance in the stands over a wider geographic area. Smith (1971) suggests that crown width should also be used. However, for temperate species "D" or "D^2H" 19/ are the most universally accepted predictors.

3.54 Hellden (1987) uses a height-weight model to assess the standing woody biomass of eucalyptus plantations in Ethiopia. However, there is a paucity of information on tree volume/weight functions for tropical species, and in particular for African woodland species. In the latter the stem may not be as clearly defined with low branching and multiple leaders being common. Crown diameter has been used and would be an important parameter if low-level aerial surveys are done. In Ethiopia, Hellden (1987) found that the wet weight of Acacia trees, ranging from a few kg to almost 1.5 tonnes, was a function of the crown diameter with a high degree of

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19/ D = Stem diameter at stump height or breast height
H = Total height or height to utilization limit

correlation using a logarithmic relationship. Hellden then verified that the total weight of trees and bushes in an area was a function of canopy cover. Olsson (1985) supports this correlation with similar work in Sudan. With a relationship established between Landsat TM or MSS NDVI data and canopy cover in Ethiopia, as shown in Appendix 1, and supported by Sudan canopy cover data (Olsson 1985) as assessed in high resolution air photos, it was possible to directly assess the weight of standing woody biomass using satellite imagery data, once the relationship between crown diameter and weight had been established through sampling.

3.55 As Hellden points out, the woody biomass assessment method described above is valid only for open woodlands and tree dominated grasslands. When it comes to closed canopy woodlands and forests, satellite data can only be used for delineation, vegetation/land cover stratification and area change studies. Biomass quantification needs to be based on low level aerial photo and/or ground sampling.

3.56 Chidumayo (1988) developed logarithmic regression equations for estimating biomass in wet and dry miombo woodland and coppice regrowth using only diameter at breast height (1.3M above ground) or stump height (20 cms). Stromgaard (1985), using data from sample sites in undisturbed and regrowth areas, developed logarithmic regression equations for estimating green weight of wet miombo woodland using diameter at breast height and total height. He found that a polynomial regression equation, where diameter and height values are squared, had a slightly higher coefficient of multiple determination ($R^2 = 0.72$) than a simple multiple regression with log (biomass weight) a function of log (dbh) and log (height). CIDA (1987) found in their biomass fuel/fodder survey, conducted as part of the Andhra Pradesh Social Forestry Project, that, since weight and volume are significantly correlated (0.99), the dimensions commonly used to predict volume, i.e. dbh and height, are the best predictors of stem weight. The weight of foliage and branchwood are also highly correlated with dbh and tree height. Rockwood et al (1982) found in eucalypt plantations in Florida that dbh was the dominant variable in biomass equations. Models involving $(dbh)^2$ only were often excellent predictors of air dry weight or volume and the inclusion of tree height resulted in very little improvement in yield estimation. However, in this plantation situation there was a high degree of uniformity in the heights for trees of similar dbh, something that may not be the case in African woodlands or for countrywide as opposed to limited area situations.

3.57 Tree-weight functions are usually in the form of some type of regression equation. The two most commonly used equations take the form of:

(a) $\log(\text{weight}) = b_0 + b_1 \log$
where $X = D$ or D^2H and b_0 and b_1 are constants,

or

(b) $\text{weight} = b_0 + b_1 X$
where X = basal area, D^2 or D^2H.

3.58 The choice of regression techniques and the use of logarithms is a subject of some controversy and should be decided by experts involved in assessment of a particular forest/woodland type. However, as Hitchcock and McDonald (1981) point out, it is important to be able to compare and pool various tree-weight functions, particularly for similar vegetation types, and it is extremely difficult to pool tree-weight functions that use different dependent and independent variables, component definitions and equation forms. Certainly if an equation exists for the same or a similar vegetation type, but in another area from that being sampled, it would be useful to take minimum samples and determine the correlation to see if, in fact, the existing equation could be utilized. Obviously, the first task would be a literature search to determine what equations or tree-weight tables exist for similar vegetation types.

Field Inventory

3.59 The first point in carrying out an inventory is to understand the objectives of that inventory. This will then dictate the area to be covered, the sampling intensity and the utilization limits to be considered. These factors, in turn, will determine the cost.

3.60 Undertaking a field inventory requires that the sampling techniques be decided upon and the field teams briefed and, if necessary trained in these techniques. The techniques to be decided include the parameters to be measured, the type of sampling, the plot size, and the sample intensity. A decision may need to be made as to whether aerial sampling, using low-flying aircraft or aerial photography, would supplement ground sampling, particularly in the more remote and inaccessible areas. From a practical point-of-view it is important that the field teams be adequately supplied with the necessary equipment to carry out the sampling and, if necessary, to camp. Logistics and adequate transportation are also critical for an efficient sampling operation.

3.61 The area to be sampled should be stratified into vegetation/biomass classes determined from imagery, aerial photography or existing vegetation maps. Either a random or systematic sampling system might be used depending upon access and the ease with which sampling points can be determined by the sampling teams. A series of permanent sample plots should be established to ascertain, over time, the net growth of the vegetation type. It will also be important to carry out a sub-sample for young regeneration, recording the number of seedlings by height classes and species.

3.62 Sample Intensity The intensity of the sample will depend on the accuracy required e.g., standard error of the mean within a given probability limit for total standing stock for all size classes and all species. For low level assessments over a region within a vegetation type, time and cost may preclude anything better than ± 25% standard error. However, within stratified types in a relatively limited urban woodfuel catchment area, where the inventory data will be needed for management purposes, a standard error of ± 15% within 95% confidence limits is desirable. To obtain an estimate of the number of plots required for a given standard error a few random plots may be sampled. The variance is then used to estimate the number of plots.

3.63 Woodfuels are a relatively low value, but high volume product, and therefore total income from the sale of the wood raw material could be considerable. The areas to be assessed are usually large and heterogenous from the point of view of species and size classes, depending on the ecology of the area and the intensity of use or interference by humans and/or livestock. Therefore, although there is an ideal standard error desired, the time devoted to the assessment of a particular biomass resource should be determined by its relative importance from an accessible woodfuel production point-of-view as well as its relative importance for other products such as poles, industrial wood, fodder and honey. Relatively unproductive woodland does not deserve the same intensity of sampling as woodland from which large amounts of woodfuel may be produced. To obtain a precision of more than 15% frequently requires a sampling intensity of 0.05-0.5%. This will vary with the size of the area to be assessed and the variability of sizes and species, but in the end, cost may be the overriding consideration at the expense of precision.

3.64 Type of Sampling The type of sampling to be carried out is something to be decided for each woody biomass sample area. Apart from whether the sample should be systematic or random, other factors to be considered include plot size, the use of phasing and multi-staging, and the parameters to be measured. Again cost control will be an important factor, while endeavouring to obtain a desirable level of accuracy with the sample.

3.65 Multi-stage sampling is one way of maintaining accuracy and reducing costs with sub-samples being made for the whole sample population, certain parameters or for sub-sets of the sample population, such as small trees or shrubs amongst larger trees. In high forests without considerable undergrowth the use of a prism or relascope to determine basal area factors in variable-sized plots and the correlation of basal area to plot tree weight to a suitable limit is a cost efficient approach that has been used in North America. However, it would probably not be suitable for African woodlands where low branching may confuse the estimation of basal area. Another short cut to assessing utilizable woody biomass in North America is the establishment of correlations between industrial wood volumes (for sawlogs, peeler logs or fibre wood) and the weight of utilizable woody biomass. With inventories often having been done for the former, it is then possible to obtain quick estimates of the latter.

3.66 The parameters to be measured were discussed under "Establishing Tree-Weight Functions" and if one variable such as stem diameter (at breast height, stump height or above root collar) gives a satisfactory estimate for tree weight then time and money is saved when compared with measuring two variables.

3.67 Plot Dimensions Plot size is determined by terrain and the stand characteristics as well as by the type of sampling being applied. The size of the plots may vary from 0.005 ha (7 m x 7 m) to 0.5 ha (50 m * 100 m). There are also continuous strip plots that may be 5 ha (20 m x 2,500 m) or more in size and, finally, there are variable sized plots based on the use of a relascope or prism. The shape of the plot may be square, rectangular or circular and is dependent on the method of sampling and the terrain, e.g. variable sized plots tend to be somewhat circular and point random sampling may also utilize circular plots, but not necessarily so, while plots on lines tend to be rectangular. The size of the plot will affect the accuracy. Versteegh (1980) found that for various plot sizes on a strip ranging from 24 plots of 0.04 ha (20 m x 20 m) to 2 plots of 0.48 ha (240 m x 20 m) and a continuous strip of 4 ha (2000 m x 20 m) the full strip enumeration offered the best precision. Chidumayo (1989) in measuring biomass in Zambian woodlands used 20 x 10 m sample plots at sample sites that covered two types of woodland and two age classes: coppice regrowth and old-growth (mature), although the latter often consisted of mixed aged stems due to natural or human disturbances. For a given assessment, preliminary sampling of different sized plots overlapping each other at several random sites would indicate the optimum plot size.

3.68 The plots associated with the use of prisms that determine basal area are roughly circular, but have variable radii as trees included in the plot are determined by the basal area factor of the prism, the distance from the center of the plot, and the diameter of the tree bole. They are an effective method of woody biomass assessment in relatively open stands where boles can be clearly distinguished. However, where the plots are in thick forest or woodlands with heavy undergrowth another method would be preferable.

3.69 If strip or rectangular plots are used they should be arranged so that, to the maximum extent possible, they cross contours and soil and/or vegetation changes. The same should be the case for plots set out on a line. Ribe (1979) introduces the concept of a variable size plot with the plot size being inversely proportional to tree density. This allows time and cost factors to be introduced into the determination of plot size with plot areas being arbitrarily defined to contain a specified number of trees.

3.70 Sample plots may contain one or more sub-plots. The smaller plots are used to tally smaller trees, shrubs and regeneration that occur in greater numbers than the larger trees in the main sample plot. In Papua New Guinea, Ryan used one chain (20 m) radius circular plots to tally trees above 50 cm dbh and a smaller concentric plot (3 m) radius for trees between 10 and 50 cm dbh. Similarly, in Canada, Alemdag and Bonnor (1985) used a sampling unit consisting of three sample plots to determine forest biomass. These plots consisted of a 400 m^2 main sample plot in which all trees 8.1 cm dbh and larger were measured; a 100 m^2 sub-plot comprising the southeast quadrant in which all trees between 0.1 and 8.0 cm were tallied; and a 4 m^2 sub-plot in the center of the main plot to tally all woody regeneration with heights between 0.31 m and 1.30 m.

3.71 Permanent Plots In order to obtain time series data on the woody biomass being sampled, permanent plots may be established and regular measurements made. These are particularly useful where growth data is needed, but they also serve to show the dynamics of the forest in broader terms such as the effect of management and silvicultural practices. In many cases sampling with partial replacement is carried out in which some plots are temporary and others permanent, particularly where intensive sampling is being done overall or large areas are being covered. However, for smaller less intensively sampled areas all the plots may be permanent. Usually the permanent plots have more substantial marking to facilitate future location but, the extra time and cost may be inconsequential compared to temporary plots.

