Assessment methods for non-timber forest products in off-reserve forests
Case study of Goaso district, Ghana

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Abbreviations and Acronyms

AFP	Alternative Forest Product
DBH	Diameter at Breast Height
CBUD	Centre for Biodiversity Utilization and Development
CI	Confidence Interval
FAO	Food and Agriculture Organization
FMU's	Forest Management Units
FRMP	Forest Resource Management Project
GPS	Global Position System
ITTO	International Tropical Timber Organisation
LUS	Lesser Used Species
MFP	Minor Forest Products / Miscellaneous Forest Products
MRI	Multi-purpose Resource Inventory
NGOs	Non-Governmental Organisations
NTFPs	Non-timber Forest Products
NTFR	Non-timber Forest Resource
NTRV	Non-timber Forest Resources and Values
NWFB	Non-Wood Forest Benefits
NWFPs	Non-Wood Forest Products
NWGB	Non-Wood Goods and Benefits
NWGS	Non-Wood Goods and Services
PLA	Participatory Learning and Action
PPS	Probability Proportional to Size
PRA	Participatory Rural Appraisal
PSPs	Permanent Sample Plots

RMSC	Resource Management Support Centre
RRA	Rapid Rural Appraisal
SFP	Special Forest Products
TROF	Tree Resources Outside Forest
UNDP	United Nation Development Programme

Abstract

Many studies have been conducted on non-timber forest products (NTFPs) over the years. These studies have however, concentrated more on socio-economic issues of NTFPs than methods of inventory. Forest inventory methods developed for timber have been found to be inefficient for NTFPs because of the special characteristics of NTFPs. Efficient inventory methods are essential to provide quality information on the abundance and distribution of the species for sustainable management. This study contributes to methods of NTFP inventory by comparing the efficiency of systematic sampling method with adaptive cluster sampling method for inventorying 3 NTFP species in off-reserve areas of the Goaso forest district, Ghana. Three NTFP species; *Calamus deeratus*, raphia palms and bamboo were selected and inventoried in the off-reserve areas of the Goaso forest district. Adaptive cluster sampling with a systematic base was designed to inventory the three species. Tree species used as NTFPs were also inventoried using systematic cluster sampling. The results showed that adaptive cluster sampling was about 8 times efficient than systematic sampling for all the 3 species inventoried. The density of the species however, was found to be low and this was attributed to habitat destruction. It was suggested that the methods be tried in a forest reserve where habitat destruction is minimum.

1. Introduction

1.1 The problem

Various studies have been carried out on non-timber forest products (NTFPs), particularly after the International Tropical Timber organisation (ITTO) called for extensive studies on NTFPs (ITTO, 1988). However, many of these studies have concentrated on socio-economic issues of NTFPs (e.g. Peters et al.1989; de Beer and McDormot 1989; Schwartzman 1989, Padock and De Jong 1989; Falconer 1990; Malhotra et al. 1991; May 1991; Wickens 1991; Richards 1992, Karmann 1998, Grossmann 2000) than biometric aspects of inventory methods. Many of these and other studies from ethnobotany and anthropology unearthed the importance of the then so called ‘minor’ forest products and the need for their inclusion in forest management. It is already a known fact that for any natural resource to be managed sustainably, sound knowledge of the ecology, spatial distribution and abundance of the resource is essential (Wong, 2000). Such information could be obtained from a number of sources including indigenous or local peoples’ knowledge as well as formal scientific enquiry through forest inventories (Wong, 2000). However, forest inventories have been focused on timber and little has been done on NTFP inventories. Nevertheless, the intense exploitation of traditional products such as bamboo and rattan in South-East Asia has prompted an increasing interest in resource assessment methodology for these products (e.g. Supardi et al. 1999).

In a study to review NTFP inventories, Wong (2000) realised that the few NTFP inventories which have been ‘undertaken by foresters have most often adapted or grafted NTFPs onto conventional timber inventory. The choice of sampling designs and plot configurations are therefore determined by the needs of the conventional timber inventory and there is little scope of adapting designs to meet the specific needs of NTFPs’ (Wong 2000: 32). Methods for timber inventory have been found to be inefficient for NTFPs due to special characteristics of NTFPs such as being variable, rare or may occur in clumps. For example, although bamboo was included in Ghana’s 2001 multi resource inventory, much bamboo clumps could not be captured because the method used was not suitable to capture enough bamboo clumps for analysis (RMSC, 2001). Inefficient methods of inventory yield unreliable information on NTFP resources which does not provide sound basis for management. It is therefore not surprising that overexploitation has characterised most NTFPs exploited on a commercial basis (Teweri 1999). Wong (2000) therefore suggested the development of methods specific for NTFPs.

NTFP inventories in Ghana have taken place only in the forest reserves. In their studies on NTFPs in southern Ghana, Falconer (1992a and b) and Towson (1995a and b) contended that off-reserve areas provide the bulk of NTFPs in Ghana. However, there has been no work done to quantify the abundance and distribution of off-reserve resource. This study was therefore conducted in off-reserve areas of the Goaso forest district as a case study of off-reserve NTFP quantification and to investigate the suitability of adaptive cluster sampling for inventorying the NTFPs. The study would answer the following questions:

- What NTFPs are obtainable off-reserve?
- What is their significance to local people?
- What methods are efficient for their assessment?
- What quantities are there?

1.2 The significance of NTFPs

Non-timber forest products (NTFPs) have in the past been referred to 'minor' forest products. This term 'minor' forest product underestimated the importance of NTFPs and hence created a bias impression on the mind of practising foresters on their management. Lintu (1986) observed however, that many of the commonly 'minor' forest products were more significant in certain regions or countries than wood and the term 'minor' forest product was not only misleading but also underestimating the relative significance of such products. De Beer and McDormot (1989) echoed this assertion and argued that the extraction and prudent marketing of plants and animal products could increase rural income. In a FAO publication, Falconer (1990) echoed the significance of NTFPs by revealing the significance of the so called 'minor' forest products in the livelihood of rural people across the West African region. NTFPs are now even perceived to be of importance to some local and national economies as well as being important elements in sustainable forestry and for their "contribution to environmental objectives, including the conservation of biological diversity" (FAO 2003).

Taylor (1999) observed that although trade in NWFPs is still a small fraction of the world trade in timber products, it is far from being insignificant. Freese (1998) estimates world trade in medicinal plants alone to be US$10 000 million annually. He also noted that trade in non wood forest products (NWFPs) form a significant proportion of some national economies. For example, Indonesian exports of rattan and other NWFPs exceeded US$134 million per year, and Indian trade is estimated to be US$ 1 billion (Freese, 1998). ITTO (1997) estimated international trade in rattan to worth some US$ 6.5 billion a year while the annual domestic market in Southeast Asia was estimated by Manokaran (1984) to worth US$ 2.5 billion. Estimates of the number of people who are dependent on NTFPs for at least part of their income range from 200 million world-wide to 1 billion in Asia and the Pacific. Many of these activities are on a small-scale and are not registered. Hence the importance of NTFPs for survival and as a source of income is not fully appreciated by national governments (Mittelman et al., 1997). Employment opportunities based on small-scale NTFP activities are of increasing importance for the rural economy in almost all developing countries (van Rijsoort, 2000). According to Liedholm and Mead (1993) small-scale production and trading activities in forest products constitute one of the largest parts of rural non-farm enterprise employment. Arnold (1995) ascertained that the numerous small enterprises involved in NWFPs could foster broader-based economic growth than large-scale timber operations. He supported this assertion by revealing that such small forest enterprises employed an estimated 237000 people in Zimbabwe, compared with 16000 employed in the country's formal forest industry and because NWFP harvesting often employs women and minorities to a greater extent than large-scale timber operations, it has potentially greater equity benefits. Falconer (1994) also found that three-quarters of the women in Kwampanin, a village in Ghana, were dependent on collecting *Maranteceae* leaves as a result of economic collapse caused by repeated forest fires in agricultural areas. This she noted made an important contribution to the regional economy, providing an assured income for a large proportion of the rural and also urban distributors. Using a rough estimate, Falconer (1994) gauged the monthly demand for the leaves in a million bundles, at a value of about £47,000. Recently however, plastic bags are inexorably replacing the leaves as food rapping material thus depriving rural people who depend on the leaves of their income (cf. Gronow, 2003). In their study of the valuation of NTFPs, Van Dorp et al. (1999) also discovered that the economic value of NTFPs amounted to US$ 19 million in 1998, or around 3% of regional income in North-West and South-West provinces of Cameroon.