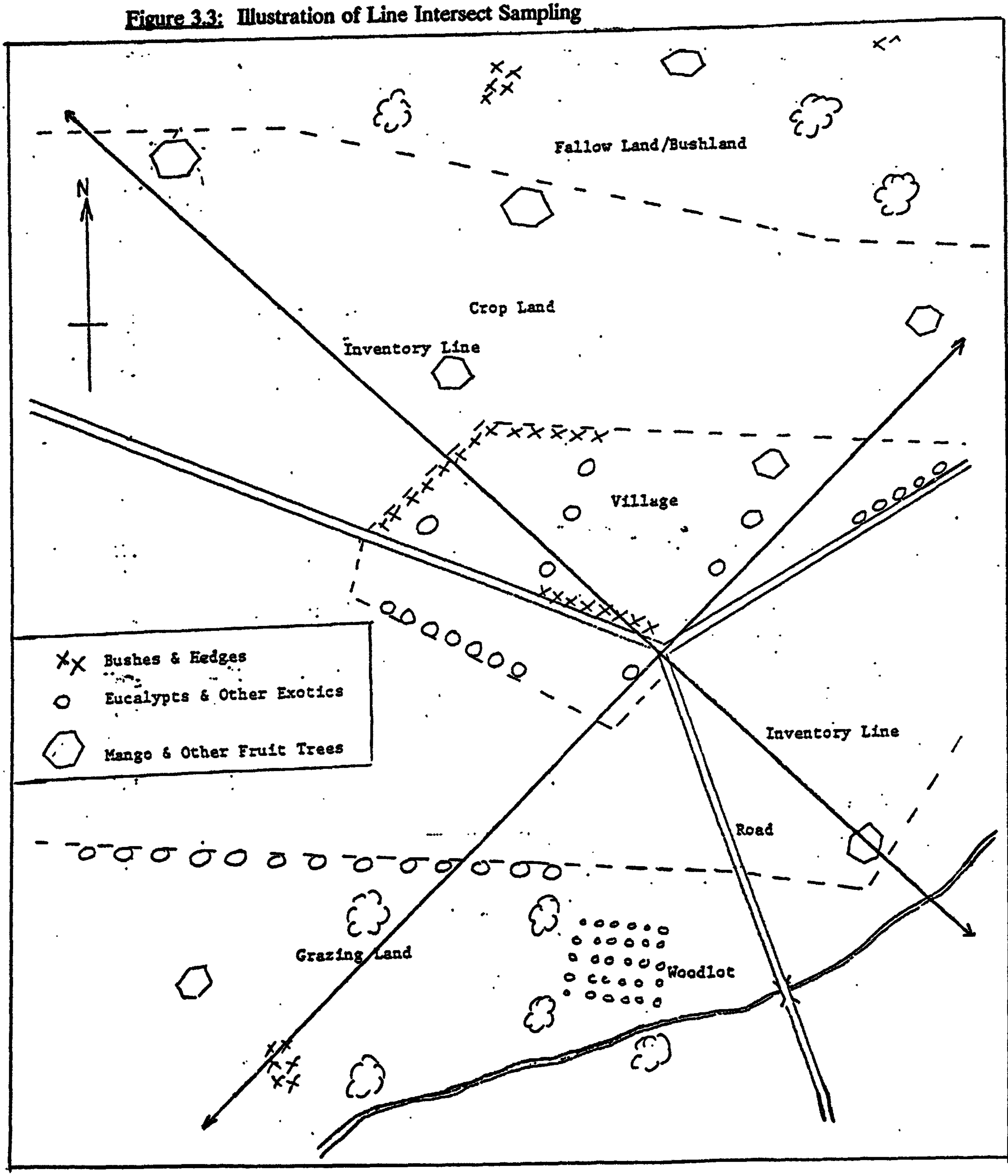
Assessment of Non-Forest Trees

3.72 Much of the woody biomass used for fuel comes from forests, woodlands, plantations or scrub that could all be classified loosely as forests. This is invariably the case for urban woodfuel supplies. However, a great deal of woody biomass for fuel comes from non-forest areas, particularly that used by the rural population. In India 45% of rural households collected wood from their own or a neighbor's farms and from roadside trees, and overall 38% of household fuels came from these sources (Natarajan, 1985). In Kenya in 1980, 60% of fuelwood and 40% of charcoal came from trees outside the forests and woodlands (Openshaw, 1982).

3.73 In forests, the general espacement of trees is such that, even though they may be scattered and there may be gaps of varying sizes, it is possible to apply the above-mentioned sampling practices. The trees in the village/farm context and along roadsides generally do not lend themselves to the same practices. They often occur as scattered individual trees, in patches or lines necessitating a different sampling approach. Standard fixed plot or point sampling methods are not designed for these types of vegetation patterns. Assessing woody biomass under such circumstances is a new concept for most countries, but it is possible. One of the common approaches is to use the Line Intersect Method. The line intersect theory has been used in logging residue surveys and to estimate the total length of wooded strips in a given land area.

3.74 Within a sample area, line intersect sampling uses a transect, established on a random or systematic basis, to select a sample from vegetation lines, patches or single plants. The same range of variables as mentioned above may then be measured from a sub-sample of the selected lines and patches as well as from all of the individual trees or clumps of vegetation. Figure 3.3 illustrates the use of the line intersect method. The transect, in this case two transects at right angles, passes through a lines of hedges and trees, a clump of low trees such as prosopis, and a single mango tree. Fixed area plots would be established in the prosopis clump and the line of trees and various parameters measured here as well as on the single tree. The plot dimensions will vary with the width of the line of trees e.g. a 0.05 ha plot would have dimensions of 10 x 50 m if the line is 10 m wide, but 5 x 100 m if the line is only 5 m wide. If standard inventory measurements are made the results can be presented in traditional forest inventory formats with tables of standing stock.

Figure 3.3: Illustration of Line Intersect Sampling



3.75 Equations have been established to determine the mean quantity of woody biomass per unit area using information from lines, clumps or isolated trees. The basic equation from which equations have been derived for the various intersected elements is:

$$X = \frac{\pi}{2L} \sum_{i=1}^{n} \frac{X_i}{L_i}$$

$$X = \sum_{i=1}^{n} \frac{X_i}{WL}$$

where n elements of the same type are found to be intersected by the transect. X_1 is the value of any characteristic of the element and L_1 a uniquely defined length associated with that element, while L is the length of the transect (CIDA, 1987).

3.76 In Andhra Pradesh, India, a CIDA Biomass Fuel/Fodder Survey used two line transects at right angles in each taluka (sub-district with an average area ranging from 600 to 1600 km^2). The direction of the first line was chosen at random from a list of three compass points: northwest, north, and northeast. Each line was six km in length or the length a team could cover in six hours of work, whichever was lower. Each cross formed by the two transects would sample an area equal to the product of the lengths of both transects.

3.77 A less complicated, but less accurate method of determining woody biomass in the village/farm context and along roadsides is to carry out continuous strip inventories. Strips are commenced on a systematic or random basis, but usually in conjunction with identifiable access routes such roads, tracks or rivers. The direction of the strips may also be random as with the line intersect method or alternatively aligned so as to cross the topography and land use/ecological systems. The area may also be stratified into different farming types to provide greater accuracy. The strips should be of a fixed length e.g. 2 km and each strip would be a sample or it may be divided into plots or plots established at regular intervals along the strip (line plots). For improved accuracy, particularly over a large area, a first stage of aerial photo plots may be established in which crown cover by various types/elements such as rows or single trees is measured and a percentage of such crown cover for each strata established. In inventories of the non-forest biomass in Georgia, USA, variable radius plots were established using a prism and trees under 5 inches dbh were measured in a 1/300th acre sub-plot around the point centers. A crown closure code was assigned to each plot that represented crown closure classes of 1-29%,30-59%, and 60%+.

3.78 Openshaw (1982) used the latter method to determine woody biomass in Kenyan farming areas. His line plots were a third-stage sample of aerial photo strips 30 km long and photo sub-plots within each of 11 land-use types, with the starting point of the line chosen randomly from a grid, but then relocated to the nearest access. The line was in the form of a rectangle with sides of 1 and 0.5 km and aligned north/south, east/west. Plots 10 X 50 m were located every 200 m. This probably introduced some bias in covering the land use types that could have been avoided using a square or straight line. All trees and shrubs that fell within the limits of the strip were measured. The strip method, although recognizing and recording that trees or shrubs were in lines, patches or as single trees, does not differentiate these elements in calculating the quantity of biomass per unit area and does not endeavour to determine the length of any tree lines or the size of any patches as the line intersect method does. Figure 3.4 is an example of such a sampling method based on a square set of line plots from a starting point (the bridge) that is chosen as the nearest recognizable point to a randomly chosen point.

3.79 If tree-weight equations are not available for the trees and bushes present within the village/farm complex then, of course, some relationship has to be established between measurable parameters and the weight of woody biomass. However, there may often be difficulty with carrying out destructive sampling of trees and bushes around villages and farms. In fact it is generally not an acceptable practice. One way around destructive sampling is to use a relascope or dendrometer to take measurements of stem and even branch diameters at several points while tree and bole height would also be measured remotely. To obtain the relationship between small branches and leaves and the larger woody mass it would be necessary to cut the same from a few trees of varying sizes. However, this could be a form of pollarding with most of the biomass being available for local use, and, in most cases the trees or bushes will continue to grow.

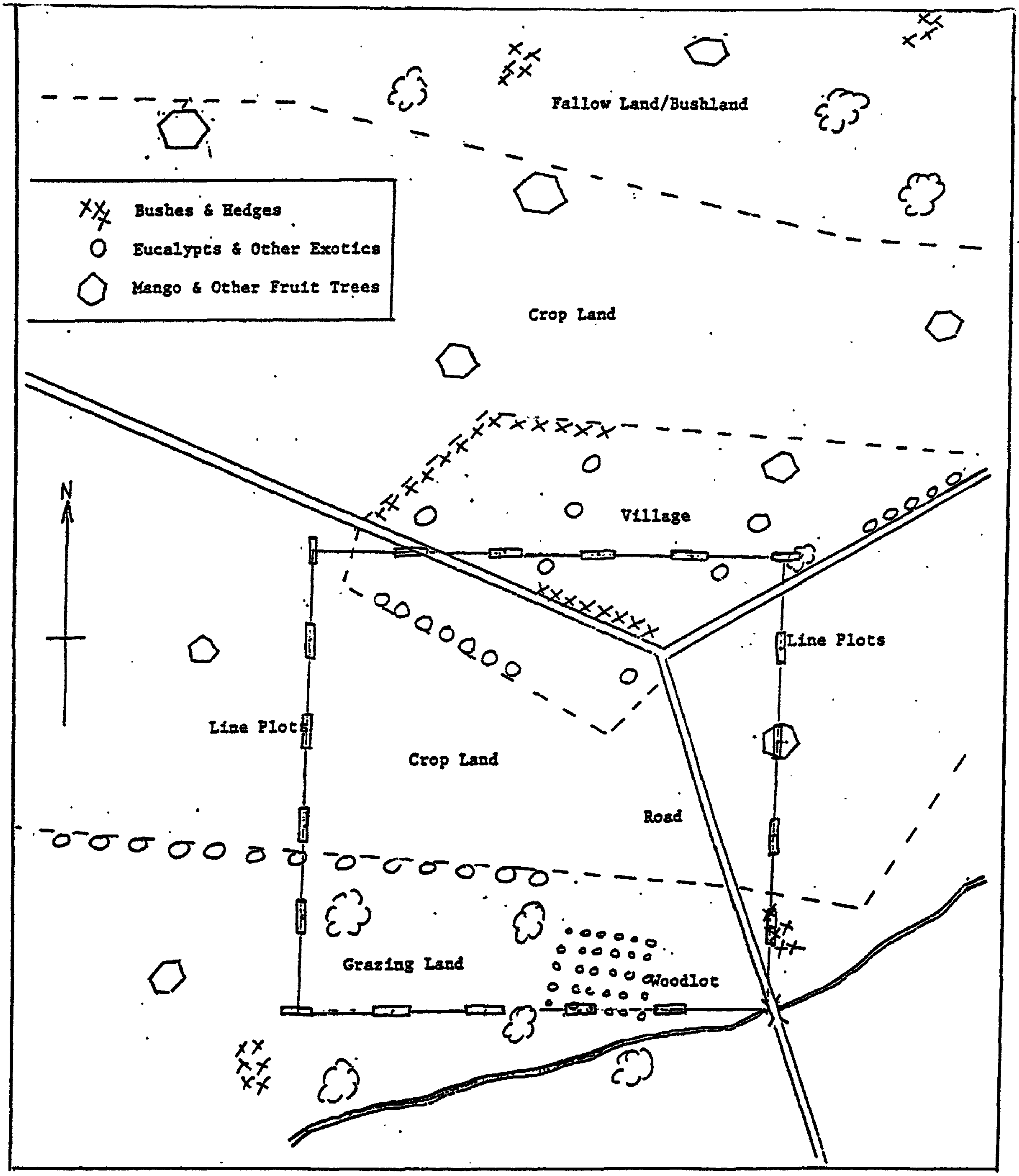
Demand Assessment

3.80 To assist in maintaining the reliability of the assessment it is useful to have a survey carried out of the woody biomass use patterns by households and small industries within the woodfuel catchment being assessed. This gives a good sense of the fuels being used, the type of wood preferred, the catchment for demand centers such as villages or towns, and a perception of supply sustainability. In fact, biomass assessments and household energy surveys play a useful complimentary role in many such contexts.

3 P Sampling

3.81 In many cases, particularly where only limited sampling is possible, the use of 3-P (probability proportional to predicted occurrence of a characteristic) can enhance the accuracy of the estimate. In woody biomass sampling there is often a higher degree of variance than for industrial wood inventories and 3-P may be useful here in that the trees samples can be reduced while retaining sample accuracy. It may also be pertinent when selecting trees or bushes for tree-weight equation sampling. Larger trees or bushes may be favored as containing proportionally the greater quantity of biomass.

Figure 3.4: Illustration of Line Plots in Non-Forest Area



3.82 Point-3P sampling as proposed by Grosenbaugh (1971) combines horizontal point sampling with 3-P sampling to produce a useful inventory technique. The method selects individuals proportional to basal area times height (BA x H). As Rennie (1976) points out, (BA x H) is commonly proportional to volume, in fact the usual combined variable model for volume estimations comprises these two parameters, therefore selection with point-3P sampling is proportional to volume or to the weight of biomass. Using point sampling methods with a prism or relascope trees may be selected proportional to basal area with the sample containing a greater proportion of larger trees. Within the sample 3-P sampling is then used to select individuals based on estimated height. Tree heights are estimated and are then paired with random numbers prepared for the occasion. Trees with heights equal to or greater than their corresponding random number are chosen for measurement.

Determining Growth Rates and Yield Potential

3.83 Of greater importance than determining the standing stock of woody biomass, which will be the main outcome of the above-mentioned inventory methodologies, is the determination of the growth rate or annual increment of a particular area of growing stock. Unfortunately, in many tropical regions this is a difficult thing to do. In temperate forests it is often possible to obtain the age of a stand by counting the annual rings that accrue due to the differential growth of spring and summer wood. Borings may be made or counts made on tree stumps. However, in tropical areas, although such rings may occur associated with marked dry periods and loss of leaves, they are infrequent. Of course where they do occur and could be considered as reliable indices of age then they may be used to determine growth or MAI in conjunction with woody biomass assessments for the same areas. Chidumayo used such a method to determine growth rates for miombo woodlands in Zambia and it has also been used in similar vegetation types in Tanzania and Botswana. One has to understand, however, the rainfall pattern and the significance of the rings as there may be more than one per year.

3.84 The most accurate method of obtaining growth data in tropical regions is to establish permanent sample plots that are monitored for extraction and measured on at least an annual if not a more frequent basis. It is advisable, if possible to establish such plots in various age classes as growth does vary with age as well as with climatic conditions and as the result of various silvicultural practices or interference. It takes time, however, to determine the average growth rate by such plots.

3.85 A rough approximation of growth rates can be obtained if the history of part or all of a tract of forest or bush is known, either through forest agency records or the knowledge of local villagers. Of course it would be very difficult to accurately reconstruct the history of the forest or bushland being considered including all wood removals and fire losses but if at least the date of the last cut was known together with some estimates of subsequent removals then, by assessing the current standing stock, a conservative growth rate could be estimated.

Dead Wood

3.86 Most inventories of woody biomass only consider the standing live trees and bushes. However, a considerable quantity of dead wood either standing or, more commonly, on the ground is collected as fuel by villagers. In fact in many rural areas in Africa and Asia such wood may represent 80 to 90% of the woodfuel collected by villagers. In some cases it is also sold into urban areas. Such wood is a result of a natural ongoing process of forest mortality, branch pruning or the effect of winds and it is estimated that it could account for between 30 and 50% of the gross MAI of the forest or non-forest trees. The more mature the trees the higher the proportion of dead fallen wood with older forests having higher than 50% of such wood in the gross production estimates.

3.87 Any woody biomass assessment should include an estimate of such wood and this is probably best done on a sub-sample basis within the regular woody biomass assessment. All the wood on the ground should be collected and weighed while any dead trees should be either measured standing or felled and then measured with "biscuits" being taken and weighed to determine wood density. The assessment of this dead wood should be applied to both the forest areas as well as the non-forest trees. However, as such dead wood is a major source of fuel for villages, with larger pieces even being sold into urban areas in some cases, the only true estimate of such wood as part of the woodfuel supply resource and its gross production has obtained through the establishment and close monitoring of permanent sample plots. The plots would have to be either conscientiously protected over a long period to prevent removal of the wood or closely monitored to record wood removals.

Woody Biomass Assessment Costs

3.88 Woody biomass assessment costs are rather specific for each assessment. Costs will vary according to the following factors:

(a) The amount of reliable data, including vegetation type maps, aerial photography or imagery, and woody biomass estimates already available for the area being assessed.

(b) The spatial area to be covered by the assessment.

(c) The intensity of the assessment as dictated by management and planning needs.

(d) The quantity and value of vehicles and equipment that need to be acquired for the assessment.

(e) The amount of expatriate or local technical assistance required.

(f) The nature of the imagery required and whether digital data and its analysis is also necessary.

(g) The cost of salaries and allowances for local staff.

Table 3.2: Cost Estimates for Woody Biomass Assessment ($/km²)

Assessment Elements	AVHRR (4-8 km Res.)	Landsat MSS	Landsat TM	SPOT	Air Photos
	Imagery Type				
Basic Imagery and Digital Data	0.01-0.02	0.02-0.05	0.10-0.15	1.00-1.50	8-10
Cartographic or Image Map Production	0.04-0.09	0.05-0.10	0.20-0.50	1.50-2.00	2-3
Ground Verification	0.02-0.05	0.05-0.10	0.20-0.40	0.50-0.80	0.10-0.20
Low Intensity Ground Assessment	-	0.20-0.40	0.20-0.50	1.00-4.00	1.00-4.00
Management Assessment	-	-	1.00-4.00	4.00-10.00	4.00-10.00

3.89 Table 3.2 shows a range of cost estimates per km² for various elements that may be involved in woody biomass assessment. The total costs of assessments may range from about $40 to $50 for assessment of a village woodfuel catchment to about $2 million for a fairly detailed assessment of urban woodfuel catchments extending over a combined area of some 140,000 km² as illustrated by the examples described below.

(a) **Village woodfuel catchment assessment involving line plots within a 4 km radius of the village.** The work would be completed in a day and involve the use of just basic field equipment. If several villages were involved stratification of land use types may be made with aerial photos. The cost range per village catchment would be $40 to $50.

(b) **Very broad overview of the spatial distribution and area of woody biomass types with rough approximation of standing stock and yield potential based mainly on use of existing data.** AVHRR 4 or 8 km resolution data would be used with limited ground verification. Imagery data processing would be done at existing facilities. The cost for such a survey covering 20 million km² (all of Sub-Saharan Africa) would be $400,000 - $500,000.

(c) **Assessment of woodfuel resources over a region, using Landsat TM or MSS imagery, or AVHRR 4 km data and SPOT imagery subplots.** Ground surveys would be undertaken extremely. Imagery data and assessment data would be analyzed in-country with purchase of equipment and software. The cost estimate over a large country or within biomass types across a region of several countries would be $600,000 to $800,000 for an area of about 2 million km².

(d) **Assessment of woodfuel resources in urban woodfuel catchments using SPOT imagery to produce imagery maps with ground cover overlays.** Fairly intensive ground verification would be carried out and ground inventory to obtain a SE of ± - 25% with destructive sampling to establish tree weight equations. The cost for an area of about 100,000 km² would be between $1.5 and $2 million, with imagery maps and overlays production costing some $500,000.

3.90 Most woody biomass assessments would require at least one person with expertise in forest mensuration and statistics and their application to total above-ground woody biomass assessment. Team leaders and other field staff would probably need to be trained in the methodologies involved and the field work monitored. Woody biomass assessments do not require a great deal of expensive equipment. An appropriate means of identifying the spatial extent of the resource such as vegetation type maps, aerial photos or satellite imagery should be available or acquired. Field teams and supervisors will need mobility and if suitable vehicles are not available they would need to be purchased. Field equipment such as tapes, height measuring instruments, relascopes and weighing scales would probably need to be purchased and so too may camping equipment. Computer hardware and software should be available for compilation and analysis of the results, although this can be done by a pocket calculator. Expensive laboratory equipment to test samples is usually not warranted as the samples may be shipped to laboratories for appropriate tests.

IV. THE MEASUREMENT OF NON-WOODY BIOMASS

Introduction

4.1 The previous chapters have dealt with the measurement of woody biomass, usually the most important form of renewable energy. However, in certain countries, and in the post harvest season of many countries, non-woody biomass energy may be significant. For example in India, agricultural residues and dung comprise about 46% of biomass energy and 20% of total energy. In Lesotho, dung and shrubs are the most important forms of energy in quantity terms.

4.2 It is necessary, before any estimates are made of crop residues and dung, to determine their importance as fuels and to find out competing uses for these raw materials. If they are important as fuels in certain areas, either seasonably or year round, then the necessary effort must be made to determine production and availability. On the other hand, if they are of minor importance or only potentially important, then an estimation may be confined to orders of magnitude using standard conversion factors and knowledge of domestic animal numbers and quantities of crop production. Non woody plants usually have life cycles not more than 6 to 18 months. Their biomass can be collected, but must be used within a short period of time otherwise it will decompose. Thus from an energy standpoint the "annual production" is the potential available energy. This is also true of animal waste.

4.3 When compiling energy supply statistics it is important to avoid double counting. If crop residues and grasses are used as animal feed they should not be counted as potential biomass energy along with the dung the animals produce. If the crop residues are burnt instead of being fed to animals then dung production will be severely curtailed if these products are the main source of feed. The reverse is also true.