NWFPs are important to industrialized as well as developing economies. Chamberlain *et al.* (2000) observed that though non-timber forest resource (NTFR) use is often viewed as a marginal activity in industrialized countries, in reality the trade of these products provides significant economic benefits to many rural households and communities. Vantomme (1998) noted that in temperate regions pines have been tapped for resins for over two thousand years. Pine nuts, long used in many parts of the world, have become part of gourmet cuisines in Asia, Europe and North America. In the United States' Pacific Northwest alone, trade in non-wood forest resources (Christmas ornamentals, mushrooms and other edible products, and medicinal products) reaches at least US$200 million annually (Hansis, 1998)

Apart from income generation NTFPs provide sustenance for rural livelihoods, especially in tropical countries. According to Pimental et al. (1997) NTFP resources play a major and very often critical role in the livelihoods of a high proportion of the world’s population. UNDP (2001) ascertained that non-timber forest resources (NTFRs) are in daily use throughout the tropics, commonly providing resources crucial to people where no other social security is provided by the State. According to The Economist (2000) in a typical African country, only one person in ten has a formal job and economically important species provide a source of informal sector income. In such situations edible wild foods (fruits, wild vegetables, fungi, bushmeat and insects) commonly provide dietary supplements (Cunningham and Davis, 1997). Numerous studies have found that it is often the poorest people and households that are most dependent on these resources (Prescott-Allen and Prescott-Allen 1982; Falconer 1990 and 1992; Scoones, Melnyk and Pretty 1992; Arnold 1995; Neumann and Hirsch 2000; Nasi and Cunningham 2001). Warner (1995) observed that the degree of dependence of a community on wildlife products is determined by the condition of the resource, its proximity to the community, access rights and restrictions, local and external demand, and income earning options. Within a community, different groups rely on wild products to different degrees, and dependence is related to the availability of other household resources: land, livestock and so on. For those households with few other resources, dependence on wildlife products is likely to be high and income from them, while small, may represent the largest portion of household income (FAO, 1995; Roe, 2001). Gunnar (1982) thus argued that ‘commercial significance’ should not be the only gauge to measure the relative value of NTFPs and suggested that their ‘importance in respect of the well-being of the people concerned’ would be more applicable. He observed that evaluation based on ‘commercial significance’ often results in attention being directed to almost exclusively to products transported over long distances and, in particular, products of international trade.

NTFPs have been important to forest fringe communities in Ghana. In her study within the high forest zone of Ghana, Falconer (1992) detailed the various support NTFPs make to the livelihood of forest fringe communities. She observed that NTFPs provided a form of a safety cushion to the rural households in times of economic hardship and to support farming. The use of raphia palms to distil alcohol for instance, is an important source of income to certain communities in some parts of southern Ghana (Mayers and Kotey, 1996)

This section reviews the importance of NTFPs as sources of goods (food, fodder, fuel, medicine, construction material, and smallwood for tools and handicrafts), income and employment for local people as well as contributing to the conservation of biological diversity and thus tries to echo the reasons for their sustainable management. Although some researchers have argued that the capability of NTFPs to alleviate poverty is limited (Boot, 1997; Van Valkenburg, 1997; Van Dijk, 1999 a; Ros-Tonen and Wiersum, 2003), the importance of NTFPs in the livelihood of forest fringe communities, especially in tropical countries, cannot be underestimated (Parren and de Graaf, 1995) and their sustainable management needs the necessary attention.

1.3 NTFP inventory

Forest inventory is the procedure of obtaining information on the quantity and quality of forest resources to assist in their management. Although forests provide a variety of goods and services, timber production had dominated the interest of forest managers and hence has been the main objective of forest inventories (Husch et al., 2003). In western European countries forest management methods to regulate timber production were established far back in the 18th century (Speidel, 1972; Kurth, 1994). Forest management inventories are thus timber oriented and little attention has been given to inventory of NTFPs. However, the institutional rediscovery of the significance of the value of other products such as NTFPs, the formulation of the concept of multiple use of forests and maintenance of biodiversity have recently encouraged the resurgence of interest in NTFPs and hence their sustainable management. NTFPs have also been seen as a means of involving local people, especially forest fringe communities, in forest management through their collaboration. The assumption of NTFPs being a means of involving local people in forest management implies that local people, especially forest fringe communities, would be more interested in forest management if they could derive some benefits through the use of NTFPs from the forest. This implies also that for continued sustenance of local people's interest in forest management, there should be a sustained supply of NTFPs used by local people. If local people participation is necessary for sustainable management of tropical forests, then the sustainable management of NTFPs would also be necessary for sustainable forest management in the tropics.

For the management of any natural resource to be sustainable, sound knowledge of the ecology, spatial distribution and abundance of the resource is essential. Such information could be obtained from a number of sources including indigenous or local peoples' knowledge as well as formal scientific enquiry through forest inventories (Wong, 2000). These inventories provide information on the resource base on which management decision depends. Thus the suitability of the method of inventory is essential in providing any useful information about the resource. However, in many situations of tropical forest management, timber has been the main focus and little has been done on NTFPs management. Although there is often considerable indigenous knowledge for specific NTFPs as well as many anthropological and ethnological studies, formal resource assessment of NTFPs, especially in tropical countries, is relatively new and has received little attention to date. Some methodologies have however, been developed by individual researchers in response to local circumstances and the peculiarities of the resource under study but these have been found to be methods used for traditional forest inventory (Wong, 2000). NTFP management has been hampered by their multitude and variety, lack of appropriate methods of assessment, organisational and financial constrains (FAO, 2001). The variety of life forms and distribution pattern of NTFPs (being rare or found in clumps) mean that traditional forest inventory techniques for timber cannot be adapted easily for NTFPs because they tend to be inefficient. For example in a recent multi-resource forest inventory in Ghana, the method of inventory could not capture significant bamboo clumps, even though bamboo was included in the species selected for the inventory (RMSC, 2002). The inefficiency of traditional forest inventory methods for NTFPs has prompted a call for more properly researched NTFP-specific sampling designs and the application of novel sampling strategies to NTFPs (Wong, 2000).

NTFP inventories in Ghana have been concentrated on the forest reserves. Falconer (1992) first conducted an inventory of NTFPs within forest reserves of the high forest zones of Ghana and strongly emphasised the need to consider NTFPs resource in off-reserve[1] areas.

[1] Consists of patches of forest, fallow lands and farmlands outside forest reserves.

She declared that off-reserve areas, especially fallow areas, provided the bulk of locally important NTFPs. However, subsequent forest inventories which included NTFPs have also been conducted in the forest reserves (RMSC, 2002). There is thus lack of information on NTFPs resource outside forest reserves.

1.4 Objectives and structure of the study

In Ghana as well as other tropical countries, NTFPs play a vital role in the lives of forest fringe communities and even some people in the cities still depend on NTFP processing and marketing for their livelihood. Besides, NTFPs are a subset of biodiversity that has utility to humans and their sustainable management would also contribute to enriching biodiversity. However, management of NTFPs has been limited and so is management information. The variety of NTFPs, the multiplicity of interest and disciplines involved in NTFP assessment, organisational and financial constrains, no globally or even nationally recognised common terminology, units of measurements and appropriate methods of assessment all contribute to bewilder the assessment of NTFPs and the resources providing them (FAO, 2001). This dissertation aims at contributing to management information on NTFPs in the off-reserve areas of the Goaso forest district of Ghana by:

- Testing efficient methods for inventorying the selected NTFPs;
- Making an inventory of selected NTFPs;
- Exploring the potential of the selected NTFPs for income generation;
- Investigating how factors like distance from communities and tree cover influence the spatial distribution of the selected NTFPs.

The study begins by defining the research problem and reviews the importance of NTFPs in the economic and socio-cultural sense. It continues by exploring forest inventory methods and their suitability for timber and introduces the problem of the need for inventory methods suitable for NTFPs. Chapter two reviews the various definitions and terminologies given to the NTFPs to echo the diverse use of terminology and the need for a common definition and scope of NTFPs. It continues by giving background information on forest resources in Ghana, the species exploited as NTFPs, their significance to local economy. The significance of resource assessment in the exploitation of NTFPs is also introduced. Different typologies used for NTFP inventory design are also reviewed. Chapter three reviews the different methods of assessing NTFPs by exploring social, economic and quantitative techniques. It also reviews methods of determining sustainable harvesting levels. The different methods reviewed sought to determine levels of harvest that could sustain the species exploited through growth and productivity studies. Although other sources of literature were used, much was drawn from the work done by Wong (2000) which gives much information on the methods for NTFP inventories. Chapter four describes the study area by reviewing its location and demography, climate, soils and vegetation cover as well as land use types. The methodology of the study is described in chapter five. This includes community and market study as well as different sampling methods used for NTFPs. The selection of each of the methods was based on its suitability for the species concerned. Although ranked set sampling was described as a method which could be useful in NTFP inventory, it was not applied due to lack of adequate information on the cover types in the study area to aid in plot ranking. The results of the study are presented in Chapter six. The results compare the efficiency of systematic and adaptive cluster sampling methods for inventorying selected NTFPs as well as the quantities and distribution of the species inventoried. The study ends in chapter seven by discussing the results and drawing some conclusions.