4.4 The division between woody and non-woody plants is not clear cut, cassava and cotton stems are woody, but because they are strictly agricultural crops it is easier to treat them under non-woody plants, likewise with bananas and plantains, although sometimes these plants are called 'banana' trees. On the other hand, coffee husks are treated as residues whereas the coffee clippings and stems as wood. What is important to know is the kind of agricultural crops and residues that are generally suitable and available as fuel, rather than what is the total non-woody biomass production on any given site. This is because many plants are unsuitable as fuel and most have alternative uses such as animal feed, roofing thatch, weaving materials and green manure.

4.5 Demand surveys should give an indication of what kinds of crop residues are used and over what period. Rice and maize straw may be used as the principal fuel by householders for a period immediately after the harvest, but on the other hand they may be used just for lighting fires. Industry, especially rural industry, may be dependent on crop residues to raise steam, as in sugar factories with bagasse, or to fire pottery or bricks with coffee husks. Therefore it is important to understand the intensity of use of agricultural residues, for this should determine how much effort is to be placed in measuring it's supply. Generally speaking, crop residues are a less desirable household fuel than wood or charcoal because they require much more tending. The degree of use is usually an indication of the scarcity of wood. However, in some countries, they have become the accepted fuel and may be preferred to wood. Much non-woody biomass is wasted, being burnt on site, but as wood becomes scarce this biomass will be used to a greater extent.

4.6 In measuring non-woody biomass it is as well to distinguish between biomass that is in the field, biomass that is at the house and biomass that is processed at a factory. This is because the further away it is from the consumption center the less it will be used. Also some crop residues are left standing while others are cut, the latter being more easily collected. Table 4.1 gives an example of the various types of non-woody biomass at different sites.

Table 4.1 Types of "Non-Woody" Biomass From Different Crops at Various Sites

Corp	Field (Standing)	Field (Cut)	House	Factory
A. Subsistence/Cash				
Cereals				
Maize	Stover & Leave	Cob leaves	Cob	Parchment
Deep water paddy	Tough straw (nara)	Tender straw (kher)	Kher	Husk
Normal rice paddy	Stubble	Straw	Straw	Husk
Millet; sorghum	Straw	-	Chaff	-
Wheat etc	Stubble	Straw	Straw	Husk (bran)
Cassava	-	Stem	-	Waste
Pulses	Stem	-	-	-
Plantain, Banana	-	Stem	Fruit stem	-
Papyrus	Stem	-	-	-
Heather etc.	Whole plant(1)	-	-	-
B. Cash crops				
Coffee (dry process)	(Woody biomass)		Cherries(2)	Parchment;husk
Coffee (wet process)	(Woody biomass)		-	Cherries;husk
Cotton	-	Roots+stems(3)	-	(tow)
Coconut; Palm nut	(Wood),	Fronds	Husks;shell	Husks;shell
Nut trees	(Woody biomass)		Shell	Shell
Groundnut	-	Stems	Shell	Shell
Sugar cane	-	-		Bagasse
Sugar beet	-	-	-	Waste
Sisal	-	Old plants		Waste
Jute; Kenaf, Flax	-	Waste	-	Waste
Pineapple	-	Old plants	-	Waste
C. Indirect Use				
Grasses (4)	(Grass)	(Hay)	-	-

1) In some countries such as Lesotho, heather type plants are uprooted from upland areas, dried and burnt by householders;

2) Coffee cherries make a good fertilizer;

3) Cotton stems and roots have to be uprooted and removed/destroyed within two months of harvest because of pathogens and nematode problems;

4) Grasses are mainly used for animal feed, a byproduct being dung.

4.7 For each of the above, measurements can be taken and related to the production of the food part of the plant. Of course there are different varieties of the same species with different yield characteristics. For example rice paddy has the deep water, the upland, the high yielding, the traditional and the glutinous (sticky) types to name but some. If rice is an important fuel and there are significant differences between the biomass yields of the different varieties then separate and detailed measurements should be carried out for that particular country. On the other hand if a particular crop is only a marginal fuel then superficial measurements may suffice.

4.8 Most crop residues have other uses which may be of greater economic or ecological value. In order to maintain the friability, water retention capacity and organic matter content of the soil a certain amount of residue should be left in the soil; what this proportion should be, is still under debate. Estimates range from 33 to 50% but much of this appears to be a gut feeling. What is certain, is that under a tree crop system which basically does not remove many mineral elements when only wood is extracted, the site fertility and soil/water characteristics may improve over time. If the land is cleared for agricultural production then these characteristics are quickly lost without inputs of natural and/or artificial fertilizers.

4.9 Another important use of crop residues is for animal feed and a study by Revinoranath and Reddy quoted in Woodfuel Surveys (FAO 1983) showed that in a specific Indian village over 50% of the rice straw and practically all the sorghum straw were used for animal feed. In all, more than 50% of the above-ground crop residues were used for feed. Finally crop residues can be an important construction material especially for roofs and even for walls of house. All these uses are important and if crop residues are being burnt to a great extent it may mean that people are desperate for fuel and the quality plus fertility of the land is deteriorating.

4.10 Where food, fibers and beverages are processed at a factory, there is processed waste which can and in many instances is used for fuel. Sugar cane waste (bagasse) is a key fuel which if burnt in efficient boilers should supply more than enough energy to meet the factory's requirements. The excess energy could be used for various purposes such as electrical generation. Where the biomass is delivered to a factory it is relatively easy to measure the residues. Being in a concentrated quantity, uses can be found for them, particularly as a fuel, although some products such as coffee cherries can be used as a fertilizer.

4.11 The amount of above ground plant biomass produced by crops is usually one to three times the weight of the actual crop itself. Estimates have been made of these residues in various countries and Table 4.2 gives a summary of them. However, it must be pointed out that in order to obtain accurate estimates of residue production it is important to have good estimates of crop production by region or district. This may entail undertaking surveys, especially in the subsistence sector, to determine production of both crops and plant residues. Such surveys should also determine the use of the crop residues, for example, burning in situ, mulching, animal feed, house building, and fuel, and in what proportion. Without this information then the potential quantity of residues available for fuel cannot be assessed. Finally except for groundnuts and perhaps in part cotton, the crop residues are above ground quantities. Some communities may burn crop roots as well. If so this should be recorded and measured.

Table 4.2: Ratios of crop to residue specific for agricultural crops
Unit air dry weight of residue per (air dry) tonne of crop (seed) produced

Crop	Residue	Ratio	Residue	Ratio	Residue	Ratio
Maize	Stover & Leaves	1.0-2.5	Cob	0.2-0.5	Husk	0.2
Deep water rice	Straw	2.0-14.0	Bran	0.1	Husk	0.3
Rice	Straw	1.1-2.9	Bran	0.1	Husk	0.3
Millet	Stalk	2.0-3.7				
Sorghum	Stalk	0.9-4.6				
Wheat	Straw	0.7-1.8				
Barley	Straw	0.6-1.8				
Rye	Straw	1.1-2.0				
Oats	Straw	0.9-1.8				
Cassava	Stem	0.2				
Cow pea	Stalk	2.9				
Pigeon pea	Stalk	5.0				
Coffee (wet process)			Cherry	0.75	Husk	0.25
Coffee (dry process)			Cherry and		Husk	1.0
Cotton	Stem	3.5-4.0				
Coconut	Fronds	5.0	Shell	0.65	Husk	1.60
Ground nuts	Straw	2.3-2.9	Shell	0.5		
Sugar cane	Bagasse	0.1-0.3				
Sugar beet	Pulp	0.1-0.2				
Sisal	Waste	1.2				
Sesamum	Stalk	3.0-5.0				
Jute	Stick	2.0				
Papyrus (Sustained Production)	10 - 15 ADT/ha/yr					

Sources: Agricultural residues as fuel in the third world (Barnard and Kristoferson 1985). Methane generation from waster (National Academy of Sciences 1977). The commercial potential of agricultural residues as fuels (World Bank 1985). Fuel from Papyrus (Energy Initiatives for Africa 1984). Ministry of Agriculture, Myanmar.

4.12 If general estimates of crop residues, are required crop production figures may be obtained from country statistics or from such publications as the Food and Agricultural Organization of the UN (FAO) Annual Yearbook of Agricultural Production. Such statistics may only be based on guesses at subsistence agricultural production, therefore if accurate information is required, field surveys may be necessary. On the other hand satellite imagery could be used to assess areas and even annual production of specific crops (and residues) given adequate ground verification; such information may be used directly or as a check on information obtained through other sources.

Moisture and Ash Content of Crop Residues

4.13 As with woody biomass, moisture content is important when determining the amount of energy available in crop residues. In addition, unlike wood, some crop residues have a relatively high proportion of non-combustible materials and this also affects the energy value of biomass. Rice has a high silica content especially in the husks. When the biomass is burnt all non combustible materials are usually left behind as ash. The higher the ash content the lower the energy value. On an ash free basis all non-woody plant biomass has more or less the same energy value at the same moisture content. The information on ash content in Table 4.3 has been extracted principally from Agricultural Residues as Fuel in the Third World (Bernard and Kristoferson 1985).

Table 4.3 Ash Content of Selected Crops

Residue	Ash content%	Residue	Ash content%
Maize stover	3 - 6	Cotton stalk	3 - 17
Maize cobs	1 - 2	Coconut shell	1
Rice straw	18 - 19	Coconut husk	6
Rice husk	15 - 20	Groundnut shell	4 - 14
Papyrus	6 - 8	Walnut shell	1
Coffee husk & cherry	8 - 10	Almond shell	5
Wheat straw	8 - 9	Palm nut shell	1
Alfalfa straw	6	Sugar bagasse	10 -12

Sources: Authors' own estimate; Bernard and Kristoferson 1985; Commonwealth Science Council 1986.

4.14 The large range in ash content for a particular residue such as cotton stalks and groundnut shells leads to the conclusion that the ash contents were determined at different moisture contents. Of course at 100% mc. db (dry weight basis) there is only half of the weight represented by fibers and therefore there should only be half the ash content when the residue is burnt compared to bone dry residue. There seems to be scope for undertaking experiments using bone dry residue to check some of the above stated ash contents, and to tabulate reliable values. However, it can be seen that some crop residues have large ash contents and others small ash contents, with their energy value being affected accordingly. Price husks with a moisture content of 15% db, have 85% fibers. If they have a 15% ash content, then 15% of this fibre material is non combustible and they only have 72% combustible fuel, compared to another fuel, say maize cobs with 1% ash content at 15% mc db. This gives 84% combustible fuel or 17% more than the rice husk at the same moisture content.

4.15 It should also be noted that when charcoal is made from biomass the ash accumulates. Thus if it takes three tons of coffee husks to make one ton charcoal then there will be about 27% ash content in the charcoal. This compares to about 4% ash content in wood charcoal, therefore the wood charcoal will have about 33% more energy than coffee husk charcoal per unit weight at the same moisture content. Table 4.4 gives the energy value of various types of biomass, including crop residues and dung. It illustrates the importance of moisture content and ash content for different types of fuels. This table expands and elaborates on the information previously given in Table 2.1.

<u>Table 4.4</u> Energy Value of Biomass at Different Moisture Contents
Units MJ/kg (low heat value)(1)

Biomass Type	Ash Content	Moisture Content (%)							
		.....Fresh.....				.....Air dry.....			Bone dry
	dry basis (db)	100	80	60	40	20	15	10	0
	wet basis (wb)	50	44	38	29	17	13	9	0
Wood	1	8.2	9.4	10.7	12.6	15.1	16.0	16.8	18.7
Crop residue	5	7.2	8.3	9.5	11.2	13.5	14.2	15.0	16.7
	10	6.7	7.8	8.9	10.6	12.7	13.5	14.2	15.8
	20	5.8	6.8	7.8	9.3	11.3	11.9	12.6	14.1
Animal dung	20	7.3	8.5	9.7	11.4	13.7	14.5	15.3	17.0
	25	6.8	7.9	9.0	10.6	12.8	13.6	14.3	16.0
Charcoal (ch.)					Moisture content (%)				
					db	10.0	7.5	5.0	0
					wb	9.0	7.0	5.0	0
Fully carbon-	2					29.9	30.6	31.4	33.1
nized wood ch.	4					29.3	30.0	30.8	32.4
Fully carbon-	10					27.4	28.1	28.9	30.4
nized crop	20					24.4	25.0	25.6	27.0
residue ch.	30					21.3	21.8	22.4	23.7

(1) The low heat value at different ash and moisture contents has been calculated as follows: The average high heat value for bone dry wood, crop residues and dung was determined on an ash free basis. For wood it was 20.2 MJ/kg for crop residues 18.8 MJ/kg and for dung 22.6 MJ/kg. The difference between high and low heat values is approximately 1.3 MJ/kg at 0%mc. So this amount was deducted from the high heat value to obtain the low heat value namely in MJ/kg 18.9, 17. 6 and 21.3 respectively for wood, crop residues and dung. These were the basic energy values used to determine the low heat values of the three crops at different moisture and ash contents. If wood has a moisture content of 80% db it contains 44% water and 56% fibre. If all the fibre is burnable the energy content would be 0.56 x 18.9 = 10.6MJ. However 1% is non combustible, so the energy content is 0.56 x 18.9 x 0.99 = 10.5 MJ/kg. The ash content is measured on a bone dry basis therefore the percentage remains constant irrespective of moisture content. Some of this energy is require to drive of the water. It takes approximately 2.4 MJ to expel 1 kg of water. Therefore to expel 0.44 kg will take 2.4 x 0.44 = 1.1 MJ. Thus the net energy available for heating is 10.5 - 1.1 = 9.4 MJ/kg. This formula can be used to determine the high heat value or the low heat value at a specific moisture content and a specific ash content.

Annual Residue (Dung)

4.16 Like crop residues, dung is not an important fuel in many countries and therefore not much time should be spent on trying to measure it. However, certain countries notable those in the Indian sub-continent and in one or two areas of Africa, dung is one of the primary fuels. In Lesotho for example, dung produced in different localities is given different names; the most prized for burning is that which is compacted in the animal enclosure or stable. In parts of Asia including China, horses and donkeys may have canvas buckets on their tails to catch the dropping; whether this dung is used for manure or fuel is not made clear. Again in China and India some dung from domestic and even human animals is passed through digesters and biogas is produced.

4.17 Dung production depends on the efficiency of the animals digestive system. Some species such as pigs have an efficient system whereas others, such as horses, have a poor system and much undigested grass is contained in their dung. Production also varies according to the quantity and quality of food that animals eat. Developed countries feed domestic animals more with concentrates than do farmers in developing countries. Indeed cattle ranching is much more common in Africa than in Europe, although stall feeding is becoming more popular. However, cattle herders usually go through areas that have a plentiful supply of wood so dung is not required for fuel. Also the diet of the pastoralist is dominated by milk, so much less cooking is required than in the case of arable farmer; where the herders are constantly on the move the dung is also scattered which make collection difficult.

4.18 Dung has several other uses, indeed some farmers and ecologists consider it to be too valuable to burn directly, preferring to use it as manure. It is also a material that is used in house building as a binding agent or to coat the walls and floor in some houses. The Masai of East Africa pile it outside their houses as an indication of wealth, the higher the pile the more the wealth, for cattle are wealth.

4.19 Thus all these facts have to be taken into consideration when assessing dung production and how much of it is available for fuel. In Kenya a survey of biomass energy assumed, rightly or wrongly, that no more than 10% of estimated production was available as fuel. Demand surveys, observation or enquiries will soon elicit information on the importance of dung as fuel in any society. Measurements can be made of dung production and where it is produced. Weight and moisture content, by production site, are the most important things to record. But also what is necessary to record is the moisture content at the time of burning dung and whether the dung is mixed with any other biomass such as straw, for this will affect the energy value. Figures have been produced of daily production of dung per specific weight of live animal and these are given in Table 4.5. In order to use such figures it is important to know, for example, how many dairy cattle there are per 500kg of live weight. This can vary considerably from country to country and country specific figures should be obtained. Tables 4.5 can be used to obtain a general estimate where orders of magnitude are important rather than precise figures.

4.20 However, when compiling country estimates it is necessary to obtain an accurate estimate of animal numbers and also to use relevant conversion factors. Two recent estimates for Kenya have produced dung values of 14.1 million tons (10% mc db) (Bernard & Kristoferson 1985) and 7.2 million tons (15% mc db) (Openshaw. 1982). While differences in animal numbers can account for some of the discrepancy the largest discrepancy must be related to conversion factors. Without further study it is difficult to say which estimate is nearest the truth.

4.21 Where dung is an important fuel, then as stated previously, more detailed measurements should be made of important animal species by specific areas and over time. The above report by Bernard and Kristoferson gives dung production per hectare of arable farmland and per capita of the rural population. This is very misleading, especially for countries where beef cattle rearing is concentrated on rangelands. It overestimates production on arable land and, without a population overlay, tells little about availability in specific areas. The distance from the consumer should also be recorded together with other uses and the price for the product if any. Non-woody biomass, both plant and animal, are even more site specific than wood, that is they have to be consumed very close to where they are produced. Recording such facts will not only give estimates of dung by region or district but it's availability as fuel.

4.22 When measuring the potential supply of animal residues it is important to have not only a realistic animal count by region or district, but also an estimate of their average weight. When animals are fully grown, dung production is in proportion to the food intake which is more or less related to the animal size and weight. The animal size and weight will differ from country to country and region to region. The following table (4.5) gives daily dung production per 500 kgs of animal weight. Surveys should be undertaken to determine the number of animals per 500 kgs. The estimate for Kenya is shown in table 4.5 (Openshaw 1982).

Table 4.5: Daily Dung Production Per 500kgs of Animals Live Weight

	Wet w (Kg)	Air dry wt (15% mc db)	Estimated No. of animals per 500kgs. in Kenya
Dairy cattle	38.5	3.8	3.85
Beef cattle	41.7	4.9	2.75
Swine	28.4	2.7	10
Sheep/goats	20.0	5.0	20
Poultry	31.3	7.8	150
Horses	28.0	4.9	3.20
Donkeys	28.0	4.9	3.33
Camels	28.0	4.9	1.29

Sources: Methane generation (National Academy of Science 1977 adapted).

4.23 Of course it is not necessary to work out production per 500 kgs of live weight or any other total of live weight. Production could be determined directly per animal type by undertaking direct measurements. What is important is that realistic production figures be used and accurate animal counts be undertaken. Also as mentioned previously, the dung should be graded according to availability.

4.24 The ash content of dung is much higher than that of plants because many minerals in plant food are not absorbed by the animals, but excreted in a concentrated form. Thus the ash content of dung can vary from about 23% to 27% (15% mc db) and this affects the energy content. Table 4.4 gives the energy value of dung at two ash content values and at various moisture content values. In some regions, notably parts of China and India, dung is not burnt directly, but fermented to produce biogas (methane). In this way the farmers can extract the heat value from the dung and still use the residue as a fertilizer. A count of active biogas digesters (by capacity) may be required to determine the amount of dung used. The energy value of biogas depends on its methane content, the remaining gas being mainly carbon dioxide. With a 60% methane content biogas has an energy value of between 21.5 MJ/m^3 and 23.3 MJ/m^3 where as pure methane has an energy value of 35.8 MJ/m^3.

Supply Surveys

Plant Residues

4.25 If detailed information is required on plant residue production then supply surveys will have to be undertaken. For agriculture crops timing is important, the best time being at harvest times. Governments are interested in collecting food production statistics even in the subsistence sector, therefore the problems of assessing plant residues is not as complicated as measuring woody biomass. Surveys of annual production still have to be undertaken in the subsistence sector, but this could be augmented with information of area cover from satellite imagery and aerial photography. Indeed it may be possible to use satellite imagery to estimate annual biomass production of non-woody plants. However, there must be ground surveys carried out to determine what the biomass is used for, how much of the farm area is for crop production, for green manure, under grass and in ley.

4.26 A survey should also be carried out on residue yields in the fields, at the farm house and in the factory. Moisture content, ash content and energy value could be determined and compared with previous figures and research from other countries to check for discrepancies and anomalies. If non-woody biomass is important then further studies may be required to undertake a detailed supply survey and the effect if any on the soil fertility. In fact long term studies should be set up to determine the effect of removing varying amounts of biomass, both plant and animal.

The effort spent in determining plant and residue supply should be commensurate with demand, and demand in specific areas. The initial cost of setting up a detailed study may be of the order of US $ one million for a country the size of Kenya, but the recurrent cost if linked to agricultural surveys should be marginal.

Animal Residues

4.27 The intensity of survey work should be tied to consumption. However, accurate animal counts are a necessary pre-requisite to obtain an estimate of dung production. Not only that, it is important to find out the sites of production and alternative uses of dung. Research should be undertaken on average dung production per animal or per target live weight such as 500 kgs. This can be checked with published work. Also moisture content, ash content and energy value tests are required. The cost of such work should be similar or less than that for crop residues and again much survey work could be added on to existing studies. It is probable that most regional or district agricultural offices already collect statistics, but in many instances they are just filed or not fully used because the job of analyzing them has been time consuming. This can now be foreshortened considerable with the help of computers, but it must be remember that the results of any study will only be as good as the data fed into the study.

4.32 Crop residues and dung, like woody biomass, are conditional renewable resources; conditional on their being managed in such a way as to match demand with a sustained supply. The importance of this cannot be over emphasized for biomass can last indefinitely and be available when all the finite energy forms are exhausted. This is an overriding reason why biomass supply (and demand) statistics should be recorded as accurately as possible.

V. BIOMASS DATA BASE AND ITS USE

Presentation

5.1 The end result of the field inventory/assessment for woody biomass is a data base of raw statistics based on the tally sheets for each of the samples within strata that have been defined e.g. the number of trees or bushes by species with measurements of the agreed upon parameters such as stem diameter (at butt or breast height), crown diameter and height to crown break or tree top. This data must then be compiled as computer data files. Measurements of parameters will be used in combination with the tree-weight equations or tree-weight tables to determine the standing stock of woody biomass for the samples. The result is a data base that shows for each strata or vegetation type the weight of woody biomass per unit area by size classes. It is useful to have this broken down on the basis of utilization potential e.g. larger boles for timber or veneer, smaller boles for poles, and other wood, and possibly leaves, for fuel. Table 5.1 illustrates this breakdown while Table 5.2 and 5.3 are actual examples of unit area estimates and Table 5.4 shows the standing stock and growth for sample areas. These estimates may then be extrapolated to standing stock by vegetation strata and standing stock for the whole sample area as Table 5.3 illustrates. Table 5.5 is a summary of the area growing stock and MAI data estimated for the major biomass/vegetation types for Sub-Saharan Africa under the biomass Mapping and Assessment project (Ryan et al 1991).

5.2 Data may be compiled that show the following information:

(a) Growing stock in ADT by size classes e.g. stem diameters.

(b) Growing stock in relation to species or species type e.g. non-conifers, conifers, shrubs, trees.

(c) Growth data (MAI), gross and net, taking into account dead wood and its removal.