2. Background to NTFP resource assessment

2.1 Definitions of NTFPs

The study of non-timber forest products has been dealt with by people from varied fields of study such as forestry, ethnobiology, economic botany, social development, natural resource economics, conservation biology, protected area management, agro-forestry, marketing, commercial development, ecological anthropology, cultural geography and human ecology. This according to Wong (2000) has led to much discussion and no agreement on universally acceptable terminology to describe products of interest. The only terminology which is perceived as having flaws and has nearly deceased from general use in the early 1990's is 'minor forest products' (Chanderasekharan, 1995). However, there is an overabundance of terminologies in use with single terms having a range of interpretations, none of which are universally recognized. I will put the various terminologies into two groups and define them. Terminologies which include wood and wood products other than those from industrial wood. For example; Minor forest products, miscellaneous forest products (MFP). Here timber is the major product and all other products are considered 'minor' (Falconer, 1990). This term is considered to have shortcomings because it tends to diminish the importance of other forest products which are not commercial timber. Another term is alternative forest product (AFP). This term keeps timber as the main product and other products as alternatives. Others call them non-timber forest products (NTFPs). Arnold and Ruiz-Perez (1996) defined NTFPs as any non-timber products dependent on a forest environment. Mallet (1999) referred to NTFPs as products with the exception of timber, harvested from a forest ecosystem. NTFPs could also be all tangible animal and plant products other than industrial wood, coming from natural forests, including managed secondary forests and enriched forests (Ros-Tonen et al., 1998). Others consider them as resources because often the raw materials are extracted and hence prefer the term non-timber forest resources (NTFRs) (UNDP, 2001). Some authors use the term special forest products (SFP) to refer to products other than timber harvested from forests (Vance and Thomas, 1997). Non-timber plant products (NTPP) comprise only plant products other than timber (Cotton, 1996). Messerschmidt and Hammett (1998) argued that what is very often harvested is a raw material and not 'product' and preferred calling them resources instead of products. Hence terms like non-timber forest resources and values (NTRV) are also in use.

Other terminologies tend to exclude wood products in all forms. The FAO invented the term non-wood forest products (NWFP) and prefers it to other terms. FAO (2000) defines non-wood forest products as goods of biological origin other than wood, derived from forests, other wooded land and trees outside forests. This excludes wood in all its forms. Chandrasekharan (1995) also felt non-tangible benefits of forests should be included and thus carved the term non-wood forest benefits (NWFB). Benefits here is considered as an advantage, favourable effect, output, profit and includes non-tangible products such as recreation, landscape values, ecological values etc. Lund (1998) called them non-wood forest resources (NWFR) to mean all resources found or originating on forest lands regardless if they are currently recognised as goods, as products, as providing a service. There are also other terms such as non-wood goods and services (NWGS) and non-wood goods and benefits (NWGB) in use (Wong, 2000). Although these different terminologies exist, the terms NTFP and NWFP seem to be more common in literature. The term NTFP differs from the commonly used NWFP by the FAO by including wood for uses other than for timber while NWFP excludes wood in all forms (FAO, 2001).

The confusion over the definition and scope of 'NTFP' continues and there is no standard definition. Even the terms 'forest' and 'product' are debatable (FAO, 2001). The lack of common definitions, terminologies as well as the multiplicity of interest have been seen as hindrances to the development of research on products considered as NTFPs (FAO, 2001). A key component of all definitions is that they exclude commercial timber, and that the product, benefit or service should come from a forest, or from trees on other land cover types. The central part of the concept of NTFP is that the product of interest is of use to humans. As such, any part of any plant or animal harvested for use can be described as an NTFP. The following definition is adopted for this study: NTFPs consist of goods of biological origin other than timber, derived from forests, other wooded land and trees outside forests (FAO, 1999).

2.2 Forest resources in Ghana

The creation of forest and wildlife reserves has led to islands of forest reserves in a sea of mostly agricultural off-reserve lands. Resources in the forest reserves and off-reserves are under different management regimes. This section reviews the land use and cover types and examines the management regimes of forest reserves and off-reserve lands.

2.2.1 Land use and land cover types

Ghana has three principal land cover types; coastal savannah, forest and northern savannah.

The coastal savannah is in the south-eastern plains around Accra, consists of a mixture of scrub and tall grass (mostly Guinea grass). This contains thicket clumps that often include Elaeophorbia and other drought and fire resistant species such as the baobab (*Adansonia digitata*).

The southern third of the country (and the area along the Akwapim-Togo Ranges) is predominantly covered with evergreen and tropical semi-deciduous forest. This area is also referred to as the high forest zone. There are tall trees of varying heights forming a closed canopy at the top, above which tower a few giant trees such as *Ceiba pentandra*, *Triplochiton scleroxylon, Khaya spp* etc. The evergreen forest is in the extreme southwest while the semi-deciduous forest covers farther north. The forest cover area could be divided into two areas; forest reserves and off-reserves. Forest reserves are areas of forest lands demarcated to be kept as a permanent forest estate. Outside these forest reserves are the off-reserve areas which are used mainly for agricultural purposes. Off-reserve areas thus consist of a mosaic of perennial crops such as cocoa, oil palm, citrus and annuals and biennials as well as patches of forests or fallow lands at different stages of growth. The patches of forests in off-reserve areas may either be sacred groves which have been preserved on the basis of religious beliefs (Mayers and Kotey, 1996) or as forestland in transition. Mayers and Kotey (1996) description of the forest zone as an archipelago of protected forest islands in a sea of farmlands fits it well. The next section will give more details on forest reserves and off-reserves.

The northern savannah covers the northern two-thirds of the country. It consists mostly of tall Guinea grass with low trees scattered across the landscape. The shea butter tree (*Butryospermum parkii*), various species of acacia, baobabs (*Adansonia digitata*) and other fire resistant tree species are found in this area. Along the northern border of the savannah is a more open type of grassland that has developed largely as a result of prolonged human interference. The northern savannah is mainly the source of production of cereals and legumes, yams and ruminants in Ghana.

2.2.2 Resources within forest reserves and their management regimes

The need for the establishment of forest reserves in Ghana was motivated by H. N Thompson's report on Ghana's forest estate which highlighted an alarming level of deforestation (Thompson, 1910). To forestall total destruction of Ghana's forests, many of the reserves in modern Ghana were established in the 1930's and 40's by the then British colonial administration after serious initial land right disputes (Hawthorne and Juam, 1993). Forest reserves were established among others to perform the following functions:

- Protect and preserve water supply sources;
- Maintain favourable climatic conditions for the growth of principal agricultural crops;
- Minimise soil erosion;
- Meet actual and potential local wood requirements, including the demand for export trade (Foggie, 1962).

There are prominently 280 reserves in Ghana, 214 of which are in the high forest zone and the remainder in the savannah zone. These reserves are put under various management regimes which are known as working cycles. The main working cycles are selection working cycle, conversion working cycle, protection working cycle, and research working cycle. I will briefly describe what each working cycle entails.

In selection working cycle or production working cycle, logging is permitted and the forest is managed for timber production. Selection system is used in harvesting timber from such forests and hence the name selection working cycle. At present a 40 year selection cycle is used for such reserves on the assumption that the forest would be able to recover to produce another yield of timber during this period. However, rules for logging are sometimes not followed by loggers and harvesting could be done illegally above the permissible yield of the forest making the forest unable to recover within the selection cycle. When stocking of production reserves become low due to factors such as fire incidence or excessive human interference as those mentioned above, they are moved into a new working cycle category called conversion working cycle. In conversion working cycle the poorly stocked reserves are converted to plantations. These plantations have in the past been mainly stands of *Tectona grandis, Cedrela odorata* and *Gmelina arborea* (Agyarko, 2001). However, efforts are now being made to use indigenous tree species in a mix for such purposes. Reserves in which no logging is permitted and are solely for environmental protection are under protection working cycle. Such reserves are mostly found on steep slopes, watershed or areas including headwater catchments and river banks. Research working cycle is used for research purposes and this forms an insignificant proportion of reserves (Forest Inventory Project, 1989). According to data from the Forest Inventory Project (1989), 1.1 million hectares (73%) of reserves in Ghana is under selection working cycle while 0.4 million hectares (27%) is under protection working cycle.

Timber resources within production forest reserves are managed and specific yield is allocated to concessionaires based on inventory data. However, gatherers of NTFPs are only required to obtain permit for collection (usually from the district forestry office). While forest Guards may arrest users for collection without a permit, they may not collect monies for the permit. The gatherer pays for the desired quantity before they enter the forest to see what is available. According to Falconer (1992), there are no controls on the quantities which can be collected as long as it is paid for and no control on where the NTFP is gathered (within the reserve or even within the district). She ascertained that there is little control on actual quantities gathered and in general it is the regular traders and urban gathering groups (in the case of canes, pestles and chewing sticks) who obtain permits for harvesting from the forest reserves. However, people of the forest fringe communities rarely go to the forest offices to obtain permits. The giving of permits as a way of controlling non-timber resource utilisation in the forest reserves may lead to overexploitation of the resources as utilisation is not done according to the production capacity of the species exploited.

2.2.3 Resources outside forest reserves and their management regimes

Off-reserves are lands outside the demarcated forest reserves which are mostly used for agricultural purposes. Resources off-reserves encompass a mix of property rites. FAO (1995) divides property rites into the following categories:

- Private property is owned by an individual or a group of individuals with recognised access rights and can limit access to others;
- Common property resources have clearly recognised users who, although may not own the resource, have recognized access right and ability to limit access to others. Many traditional communal systems for land use are common property systems;
- Open-access resources are accessible to all, have no recognised users and are not easily controlled;

- State or public property often requires users to negotiate rights or obtain authorization for secure rights or access.

Off-reserve lands are owned by stools within traditional areas of which the chiefs are the custodians. However, the farmlands are in the hands of families or individual family members but timber resources on these lands are owned by the government. Non-timber resources are for land owners (private property) but traditionally access is open to other members of the community. Access is limited in only a few cases.

Timber resources in off-reserves were regarded as temporal and were to be removed before they are destroyed by farmers. The only means of control of timber exploitation in off-reserves has been girth limit of 70cm. Timber is harvested from off-reserves as far as it is accessible to the concessionaire and meets the girth limit. Timber resource off-reserves is owned by the government and is controlled by the forestry commission. However, the trees are found on farmlands of farmers who might have acquired the land through family, purchase or tenancy arrangement which could be 'Abunu' or 'Abusa' system (Mayers and Kotey, 1996) but have no right to claim ownership of the trees on their farms. Royalties paid by timber contractors go to the paramount chief of the area. Timber contractors are supposed to pay compensation to farmers when damages are caused to farms due to timber harvesting but have not been done to the satisfaction of farmers. These situations seem to be discouraging farmers from keeping timber trees on their farms or leading to deliberate destruction of timber trees and also conniving with chainsaw loggers to harvest trees on their farms illegally. Most forests in off-reserves have been converted to farms and this coupled with the problems above has reduced timber resource off-reserve. However, timber resources off-serve have formed a third to two-thirds of timber exploited in Ghana and thus a reduction in timber resource off-reserve will cause a shortfall in timber supply to the timber industry. This situation is already being felt by the timber industry in Ghana.

Off-reserve non-timber forest resources are not under any particular management or protection. They are mostly common pool resources for communities. Access is normally open to members of the communities. However, the decision to preserve such resources is at the discretion of the landowner on whose land the resources are found. In cases where those species are used for commercial purposes, usage is restricted and the resources are protected by land owners. In this case one would have to obtain permission from the landowner to use the NTFPs. If one wants to use NTFPs for commercial purposes, different arrangements for sharing the produce are made between the landowner and the user of the resource.

2.3 NTFPs in Ghana

2.3.1 Species exploited as NTFPs in the high forest zone of Ghana

NTFPs are in general diverse so are the species exploited. According to Mayers and Kotey (1996); Falconer (1992) products of the different species commonly exploited, traded and also for subsistence include the following:

- Food (snails, bushmeat, mushrooms, fruit and seeds);
- Spices (*Piper guineensis*, *Xylopia* spp, *Tetrapleura tetraptera*);
- Chewing sticks (*Garcinia kola*);
- Sponge (*Momordica* spp);
- Cola nuts;
- Charcoal;
- Medicines (*Alstonia boonei*, *Rauwolfia vomitoria*);
- Household goods (sponges, mortars, pestles, utensils, wooden trays, grinders, mats and baskets);
- Food-wrapping leaves (Marantaceae); and ,
- Tool handles.

Falconer (1992) has tabulated some of the species and their products used commonly as household items and agricultural equipment in the forest zone of southern Ghana. Some of these species and their uses are given in Table 2.1

Although the species exploited as NTFPs are diverse, they might be distributed differently in forest reserves and off-reserves. This study would only consider NTFP species obtained from off-reserve lands.

Species	Uses
Rattan	Baskets, furniture, crop-drying mat, building material
Bamboo	Construction of animal pens, barns, Palm tapping tool, yam stakes
Raphia	Construction of animal pens, barns, thatch, palm wine for alcohol production, crop-drying mat, cocoa harvesting tool handle.
Nuclea sp.	Mortar, carvings
Alstonia boonei	Stools, carvings, medicinal
Ficus exasperata	Abrasive cleaners, medicinal
Tetrapleura tetraptera	Spice, medicinal
Christiana africana	Carving
Rauwolfia vomitoria	Medicinal
Margaritaria discoidea	Construction
Spathodea campanulata	Medicinal
Chrysophyllum albidum	Fruit
Ricinodendron heudelotii	Curving, medicinal, oil from seeds

Table 2.1: Uses of some NTFPs. Only a few common species are included in the table

2.3.2 Significance of NTFPs in the Ghanaian economy

NTFPs play important role in the Ghanaian economy by way of supporting rural livelihoods in Ghana. In a survey covering a wide range of products and users in the forest zone of southern Ghana, Townson (1995b) found 10% of rural people and 38% of households sell forest products. In a similar study covering households in villages around the large market centre of Kumasi, Falconer (1994) found that 68% of the households surveyed were involved in supplying NTFPs to the market. Scoones, Melnyk and Pretty (1992) also asserted that the collection and sale of wild meat realises an income similar to that received by government employees.

Many rural communities in Ghana use NTFPs to support their livelihoods. Medicinal plants are used by people in Ghana to cure various diseases (Irvine, 1961). Rural people especially depend very much on traditional medicinal sources for their health. Falconer (1992) has tabulated different medicinal plants and animal products used to cure various diseases. Trade and use of medicinal plant products have of late assumed a wider dimension with more plant medicinal products being traded on the local market. As noted by Gunnar (1982) most of these medicinal plant products are still not understood, both in respect of their efficacy and chemical structure. To scientifically establish the efficacy of plant medicinal products and to include them in the main stream medicine for health delivery, a centre for scientific research into plants medicine was established in 1975 in Ghana. Although some of these medicinal plants have been catalogued, many are believed to be unknown to scientists as they are known by some traditional healers who are unprepared to release them to scientists for fear of losing them.

NTFPs provide employment for some people in Ghana. People are engaged in making carvings, baskets and cane furniture for both local and export market. These activities are mostly done in the cities or in towns closer to the cities. For instance in Anhwia, a town near Kumasi, about 2000 people are estimated to be engaged in wood carving (Cudjoe, 2005). Okra (2002) ascertained that the retrenchment of workers from the formal sector as part of the World Bank's Structural Adjustment Programme led to more people resorting to the informal sector of the Ghanaian economy, such as woodcarving and other activities that may involve the use of forest resources. People living in forest fringe communities could also make baskets and transport them to market centres for sale. Falconer (1994) reported that a great many people of Nkwanta and surrounding communities depend on NTFP trade especially basket weaving for income generation. Employment and income activities from NTFPs may play some significant role in the Ghanaian economy especially where there are limited jobs in the formal sector. However, the resource base to support such activities may have been exploited in an unsustainable manner, leading to the collapse of some of these activities. Although the state has been promoting such NTFP income generating activities in line with tourism promotion and alternative income sources policies, equal attention has not been given to sustaining the resource base which support these activities (cf. Cudjoe, 2005).

2.3.3 NTFP resource assessment in Ghana

NTFPs have been exploited in the forests of Ghana for long without any kind of records on the resource base to guide exploitation. Realising the increasing use and trade of some NTFPs such as cane products and a growing interest in managing them for sustainable production from the existing forest, an inventory of NTFPs was incorporated into the Forest Resource Management Project (FRMP) that ran from 1989 to 1995 (Falconer, 1992). An inventory of selected NTFPs was started in March 1990 and completed in 1991. In all 43 forest reserves were assessed for NTFPs covering approximately 382580 hectares of forest across all ecological types in the high forest zone in Ghana. The inventory focused on existing stock of a core group of NTFPs (canes, climbers, and several herbaceous and other medicinal plants) which were widely traded and believed to be under increasing pressure (Falconer, 1992). Analysis of distribution of the selected NTFPs across the forest management units (FMU's) level was done. A selection of the NTFPs was also integrated into permanent sample plots (PSPs) to investigate growth processes and dynamics of the selected species to improve the ability of the forestry department to plan and manage those NTFP resources. In the recent multi-resource inventory (RMSC, 2002) some number of NTFPs were included. The species included in the inventory were determined using the criteria of market demand, perceived scarcity of the resource, cultural significance, and perceived potential for commercial exploitation. Stocks of Rattans, climbers used mostly as sponges, trees such as *Garcinia spp*, *Tetrapleura tetraptera*, bamboo etc. were inventoried.