Table 5.1: Example of Woody Biomass Data Profile

Utilization Classes	Forest/Vegetation Type: Dense Woodland	Open Woodland	Bushland	Non-Forest Trees 20/
Standing Stock (ADT/ha)				
Trees 50 cm dbh +:				
Bole to 25 cm top) Sawn timber and veneer with residues and non-merchantable				
Bole to 10 cm top) species as fuel				
Tops & Branches]				
Twigs] Fuel, although some large branches may be sawn for small				
(Foliage)] articles or parquet flooring. Foliage may e used as				
Sub-Total] fodder.				
Trees 20 cm butt diam +:				
Bole to 10 cm top - Mainly poles or perhaps pulpwood (if market)				
Tops & Branches)				
Twigs) Fuel. Foliage may be used as fodder if edible.				
(Foliage))				
Sub-Total)				
Small Trees & Bushes - Fuel				
Total Standing Stock/ha				
Mean Annual Increment (ADT/ha/year)				
Bole to 25 cm top				
Bole to 10 cm top				
Branches & Tops				
Total MAI				

20/ The trees around farms and villagers and along roadsides may be subdivided by land-use types such as crop lands, grazing lands and fallows.

5.3 The data that are finally presented must be viewed with several factors in mind and annotated accordingly or allowances made. Firstly the data will usually represent the total above-ground woody biomass present in an area. However, much of that wood may have much higher valued end uses than fuel e.g. timber, plywood, pulpwood, or areas containing the biomass may preferably be reserved for recreation and/or environmental reasons. Economic accessibility has also to be considered vis-a-vis both urban and rural woodfuel/biomass consumption points. Such factors have to be taken into consideration when considering the woody biomass that would be available, firstly, for any purpose and, secondly, for fuel. When considering high (closed) forests one might assume, depending on the forest and the region, that 50 to 60% of the total standing volume could be utilized for industrial wood. The remainder, mainly branches and tops, but including some unmerchantable species or trees, could be used for fuel. However, of the portion reserved for industrial wood use perhaps 40 to 50% could be considered as fuel as this would be sawmilling and logging waste including sawdust, slabs and offcuts. Peeler logs would have only 20 to 30% of such waste.

5.4 Apart from the purely statistical aspects of the data that are presented it is also important to include information of a descriptive nature on the condition of the resource, its regeneration or yield potential and its accessibility to demand centers. In fact it is a useful practice to include several regeneration sub-plots (10 m^2) to ascertain the quantity of seedlings present of desirable species. Notes on any pressure being exerted by outside influences such as agriculture and grazing are also important in determining the medium-term sustainability and yield from a given area.

Table 5.2: Percentage Distribution of Average Green Weight of Forest Biomass per Acre, Florida, USA, 1980.

Broad management and diameter classes (inches)	All age classes	Stand age class (years)				
		14	15-29	30-44	45-59	60+
	- - - - - - - - - - - - - Percent - - - - - - - - - - - - -					
Pine plantation:						
1.0-4.9	28	61	23	16	15	--
5.0-8.9	57	32	63	40	53	--
9.0-12.9	12	2	11	37	29	--
13.0+	3	5	3	7	3	--
All classes	100	100	100	100	100	--
Natural pine:						
1.0-4.9	12	32	19	11	8	6
5.0-8.9	27	27	39	28	20	13
9.0-12.9	38	25	33	39	40	38
13.0+	23	16	9	22	32	43
All classes	100	100	100	100	100	100
Oak pine:						
1.0-4.9	16	36	27	16	13	8
5.0-8.9	23	28	24	27	18	18
9.0-12.9	26	15	25	27	28	26
13.0+	35	21	24	30	41	48
All classes	100	100	100	100	100	100
Upland Hardwood:						
1.0-4.9	16	29	28	15	11	8
5.0-8.9	20	27	27	24	19	11
9.0-12.9	21	16	18	26	26	16
13.0+	43	28	27	35	44	67
All classes	100	100	100	100	100	100
Lowland hardwood:						
1.0-4.9	12	31	30	15	11	8
5.0-8.9	21	21	26	26	23	17
9.0-12.9	28	17	22	30	29	28
13.0+	39	31	22	29	37	48
All classes	100	100	100	100	100	100

Source: Cost and McClure

Table 5.3: Estimates of Growing Stock and Annual Yield For Major Woodland Density Classes - Eastern Botswana

Density Classes	Growing Stock (bone dry ton/ha)	Annual Yield (bone dry ton/ha)
High density woodland	48.0 +/- 10.6	2.1
Mid density woodland	25.9 +/- 12.7	1.4
Low density woodland	18.9 +/- 6.6	1.0
Sparse vegetation	2.6 +/- 4.3	0.3

Source: ERL, 1989

Table 5.4: Standing Stock and Annual Increment of Unused Woodland, Zambia (million bone dry tonnes)

	Total Area			Accessible Area		
Catchment Areas	Area (km^2)	Growing Stock	Annual Incremt	Area (km^2)	Growing Stock	Annual Incrmt
Copperbelt	16,157	210	6.1	16,157	210	6.1
Kabwe	7,962	57	1.8	7,616	55	1.7
Mumbwa	4,944	36	1.1	4,906	35	1.1
Lusaka	5,412	39	1.2	1,692	12	0.4

Source: ESMAP, 1989.

Table 5.5: Mainland Sub-Saharan Africa: Estimated Volume/Mass and Increment by Biomass Type

	Wooded Grassland Area	Shrub-land	Bushland and Thikcet	Low woody Biomass Mosaic	Wood-land	High woody Biomass Mosaic	Forest	Total
Area (mill ha) a.d	266.9	68.7	311.8	81.1	681.1	237.5	223.1	1870.3
Growing stock (10^6t)	560.5	419.1	7140.2	1516.6	30649.5	15057.5	31234.0	86577.4
Increment (10^6t)	21.4	13.7	218.3	48.7	953.5	451.2	937.0	2643.8
Growing stock (10^6 m^3)	800.7	590.8	10008.8	2124.8	42909.3	21090.0	43727.6	121252.0
Increment (10^6 m^3)	29.4	20.6	311.8	73.0	1362.2	661.2	1316.3	3754.5

Source: Millington et al (1991)

Reliability of Data

5.5 As part of the compilation and analysis of the assessment data it is important to carry out the usual statistical analysis to determine the accuracy of the data. Standard error of the mean for the whole sample is of primary interest, but it may also be useful to have the standard error for selected populations such as particular species or vegetation types. In forest inventories the target standard error will vary with the type of inventory and its end use. With a general reconnaissance inventory +/- 15 to 20% would often be acceptable; however, a more detailed management inventory would require an accuracy of +/- 10% or better at the 95% probability level.

5.6 Achieving the desired accuracy depends on the variance within the population being sampled, the degree to which one can stratify, and the intensity of the sampling. With industrial wood inventories, that have relatively high valued products and relatively high extraction costs, it may be worthwhile to undertake intensive inventories. With woody biomass assessments the variation in the sample population is usually much higher than with industrial forestry, particularly as total tree above-ground woody biomass is being assessed, including bushes, not just the boles of merchantable trees. Woody biomass for fuel is a relatively low valued product and financial resources are usually scarce for assessments. Therefore to achieve a standard error of +/- 25% is acceptable. Of course 15 to 20% would be preferable, but it would depend on the funds and time available. After all the assessment/inventory is only a management tool and not an end in itself. The objective is to obtain sufficiently reliable data in a cost effective manner to enable management and planning decisions to be made.

Use of Biomass Data

5.7 As mentioned above biomass assessments are a fundamental tool for planning and, subsequently, for management of woodfuels resource development and conservation programs. The data from the assessments should provide information on the current standing stock of woody biomass, its growth rate, and the potential for sustainable management. They also provide vital planning information for other programs such as land-use, forage development and management, and the sequestration of carbon. The data may be used to demonstrate the current situation as well as the dynamics of the area of biomass being considered.

5.8 Generally, for the above planning activities there is a need to link the biomass data with some concept of area. This may be a country, region or a zone such as a woodfuel catchment area for a major urban center. This is usually done through the use of vegetation/biomass type maps that have been prepared, possibly through processes mentioned earlier in this report. The data per unit area may then be extrapolated to cover the desired area within the vegetation types that have been used to stratify the sample.

5.9 A useful approach, particularly if temporal changes in the data base are likely and/or if further factors need to be linked to the data is to use the mapping data to establish a geographic information system (GIS). This may be done by digitising maps that are being used or, if satellite data is being used, then the imagery spatial data may be digitised. The resultant GIS may then be interfaced with the biomass data. It may also be interfaced with demographic or energy consumption data to put biomass fuel stocks in perspective as regard current and projected demand. The biomass data may then be used to carry out demand and supply modeling for various woodfuel demand scenarios. With time series mapping/imagery data and various demographic and other socio-economic factors, trends of various correlations between biomass supplies and other factors may be determined.

5.10 The GIS may be used to interface edaphic, climatic and slope data to obtain a correlation between biomass productivity and these factors as well as to determine the potential for future biomass productivity either through management of the existing resource or through plantations. Such correlations may also be used to estimate potential productivity of biomass, particularly woody biomass standing stocks and productivity in areas with similar geoclimatic characteristics that have not been assessed but for which edaphic, climatic and demographic data is available.

Conclusion

5.11 As was stated in the Introduction, there is a paucity of reliable data on the standing stock and sustainable yield or production of biomass for use as fuel within the economic catchments of demand centers. This particularly applies to woody biomass (woodfuels), the principal form of energy in many developing countries. Without data, that has some degree of reliability, it is difficult to undertake meaningful energy policy and investment planning where biomass fuels play a significant role. In many instances to date energy assessments and plans have taken rather rough estimates of woody and perhaps non-woody biomass, usually on a macro basis. Wood from non-forest sources is, invariably, not included and usually no account is taken of accessibility or of the variation in demand patterns between urban and rural areas. The resultant macro woodfuel demand-supply gap estimate may result in poorly conceived interventions, that in some cases may not be worthwhile, while in others they may be needed to a greater degree than postulated.

5.12 Obviously, the apparent need for planning and implementing energy interventions in many countries cannot and need not wait for detailed biomass assessments to be undertaken in each country. If a data base can be developed and updated on a regional basis for woody biomass standing stock and annual increment in important vegetation types such as the Sudanian or Miombo woodlands in Africa, then such data could be applied to national or local assessments once an estimate of the area of each type has been determined. This latter task could use existing imagery or up-to-date maps, probably with some degree of ground verification. Perhaps a check inventory sample could be done in the principal types to establish the degree of correlation with the regional data. A preliminary rough estimate of non-forest woody biomass could be obtained by a quick assessment of several villag^ areas in different geo-climatic zones in the country, possibly by the forestry agency. Estimates of woody biomass available for fuel could be related to rural households and extrapolated on a state/provincial basis as Ryan (1990 and 1991) did in India and Myanmar.

5.13 It may then be prudent to carry out more detailed assessments for selected urban and, in some cases, rural woodfuel catchments as a pre-project activity or during the initial stages of the project. This would not only confirm the original estimates of standing stock and increment, but also provide the necessary detailed data that would be required if improved management of the woodfuel/forest resource is one of the interventions undertaken.

5.14 The Sub-Saharan African Biomass Mapping and Assessment Project is a first step towards achieving the above-mentioned regional data base in Africa. However, the project highlighted the acute shortage of data for even broad vegetation types, while, at the same time, pointing out the major types that are important as woodfuel resources on a cross-border basis. Tables 5.6 and 5.7 show the extent of these types.