However, NTFP resources outside the forest reserves have never been inventoried. In her assessment of NTFP resources in the forest reserves of the Ghana high forest zone, Falconer (1992) affirmed that many of the NTFPs exploited by local people came from off-reserves.

Although the FRMP brought to bare the need to assess, monitor and include studies of dynamics of NTFPs in their exploitation and management, little has been achieved in this regard. Management of forest resources has been tied to the amount of revenue obtained from the resource. Compared to timber resources, the revenue from NTFPs to the forestry sector could be said to be negligible. In a developing country like Ghana which is cash strapped, it is natural that resources available to the forest sector would be mostly used to take care of timber resources which bring much revenue to the sector. Accordingly NTFPs are assigned very low priority if they were considered at all. Some more attention is however given when there is an external cash inflow for the purpose of NTFP management. However, for the management of Ghana's forest to be sustainable, local people's collaboration has been found to be essential (Amanor, 2003). NTFPs have been used as one of the main incentives for local people collaboration. This implies that sustainable management of the NTFPs would make their continue use as incentive for local people collaboration successful. It is thus imperative for the forest service to take a more serious look at management of NTFPs, even if they are used on subsistence basis, because they form an intrinsic part of the sustainability of the whole forest management system.

2.4 Role of resource assessment in sustainable NTFP exploitation

There is an old saying in management that if you can't measure it, you can't manage it. Forest resource assessments provide information about forest resources with a view to establishing, within a defined framework of expectations, the current status and probable future direction of interactions between human beings and forests, using certain criteria and indicators (FAO, 2000). Thus good NTFP resource assessments are critical to determining current status and as a basis for determining trends over time and thus are necessary for development and sustainable utilisation of NTFPs. Resource assessment evaluates some aspect of the resource based on information gathered from a variety of sources and these include socio-economic issues, market issues, or the quantity and quality of the resource (FAO, 2001). Social aspects of resource assessment provide information on ownership and/or access to the resources (private, public ownership status and trends), level of dependence of livelihoods on the resource (who, where and how are resources harvested), impact of other sectors on the resource (agriculture, labour availability, farmers), decision-making processes in the country i.e. planning cycles as well as (forest) legislation and rules (NTFP rights in timber concessions), and training/education needs (FAO, 2001). Economic aspects of resource assessment investigate how important is investment in NTFPs for the national economy, trends, the influence of national and international markets (substitutes within and between NTFPs), and financial possibilities such as joint ventures, World Bank loans and incentives, etc.

Resource assessment also investigates which resources are useful for commercial and subsistence purposes; examines the consequences of utilisation on the resources and inform appropriate management of the resource (FAO, 2001). Peters (1994) sees resource assessment as an intrinsic part of sustainable NTFP utilisation and development. He described a model for the development process and sustainable utilisation of NTFPs (see Figure 2.1).

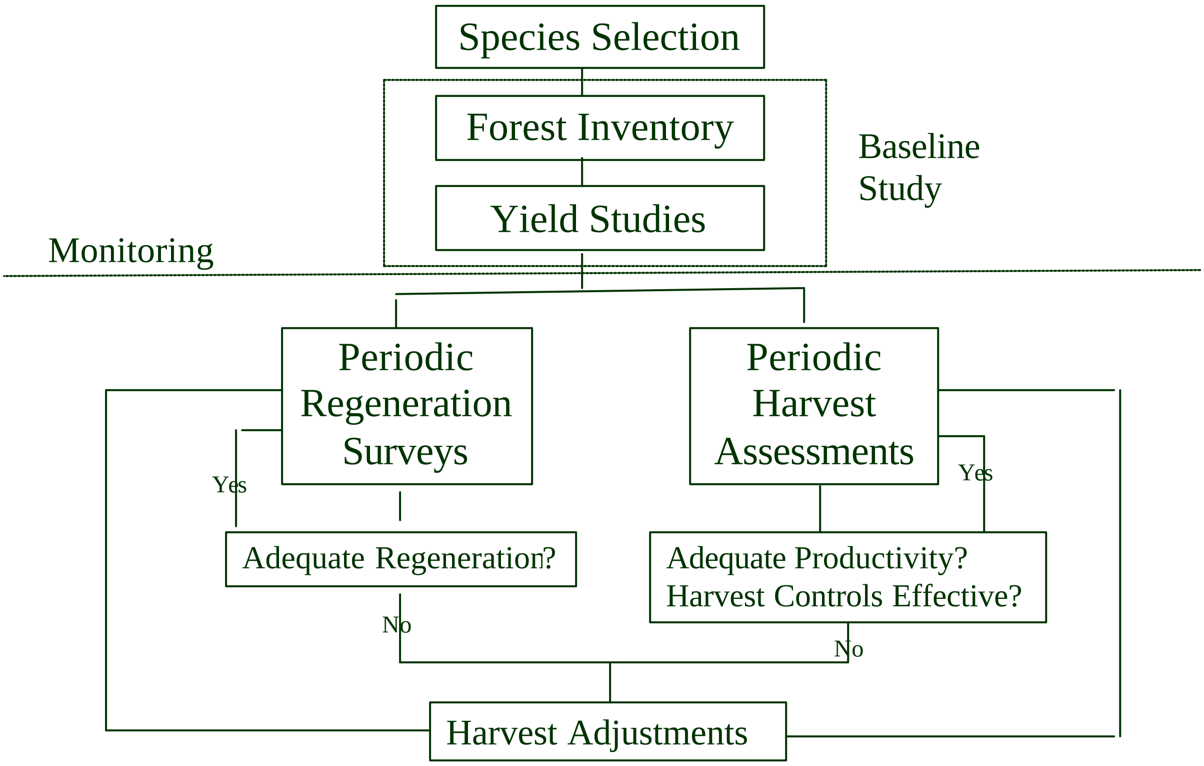


Figure 2.1: A basic strategy for establishing sustainable harvesting levels of NTFP plant resources (After Peters, 1994)

Information from resource assessment could be used at different levels. Table 2.2 gives what information from resource assessment is used for at the different levels.

Level	Use of information from resource assessment
Local	o determining sustainable harvesting quotas o monitoring the state of the resource o demonstrating sustainability to persuade authorities to allow harvesting
National	Strategic planning, including: o deciding whether to allow export quotas o considering promotion of resource-based industries
International	Informing conservation of endangered species, e.g. CITES Note: This usually relies on national level data
Others (usually international)	Fora discussing: o criteria and indicators for sustainable forestry o certification o Convention on Biological Diversity

Table 2.2: Uses of information from resource assessment at different levels. Adopted from FAO (2001)

2.4.1 NTFP typologies and resource assessment

Many efforts have been made to classify NTFPs but there is no single, commonly used classification system and the different classifications have been done to suit particular purposes (FAO, 2001). Classification systems are important in reporting, providing understanding of the uses and demand for products or help link methodologies to resources (FAO, 2001), especially in resource assessment. There are a wide range of classifications for NTFPs, and these generally classify according to products, end uses, taxonomy, management characteristics, or life-form. Wong (2000); FAO (2001) give details of the different classification systems. Classifications based on products or end uses tend to be useful in tracking the product through the market and thus could also be useful in determining their importance in national and international economies (FAO, 2001). According to the FAO

(2001) a few NTFP classifications have been constructed for the purpose of resource assessment or inventory and those available are predominantly forestry-based, which generally tend to distinguish plants based on broad life-form groups - e.g. herbs, trees, shrubs, rattans, etc. FAO (2001) also acknowledged the difficulty of adequate classification but contended that some type of grouping of the diversity of NTFPs is needed.

The diversity of NTFP resources makes some kind of typology necessary in their assessment. Biological characteristics of the species that produce NTFPs have been used to build some typology for resource assessment. Wong (2000) identified the following biological characteristics which could be used to group NTFPs for assessment:

- Life-form of the resource e.g. tree, fungi, bird, rattan, palms etc;
- seasonality – available in rainy season, dry season etc;
- whether part or the whole of the resource is harvested;
- whether harvesting is fatal or not;
- motility – whether resource is motile or sessile;
- the distribution of the resource – scale of dispersal.

In the assessment of very diverse products the development of a hierarchical typology, with each life-form subdivided into the parts that are used, is important (Wong, 2000). A group of trees may be divided into fruit, bark, stems, leaves, root etc and appropriate methodology devised for each. To reduce redundancy in the typology, however, Wong (2000) suggested that parallel typologies should be developed for a range of life-forms and parts used so that the protocol is the same for similar parts of the different life-forms. For example protocols for fruit would be much the same across a range of life forms such as palm, shrubs, lianas, trees etc. Wong (2000) also observed that few studies which have undertaken multi-species inventories have devised groupings of species based on life-form for the purpose of enumeration, analysis and presentation of results. In the Ghana multi-resource inventory, herbs were recorded as presence/absence while the numbers of rattan stems and clumps in a range of sizes were counted (Wong, 1998). Falconer, (1993) similarly counted rattan stems in the range of juvenile and mature lengths.