5.15 What is needed is more detailed assessment/sampling within these types on a regional basis to establish a data base with some credibility. The existing data base that is linked to a GIS with the various vegetation/biomass types may then be updated and the data used as a base where is insufficient local or national data. The data base may also be updated from biomass assessments carried out for distinct projects in countries such as that done by Bird and Shepherd (1989) in the Bay Region of Somalia, provided the data can be assigned to a vegetation/biomass type. A certain standardization in assessment parameters and vegetation typing would be useful here.

Table 5.6: Areas of Sudanian Woodland and Sahel-Sudanian Wooded Bushland
('000 km^2 and % of country)

Country	Sah-Sud Wd Bush	Dry Sud Wd	Sud Wd	Wet Sud Wd
Nigeria	162 (18%)	154 (17%)	151 (17%)	121 (14%)
Ghana	0	18 (8%)	47 (20%)	23 (10%)
Burkina Faso	94 (35%)	110 (41%)	47 (16%)	5 (2%)
Chad	230 (18%)	210 (16%)	26 (2%)	30 (2%)
Niger	229 (19%)	5 (1%)	0	0
Mali	178 (14%)	146 (12%)	69 (5%)	3 (<1%)
Guinea	0	3 (1%)	103 (43%)	25 (10%)
Senegal	115 (58%)	54 (27%)	3 (1%)	0
Benin	0	11 (10%)	41 (35%)	15 (13%)

Source: Millington et al, 1991

Table 5.7: Areas of Major Woody Biomass Types in Dry Zone Corridor
('000 km^2 and % of country)

Country	Seasonal Miombo	Sth Africa Open Woodland	Sahel-Sud Wooded Bushld	Dry Ac-Comm Bushld & Thkt
Zimbabwe	100 (26%)	115 (29%)	63 (16%)	0
Mozambique	423 (60%)	25 (3%)	75 (10%)	0
Malawi	54 (41%)	4 (3%)	32 (25%)	0
Zambia	448 (60%)	73 (10%)	55 (7%)	0
Tanzania	444 (47%)	21 (2%)	174 (19%)	36 (4%)

Source: Millington et al, 1991

5.16 Similar regional data bases need to be established in Asia and Latin America. In the former region the FAO Regional Wood Energy Development Program in Asia is considering such a possibility, while endeavouring to establish a dialogue with countries undertaking biomass assessments. In Asia there is probably no justification for a continental overview as was done in Africa, with much ongoing work being done with forest mapping and inventories, albeit mainly for commercial wood. However, a continental overview of Latin America may be useful as a starting point, again using 8 km AVHRR data as per Sub-Saharan Africa together with a literature review of woody biomass data for vegetation types. This is not seen as a high priority given the lower importance of wood as a source of energy in much of the area (woodfuels average 20-30% of final energy consumption).

5.17 Finally, it should be pointed out that similar use of satellite imagery or aerial photography as for biomass assessment together with variations on the ground inventory methodology may be used to assess other biological elements and environmental impacts.

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Woody Biomass Assessments (from Hellden A., 1987), An Assessment of Woody Biomass, Community Forests, Land Use and Soil Erosion in Ethiopia

It has been demonstrated in several studies that it is possible to assess total green biomass (field layer and canopy), canopy cover and woody biomass through processing multispectral digital satellite data (Hellden and Olsson, K 1982, Olsson, K 1985b, Tucker et al. 1985, Justice 1986).

The green biomass assessment is based on the fact that chlorophyll absorbs red light for the photosynthesis and reflects energy in the near-infrared part of the spectrum in proportion to the amount of chlorophyll (greenness) available. However, the size of the absorption and reflection of a tree-bush canopy is also dependent on other canopy characteristics. Factors of very great importance are proportions of stems, branches and shadows per unit area.

If satellite data are recorded during the dry season (Jan-Feb.), when nothing but the tree/bush canopy is still green, the average canopy absorption and reflection properties (including eaves, branches, stems and shadows) are measured by the satellite in 30 x 30 m squares on the ground (Landsat TM data). A 185 x 185 km area is measured within a 25 seconds period. The data set covering such an area is made up of some 38 million 30 x 30 m squares each one containing the information about the absorption/reflection properties of the crown cover in that specific square (pixel).

The following procedure was used to establish a relationship between satellite data and a canopy cover and standing woody biomass respectively in every pixel.

-1. The data resulting from the destructive measurements of the acacias in Ethiopia was merged into a corresponding set of bush and tree data collected in the Sudan. Relevant information about the Sudan study was presented by Hellden & Olsson, K 1982, and Olsson, K 1985a, 1985b.

It was found that the wet weight of an acacia, ranging in size from a few kilograms up to almost 1.5 tons, can be described as a function of the crown diameter (Table I and Fig. 6a). The logarithmic relationship indicated in Fig.6b. was used in the study.

Since the crown diameter of individual trees and bushes is highly correlated to the weight of each individual, it is most probable that the total weight of any area can be described as a function of its canopy cover up to a certain level. That this assumption is correct was clearly demonstrated in the case of the Sudan (Olsson, K. 1985a, 1985b). The assumption was verified as described in the next step.

-2. The total canopy and wet weight of seven 1 ha areas in the grasslands and woodlands of the Ethiopian Rift Valley was assessed on the ground. The resulting relationship between wet weight, expressed in ton/ha, and canopy cover, is illustrated in Fig. 7.

-3. The results presented imply that the standing woody biomass of any area can be assessed as soon as the canopy cover is known (for acacia dominated grass-, bush- and woodlands). A dry season relationship between Landsat MSS data and canopy cover is illustrated in Fig. 8. It is based on the 7 field measured plots in Ethiopia merged with 29 plots in the Sudan. The Sudan canopy cover data were assessed in high resolution air photos (Olsson 1985a, 1985b).

Table 1. Correlation matrix based on destructive measurements of 41 trees and bushes in the Sudan (32) and Ethiopia (9). 1/

	HEIGHT	D	WEIGHT	D^2	LOG W
Diameter (D)	.897				
Weight (W)	.818	.899			
D^2	.853	.952	.982		
Log W	.866	.905	.691	.759	
Log D^2	.856	.926	.691	.777	.971

D=crown diameter, W=wet weight

1/ The data is made up of a mixture of *Acacia albida, A. mellifera, A. senegal, A. seyal, A. tortillis, Albizza amara, Balanites aegyptica* represented in approximately equal proportions.

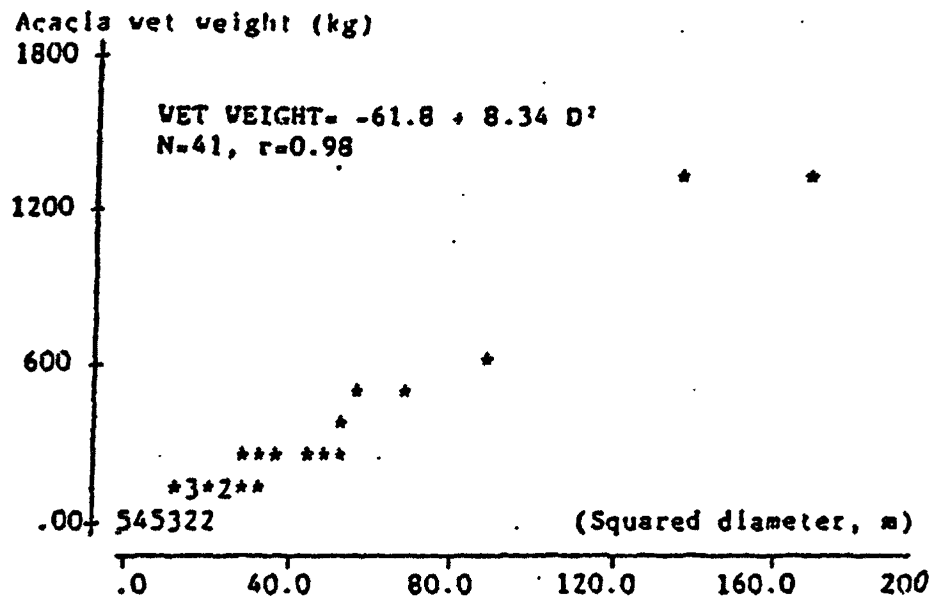

Fig. 6a. The relationship between wet weight (kg) and squared crown diameter (m) according to destructive measurements in the Sudan (32) and Ethiopia (9)

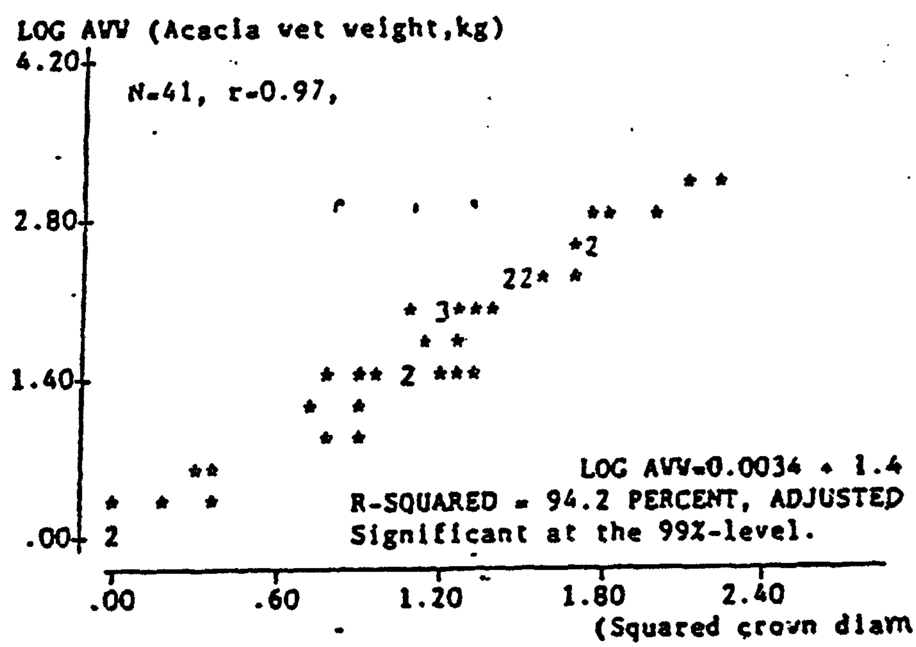

Fig. 6b. The log relationship between wet weight and squared crown diameter according to destructive measurements in the Sudan (32) and Ethiopia (9).

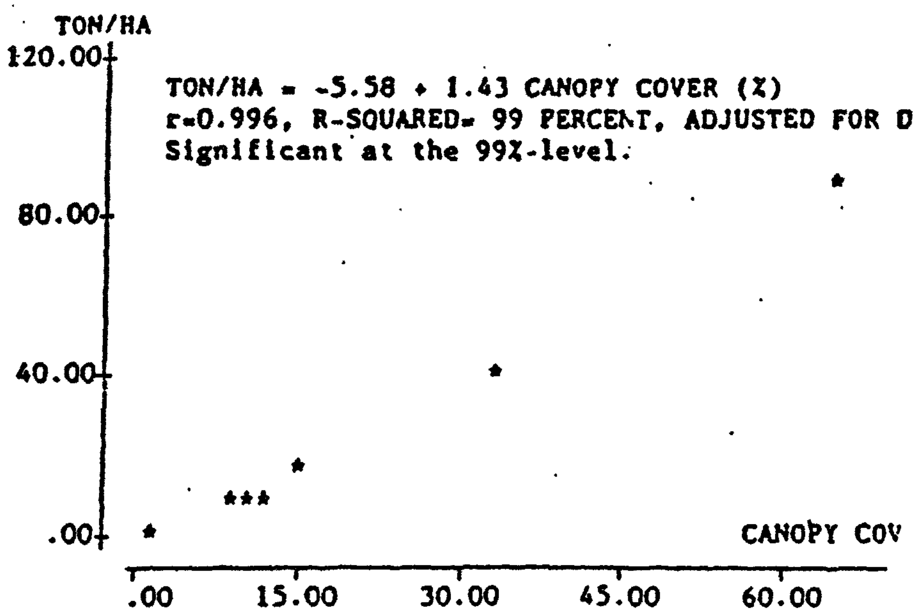

Fig. 7. The relationship between wet weight (kg) and canopy based on field measurements in seven 1 ha test areas in Ethiopian grasslands and woodlands.