2.4.2. NTFP typology for inventory design

Sampling methods are used in forest inventory design to arrive at estimates of the quantity of a forest resource (Johnson, 2000) and the design must be suitable for purpose of the inventory. Wong (2000) has maintained that many authors have made the description of the purposes the main framework for designing appropriate inventory. For NTFP inventory which aims at estimating the abundance and distribution of selected NTFPs for the purpose of making management decisions on sustainable utilization, methods used depend on the characteristics of the species selected for exploitation. The choice of methods has been mostly influenced by the features of the species distribution, size and life-history (Wong, 2000). Species population characteristics therefore influence the choice of the inventory design. Wong, (2000) also asserted that life-form affinities have been mostly used as the bases for most NTFP typologies but these alone do not always help to identify the most appropriate methods for derived products. While it would be imagined that species of the same life-form would require similar techniques, this has not been always found to be so and that the characteristics of the life-stage of the product must be taken into consideration where relevant. Wong (2000) for example observed that techniques for motile species would be inadequate for cave-dwelling birds' nests or young parrots which are non-motile and these would require non-motile techniques more familiar to plant biologists. Munthali and Mughogho (1992) used plot-based technique similar for plants to inventory Mopane worms although these were the caterpillars of a motile moth. Plants have various parts used as NTFPs and the various parts and life-stages should be similarly considered when deciding on the kind of enumeration technique to estimate the yield of particular products. Wong (2000) also found life-form, especially the distinction between plants and animals to be relevant for plot layout as well as species enumeration and product yield. Plot configuration and sampling design should therefore be tailored to suit the species being inventoried.

The choice of sampling design however, depends more on the distribution of the population than its life–form per se (Wong, 2000). Sheil (1998) echoed this view by pointing out that different designs are best for different distributions. This is understood from the development of specific protocols for particular distributions, for example adaptive cluster sampling for species distributed in clumps (Pilz et al., 1996) and guided transect sampling for sparse distributions (Stähl et al. 2000). Nur Supardi (1993) also revealed that for rattans one needs to know the distribution patterns of the species before sampling design, intensity, or the shape and size of samples could be determined. Local interviews or pilot inventories are some of the procedures to get initial information about the distribution of the particular species before the design of main inventories.

At the plot level, Freese (1984) admonished a distinction between the 'unit' on which the observation is made and the 'value' being the variable or characteristics measured on each unit. For a study to determine fruit availability, the trees would be the units while fruit weight would be the value to be measured for each tree.

Classifying NTFPs is important both for keeping records on trade, linking them to appropriate methods as well as making suitable sampling design for their inventory.

3. NTFP resource assessment methods

NTFPs are assessed using various methods due to the different objectives for NTFP assessment. This section reviews the different methods and techniques used to assess NTFPs.

3.1 Social science techniques

Social science techniques used in resource inventory tend to be based on participatory approaches to gain local involvement. They tend to be more concerned with including local knowledge than providing biometrically sound information about the resource (FAO, 2001) and the information tend to be qualitative. Social science methods have been found not to be formalized protocols, but are rather approaches to information collection and processing (FAO, 2001). This section reviews social science techniques used in resource inventory.

3.1.1 Local knowledge and its value to inventory methodology

Local knowledge may sometimes be referred to as indigenous knowledge. However, some authors have tried to make some distinction between local and indigenous knowledge. Indigenous knowledge is seen to be cultural specific whereas local knowledge is viewed by contemporary sources as being dynamic and gained through observation and experience rather than just a legacy of the past (Fairhead and Leach, 1994; Richards, 1994; Thapa *et al.*, 1995; Sillitoe, 1998; Sinclair and Walker, 1999). Sinclair and Jossh (2000) contended that local knowledge systems from geographically distant and ethnically different locations but with similar agroecological context show remarkable similarities. Such distinction of indigenous and local knowledge might not be necessary in the sense of incorporating them in resource assessment as they tend to be complementary in providing information about local people's perspective of forest resources and the environment. Warren (1991) acknowledged the relevance of inclusion of local knowledge, at least in project planning and implementation. He gave the following reasons to support the inclusion of local knowledge:

- indigenous knowledge could reveal a large variety of information on options for using and managing natural resources specific to a locality which are not yet described scientifically;

- indigenous knowledge could be blended with professional knowledge to make the process of technology generation and transfer more effective;
- incorporation of indigenous knowledge and practices could stimulate self-determination of local communities and supports efforts to enhance active local participation.

Local knowledge has been used in many NTFP inventories (Martin, 1994, Jong and Bonner 1995, Carter 1996, Guijt and Hinchcliffe 1998). However, Wong (2000) noted that the reason for utilising local knowledge tends to vary from improving the efficiency of the inventory to enhancing local people's understanding and involvement in the resource inventory for their own benefit. In designing and implementing inventory for yew in British Columbia, Jong and Bonner (1995) found inclusion of local knowledge useful in providing the best stratification and improvement in efficiency of the inventory. Many practitioners strongly recommend the involvement of local people at all stages of decision making where the purpose of undertaking an NTFP inventory relates to improving the sustainability of local livelihoods (Carter 1996, Stiglitz 1999). Wong (2000) suggested an active involvement of local people in the inventory planning processes, incorporate their ideas into the objectives and design of the inventory and they should be actively involved in the fieldwork and data analysis. Many see this as an opportunity for a two-way learning process and the fact that involvement helps to develop a sense of responsibility for the environment (Salick 1991, Shanley et al. 1997, Scott 1998). Stiglitz (1999) added that active involvement would help people to understand how and why decisions are made without which people would usually not accept the decisions over long term. In short this ultimately improves the potential for developing a sustainable participatory management system. Local participation would also ensure that data collected will actually be useful for management and that it is integrated with work on resource use and economics (Wong, 2000). Local knowledge could also be used to decide on the need for inventory, species to include in the inventory and also decide on an appropriate sampling design and enumeration methodology. Wong (2000) has tabulated some uses of local knowledge in inventory. Swiderska (2003) also identified the following hierarchy of involving local people in natural resource assessment:

- Local people act as informants for an externally framed and led assessment;
- Local people participate in planning the assessment, but not in defining the conclusions, or in subsequent decision-making;

- Local people participate in planning the assessment, analysing the findings and determining priorities, to include in external decisions;
- Local people participate in planning the assessment, in determining priorities and in subsequent external decisions relating to the assessment;
- Local people initiate, plan and conduct the assessment to inform their own natural resource decisions, as well as external natural resource assessments and decisions.

It is important to consider the category of local people to be involved in the resource assessment as this may affect the level of involvement. However, blending all categories of local people, local professionals as well as those who use the resource, would be more desirable in achieving the purpose of involving local people in the resource assessment.

Although local knowledge could be useful, its reliability in making decision about inventory design may be questionable. Wong (2000) gave two reasons for this. First, the collection and interpretation of information may not be adequate to depict a true understanding of local knowledge available. Various studies have shown a variation in methods of collecting local knowledge for forestry development projects. These may include formal social surveys, anthropological and ethnological techniques, rapid rural appraisal, participatory rural appraisal and participatory learning and action (Nichols, 1991; Chambers and Guijt, 1995; IIED, 1997). Wong (2000) argued that the participatory methods such as rapid rural appraisal, participatory rural appraisal and participatory learning and action are approaches rather than formalised methodologies. These different approaches could create a distortion in collecting and interpreting local knowledge available. Besides, the question of whether local knowledge is a true reflection of the situation on the ground comes into play. Stakeholders will have different ways of understanding their environment and will have different perspectives of change (Abbot and Guijt, 1998) and no one perspective could be considered absolute (Chambers, 1997). Case studies have indicated that the biometric adequacy of the inventory may be compromised where local people's ideas and decisions were incorporated into inventory design and implementation (Wyatt 1991, Salick et al. 1995, Abbot and Guijt 1998, Carter-Lengeler and Jones 1998). Nevertheless, local knowledge has been viewed by Wong (2000) as serving a practical purpose and a sensible starting point for understanding and/or classifying the ecological environment. She however admonished the need for the design of the inventory to include scientific verification of local anecdotal knowledge where there is still some doubt and the efficiency of the design be reviewed after an appropriate period of data collection. A conventional pilot study could be used to assess the sampling errors or may serve to change the design subsequent to an initial inventory.

3.1.2 Participatory approaches and data collection

The concept of local people participation in natural resource management and project design became institutionalised in the 1980s and 90s in vogue of most donor-supported programmes. Many non-governmental organisations (NGOs) now emphasise active community involvement and the importance of local knowledge in their projects and programmes (Guilt, 1998; Swiderska, 2001; Amanor, 2003). These have led to a proliferation of different terminologies to describe local participatory processes. There are now terms such as Rapid Rural Appraisal (RRA), Participatory Rural Appraisal (PRA) and Participatory Learning and Action (PLA) being used to describe participatory approaches. Havel (1996) describes them as a combination of tools held together by a guiding principle. According to Wong (2000) each of these approaches comprises a set of communication and development tools, different combinations and permutations which are used depending on the objectives and stage of the project or process. The methods seem to have evolved from one another with RRA being the first to be developed in the late 1970s as a concept of rural development through participation. In this sense RRA was used as a rapid means of collecting indigenous knowledge. Its main techniques include a review of secondary sources, direct observation, foot transects, familiarization, participation in activities, interviews with key informants, group interviews, workshops, mapping, diagramming etc using a broad range of social and biological disciplines in the collection of information (Chambers, 1989). A key principle in the process is triangulation being the utilisation of a variety of information gathering methods that enable detailed cross-verification of the data in the field. PRA emerged in the 1980s soon after RRA. It sought to add further tools for information collection and the concept of local people empowerment through their participation in the analysis of their situation and collective knowledge (Wong, 2000). In PRA the outsider researcher becomes more of a facilitator and analyst and less of a data collector. This according to Wong (2000) is the key difference between RRA and PRA, as the former appeared to be an extractive data collection exercise with data analysis and problem solving undertaken by outside experts. Although RRA could still be considered appropriate in some circumstances, the development of PRA became necessary due to the recognition that in many instances local people were better placed than outside researchers to analyse and seek solutions to their problems. PLA takes this further by including the concept that local people can and should be involved in learning from each other, developing research programmes to fill locally identified information gaps and determining the direction of and being actively involved in their own community development. PLA however, is much less focused on information collection than the two previous methods but is more in line with Friere's (1970) concept of rural development through participation (Wong, 2000). Havel (1996) has listed and described several participatory approaches or methodologies.

3.1.3 Reliability of informal methods

Social scientists have been engaging in discussions regarding the reliability of methodologies for data collection such as RRA, PRA etc. because they do not tend to conform to traditionally accepted statistical norms (Chambers 1983, Inglis 1991, Gilling and Cropley 1993, Gill 1993). Michael Cernea, World Bank chief sociologist reacted to the spread of rapid assessment procedures and the lack of scientific quality by saying "Rapid Assessment Procedures run the risk of sliding into little more than the quick and unreliable amateurish manner of misgathering social information that they wanted to replace in the first place. It is not an abstract risk: I have seen it at work, wreaking havoc. And I have seen it lurking in the pages of some glossy consultant firms' field report, marketed now under the newly fashionable RAP label" (Cernea, 1992, p. 17). According to Wong (2000) verification of the reliability of information collected is undertaken as part of the process rather than via data analysis after collection. Others have however, shown that utilisation of these informal methods with careful triangulation and cross verification in the field could yield reliable results (Chambers 1997, Guijt and Hinchcliffe 1998). According to Sechrest and Sedani (1995) using different tools that measure the same concept but do not share the same sources of error variance could lead to probing the internal validity of the study. The results from the different tools can then be compared and the degree to which they support each other analysed. Gill (1993) observed that results of participatory methods for local level analysis and planning could largely be verified by subsequent formal surveys. However, Gill and Cropley (1993) noted that the quality of the results obtained using these methods relies upon the skills of the facilitators who must have a clear understanding of the participatory concept, a good analytical capacity and outstanding personal skills in working with people. This shows that the level of reliability of the information collected using these informal methods is connected with the qualifications and abilities of the facilitator or researcher (Wong, 2000). Informal studies may be hard to replicate due to different personal evaluations and interpretations that researchers may give to what respondents answered or how they reacted. However, a growing number of tools exist which allow cross-checking the assessment of researchers and thereby make replicability easier. Qualitative data could be quantified through explicit ordinal scale scores such as Likert and Gutman scales (Hentschel, 1998). Wong (2000) found the methodology developed by Sinclair and Walker (1999) as powerful expert system for collecting, representing, verifying, analysing and retrieving local knowledge. She commended the following qualities of the expert system:

- Its ability to disaggregate sentences or concepts into precise units of knowledge which allows objective comparison and thus cross verification of qualitative information delivered in normal language statements.
- Retention of linkages between the units of knowledge in a way that permits retrieval of the overall concepts rather than lists of the specific units of knowledge collected.

This method may not yet be widely used but may have the potential to provide a more objective verification of qualitative ecological information informally collected from local people. However, the knowledge retrieved using the expert system and the means of retrieval is likely to be more relevant to researchers and development workers than local people who wish to analyse and seek solutions to their own problems. It was found to be complementary to PRA and PLA methods for development purposes (Wong, 2000).

Informal methods of collecting local knowledge may yield reliable results if the methods are applied appropriately. Efforts have also been made to develop systems which enable verification or cross-checking of results and the quantification of the qualitative information to allow some statistical quantitative analysis.

3.2 Economic methods

Economic methods assess the contribution of NTFPs to local and national economies through marketing and adding value and evaluate the costs and benefits of including NTFPs in management plans. They assess the potential of NTFPs to the development of new industries, markets and income sources as well as valuation studies. Economic methods are not designed to be biometrically sound methods because they do not involve direct resource assessment but use market information (econometrics). However, they can be important in the design of NTFP inventory, as information on value and income from NTFPs influences management decisions (FAO, 2001). Also economic methods are found to be particularly useful in determining the potential for commercialisation (or protection) of the resource from economic perspective and could identify obstacles to such development that are not related to resource availability (May, 1990; Godoy *et al.,* 1995; Aglionby and Whiteman, 1996).

This section reviews the use of market and income studies and cost-benefit and valuation studies as economic methods of NTFP assessment.

3.2.1 Market and income studies

Market and income studies tend to assess the income generating potential of NTFPs. Market studies could be done conventionally on a larger scale or using participatory methods at the community level. These studies involve investigating the use of NTFPs to generate income by local people and to provide export income generating opportunities to improve local economies (Tewari, 1999). Many of such studies focus on increasing the level of benefits available to forest dwellers from NTFPs utilization as these were presumed to be environmentally benign forms of forest use and could help conserve forests and improve local people's life (e.g. McNeely 1988; de Beer and McDermott 1989; Peters *et al.* 1989; Nepstad and Schwartzman 1992; Panayotou and Ashton 1992; Clay and Clement 1993; Evans 1993; Clay 1996; Peters 1996; BCN 1997). Market studies also investigate patterns and quantities of products in trading networks and highlight where there are problems in the supply chain or to improve understanding of trade relationships (FAO, 2001). Many studies have also been done to assess the proportion of local people's real or potential income derived from forest products. These have been used to measure the value of forest to people and their dependence on it (e.g Gunatilake et al. 1993, Appasamy 1993, Taweri 1999). Distinction is made here between forest income as income derived directly from forest products and wage- or trade-related income that may be related to forests. Wollenberg et al. (2001) explains the different types of incomes and how they are determined and outlines some methods used to assess forest income. These methods are mostly based on assigning values to products based on market prices or prices in related markets, price of substitutes, and where there are no market prices; contingency methods (willingness to pay), labour or energy used in extraction (optimal foraging theory) or relying on informants etc are applied (Smith 1983; Godoy et al. 1993; Wollenberg et al 2001). In quantifying NTFPs, economic studies distinguish between inventory quantities and the flow. Inventory is referred to here as the stock quantity in the forest whiles flow is the quantity actually extracted and used by people (Godoy et al. 1993). Thus markets and income studies tend to quantify flow and great differences have been reported between flow and inventory (e.g. Padoch and de Jong, 1989; Peters et al. 1989). Nevertheless, market and income studies do not involve direct resource assessment and the methods used are econometric which this study would not consider.

3.2.2 Cost-benefit and valuation studies

Cost-benefit studies investigate and analyse the current value of the resource to different stakeholders, and can be used to compare values of different land uses - e.g. comparing retaining forest cover to converting it to agriculture. Many have used cost-benefit valuations to argue for trade-offs between the value of NTFPs compared to other, presumably more destructive uses of forest such as logging or conversion to agriculture (e.g. Peters *et al.* 1989; Balick and Mendelsohn 1992; Gunatilake *et al.* 1993; Chopra, 1993; Godoy *et al.* 1995; Melnyk and Bell 1996) and to add weight to forest conservation debates. Thus cost-benefit analysis is potentially a useful tool in demonstrating the economic importance of NTFPs and related livelihoods (Wong 2000). They may include the use of inventory to quantify products harvestable from the forest and together with market prices estimate the present value of the forest.

Resource base data are needed along with economic studies for effective management of the resource. Economic studies can also identify barriers to development of the resource that are not related to the resource itself.