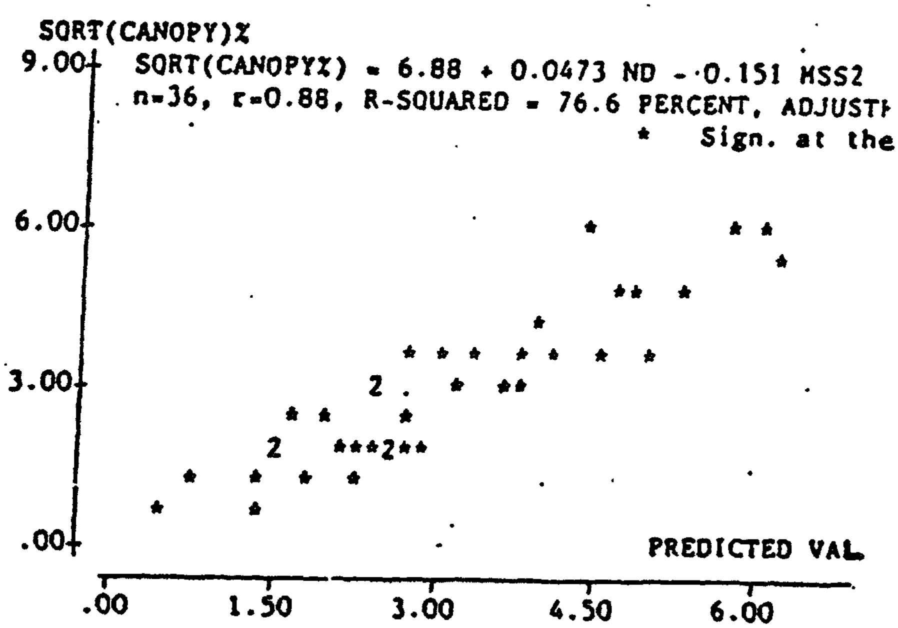

Fig. 8. Canopy cover as a function of Landsat MSS data (ND vegetation index and MSS 2) based on 36 calibration plots in the Sudan (29) and Ethiopia (7).

A corresponding dry season relationship between Landsat TM data and field measured canopy cover is presented in Fig. 9. It includes the Ethiopian data only. The Satellite data were represented in both cases by the normalized difference vegetation index (ND) (the difference of the red and near infrared bands over the sum of the same bands) and the red MSS (MSS 2) and TM (TM 3) bands respectively. The ND was included to measure the "greenness" and the red bands to measure the non-green characteristics (shadows, stems, branches) of the canopy.

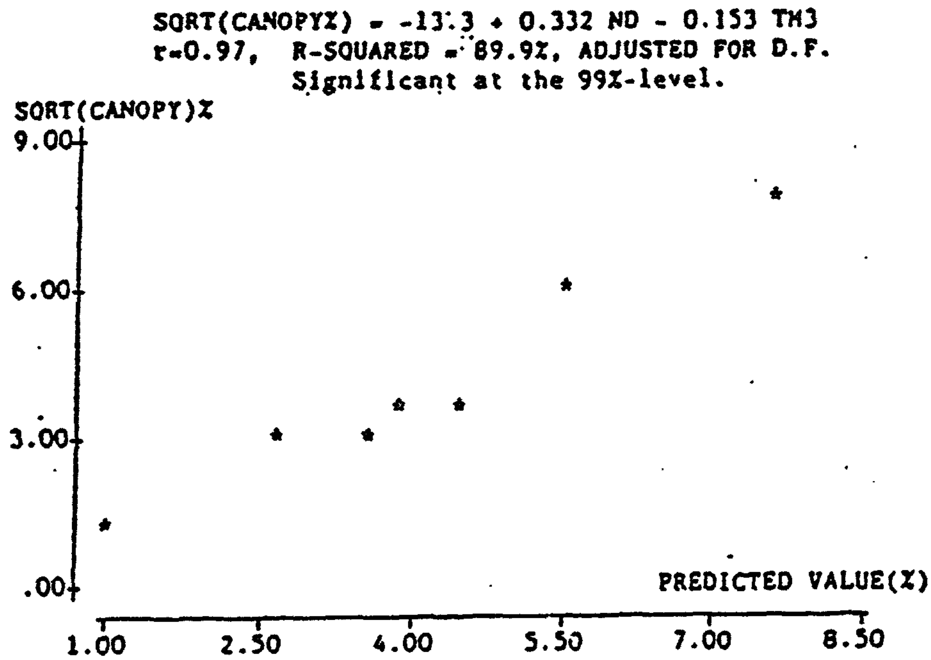

Fig. 9. Canopy cover as a function of Landsat TM data (ND vegetation index and TM3) based on 7 calibration plots in Ethiopia (step 3 in the working procedures).

It should be noted that no radiometric corrections were applied to any of the satellite data sets used. It implies that the regression models presented are only valid for the present data sets and environments. The models have to be modified in a possible operational phase employing relative radiometric calibration and correlations of the satellite data for differences in atmosphere, sun angle and solar irradiance. Methods to transform satellite digital grey levels into spectral radiance and at satellite reflectance were summarized by e.g. Ahlcrona (1987), Hall-Könyves (1987), Markham and Barker (1986).

The woody biomass assessment and monitoring approach described above is valid for acacia-dominated tree grasslands and woodlands only. When it comes to forests (closed canopy), satellite data can only be used for delineation, stratification/dominant species classification and area change studies. Quantifications must be based on air photo (stereo models) interpretation, photogrammetry (tree height measures) and field work (sampling basis or full coverage depending on size and priorities).

The overall, dominant, scattered forest-stand resource of Ethiopia beside the Acacia spp. is made up of Eucalyptus spp. The Eucalyptus usually grows in very dense and small stands. These stands were identified and delineated and the areal distribution assessed by means of Maximum-Likelihood classifications of satellite data. Knowing, or assuming, the average number of stems/area and assessing the average height in the field, from age or from air photos) of the stands, the standing woody biomass resource was assessed by employing the weight-height model illustrated in Fig. 10b. To simplify the data processing the average eucalyptus height, 10 m, and the average eucalyptus densities, 1.5 stems/m², and 0.7 stems/m² were used for the Shewa and Gojam cases respectively. However, a general Ethiopian plantation recommendation stipulating .. eucalyptus density corresponding to 0.44 stems/m² was found at a later stage.

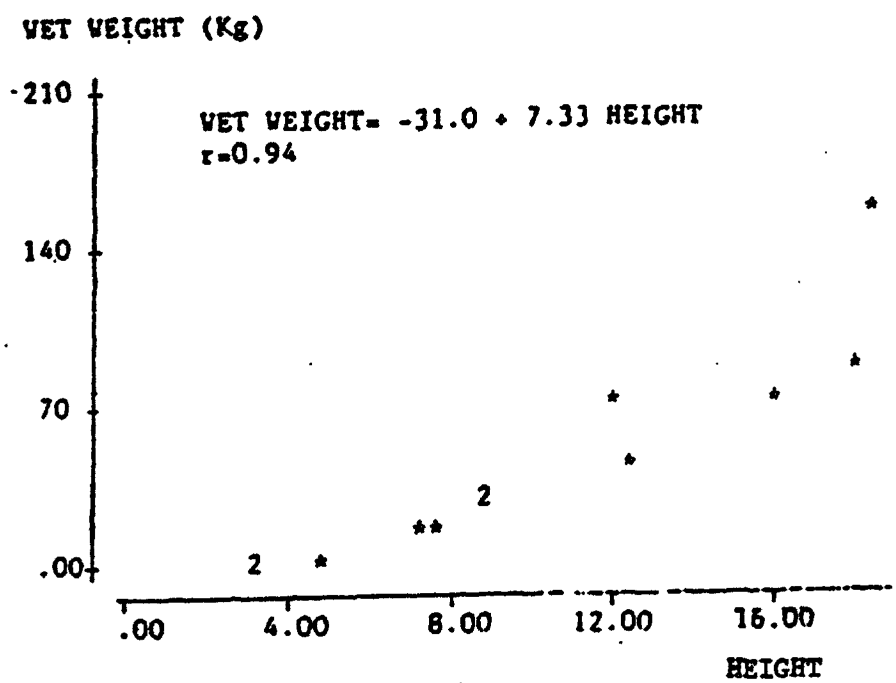

Fig. 10a. The relationship between height (m) and wet weight for 12 *Eucalyptus globulus* cut in Wondo Genet, Ethiopia (Feb. 1986).

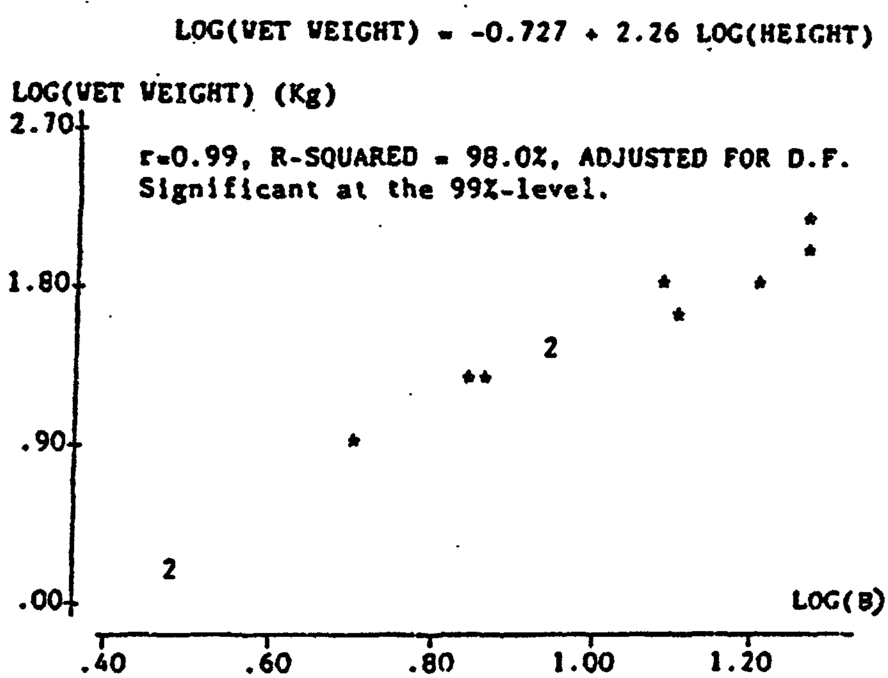

Fig. 10b. The log relationship between height and weight for 12 *Eucalyptus globulus* cut in Wondo Genet, Ethiopia (Feb. 1986).

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