3.3 Quantitative NTFP resource inventory

Quantitative inventory has been described differently by many authors. Campbell (1989) described quantitative inventory in ecological sense as the measuring of individuals and species of trees in a small patch of forest, the measurement of several important parameters of those individuals and the analysis of the abundance and distribution of those individuals as functions of their physical and biotic environments. Burkhart and Gregoire (1994 p.378) however, described quantitative inventory in the foresters' jargon as 'a sample-based survey of the forest resource'. Campbell's description seems to be somewhat different from the latter as it places emphasis on ecology and the latter on sample-based observations. Wong (2000) however, defined quantitative inventory as a biometrically rigorous enumeration of the abundance and distribution of resource populations. Biometric rigor here implies that statistical principles must be met throughout the inventory and should provide sufficient detail in reporting protocols. The main statistical principles involve: objectivity in sampling design, number of plots used and independence of observations (Schreuder et al., 1993; Wong, 2000; FAO, 2001). Although not all NTFP assessments need to be biometrically rigorous, biometric rigor becomes important where reliable and good quality information is required to give some credibility to the results and interpretation of the assessments. The extent of biometric rigor in NTFP assessment would depend on the objectives, needs and expectations of the users of the information (FAO, 2001). In general biometrically sound methodology could contribute to the following:

- Sustainable utilisation of the resource. This implies that over-harvesting could be avoided and thus ensures long term survival of the target species and the commercial ventures depending on those species. However, in most cases of NTFP utilisation over-harvesting occurs due to lack of reliable data on the NTFPs (Tewari, 1999) which leads to decline of those species and a collapse of enterprises based on them;
- Valuation of tropical forest resources by giving a standard of what is measured and data quality which could allow comparison of results of different inventory. It is difficult to compare results of inventories that are carried out differently (FAO, 2001);
- Making strategic overview for planning and prioritization at national, regional or international level. These often use data from local assessments and it is only as reliable as the data it uses (FAO, 2001);
- Giving the right advice to enhance long-term survival of species and local livelihood;
- Add weight to recommendations and give credibility to recommendations to avoid political bias. This is important where government agencies have to defend their reason for setting quotas to those who lobby for higher levels (e.g. industry/trade) or lower levels (e.g. Conservationists). The case of setting a national quota for *Prunus africanus* bark in Cameroon is an example of using biometrically reliable data to back political debates (Wong, 2000).

Inventory for NTFPs may be distinguished in three contextual settings: single resource, single purpose multiple resource and multi-purpose resource inventories. This distinction manifests the focus of the inventory and the extent to which protocols can be adapted to suit specifics of the NTFPs in question (Wong, 2000). I would briefly review these inventory settings.

3.3.1 Single resource NTFP inventories

Single resource inventories are focused exclusively on a particular NTFP. Wong (2000) believes that these studies could provide the best opportunity for development of methodologies closely tailored to the characteristics of the species from which the product is derived and should set the standards for NTFP studies. She noted however, that very few single product studies have quantification of the in situ resource as an objective. The reason being that a NTFP has to be either very valuable, or subject to legislation for it to justify a species-specific inventory. Most species specific studies have hence been done for species that are traditionally important for export such as rattan (Wong, 2000). From her review of NTFP assessment methods, Wong (2000) discovered the following reasons for the conduct of single resource inventories:

- provide knowledge of the effects of exploitation of a species for which no other work has been done, e.g. tree fruit (Shankar *et al.*1996), palm fibre (Lescure *et al.*1992), rattan (Stockdale 1994), birds (Silva and Strahl 1991), tapir (Fragoso 1991);
- assess the potential of particular products for which increased commercialisation is sought at either the national or local level, e.g. gum copal from *Agathis* (Zieck 1968), palm products (Sullivan *et al.*1995, Konstant *et al.*1995);
- assess the potential of a specific area for exploitation of a known commercial product, e.g. rattans on Barateng Island (Sharma and Bhatt 1982) and in Indonesia (Siswanto and Soemarna 1988, Siswanto and Soemarna 1990 and Siswanto 1991);
- investigate the spatial distribution of an exploited product, e.g. savanna fruit trees (Schreckenberg 1996);
- provide supporting data for the determination of quotas, this is required for several products under national legislation or international treaty such as CITES (e.g. caiman skins from Venezuela - Velasco *et al*. 1996, white tailed deer and wild turkey in the USA – Flather *et al.*1989, *Prunus africana* bark from Cameroon – Acworth *et al.*1998, American ginseng roots from the USA – Gagnon 1999b);

- may also be for academic inquiry e.g. historical understanding of role of wild yams in historical human diet (Hladick and Dounias 1993).

3.3.2 Integration of NTFP inventory with timber inventory as single purpose multi-resource inventory

This type of inventory is meant to provide quantitative information on a range of NTFPs for a single purpose, for example management planning (Wong, 2000). This is usually done in combination with selection system timber surveys and tends to record the presence and abundance of a range of species that occur on a particular portion of land.

In a selection system of managing timber resources as described by Wong (2000), the forest is divided into compartments of approximately 100ha or 1km². Before logging takes place each compartment is subjected to a stock survey which involves the location, numbering and measurement of every timber tree. Yield formulae are then used to determine the sustainable yield of timber from each compartment based on the stock survey data. Trees are selected from the stock survey map to make up the allocated yield according to rules designed to protect the environment and the future potential of the forest. Stock survey protocols are generally total or 100% enumeration with the area being inventoried covered by contiguous enumeration strips. The need for integration of NTFPs into conventional forest management has resulted in attempts to incorporate NTFPs in timber stock surveys (Wong, 2000). The Ghana forest service is developing ideas to include NTFPs in the routine timber stock survey (Wong, 2000) and some evidence of inclusion of NTFPs in community forest inventory has been reported by Gronow and Safo (1996).

Although stock surveys seem to be sound and pragmatic means of determining the distribution, abundance and NTFP management potential of the area to be logged, they could generally be very expensive to execute except over small areas. Wong (2000) also affirmed that as census, stock surveys are biometrically sound but a problem of imperfect detectability may arise when dealing with animal signs, small herbs, epiphytes etc. for which careful searches will need to be made. Census data of this type are more likely to be underestimates and may not represent true densities. It is also impossible to determine errors and hence the precision and accuracy of the estimates due to lack of replicates. Studies such as Poffenberger *et al.* (1992), Cunningham (1996a) and Dijk (1999a) have used different techniques to determine the abundance and distribution of NTFP species.

3.3.3 Multi-purpose resource inventory

The recognition of the multiple uses of forests and interest in the inclusion of NTFPs in traditional forest management has led to the development of multi-purpose resource inventories (MRI). Wong (2000: 31) affirmed this by stating that 'the increasing interest in the inclusion of NTFPs in forest and protected area management has fuelled the inclusion of NTFPs into routine forest inventory, in effect turning them into multi-purpose resource inventories'. Lund (1998b) defined Multi-purpose resource inventory as data collection effort designed to meet all or part of the information requirements for two or more products, functions (e.g. timber, NTFP management and watershed protection) or sectors (e.g. forestry and agriculture). Although Lund *et al.* (1998) showed that MRI could include many products and sectors including recreation, agriculture etc., Wong (2000) observed the majority of MRI that include NTFPs are undertaken almost exclusively by forestry staff for a restricted range of purposes, usually; standing timber volumes, NTFP distribution and abundance and plant diversity. This has been so because most NTFPs originate from forests which are under the control of state forest authority charged with the responsibility of undertaking routine resource inventory and monitoring to maintaining up-to-date forest resource data. She also contended that timber has remained the primary purpose of such inventories in most cases.

Nevertheless MRI with NTFPs have been undertaken by a number of countries in both temperate and tropics. Wong (2000) cites examples of MRI by the United States Forest Service, national forest inventories in Sweden, Lithuania, Poland and Finland. Lund (1998a) also lists further national scale MRI with NTFPs for the Russian Federation, Norway and Turkey. In northern and eastern Europe NTFPs in the form of berries and mushrooms have been recognised and included in recurrent inventory for almost a hundred years. There have been reports of inclusion of products such as bamboo and rattan in the national and state inventories of India, Indonesia, Malaysia, the Philippines and Thailand (See Sharma and Bhatt 1982; Serna 1990; Stockdale 1995a; Rai and Chauhan 1998). In Africa Wong (1998) has reported inclusion of climbers, rattans and herbs in the national forest inventory of Ghana. RMSC (2002) also reported of a MRI in which NTFPs such as chewsticks, rattan, raphia palms, climbers, bamboo and some tree species were included. Lund (1998a and b) also listed national scale MRI for Ethiopia, Senegal and Uganda which included NTFPs.

MRI offer the opportunity for information to be gathered on a wide range of forest resource and or functions as pointed out by Lund (1998b). The challenge to MRI is the development of methodology that could encompass the different life forms without making the inventory too expensive. 'The ideal of separate plots or enumeration teams for different NTFP groups would greatly increase the logistics and cost but synergy between the elements of the MRI should mean that the information effectiveness of the inventory is greatly enhanced' (Wong 2000: 32). Also as timber continues to dominate such inventories, the commitment given to NTFP inventory may be limited, especially in the face of financial and skilled labour constrains. As pointed out by Wong (2000) forestry staff may be more familiar with tree enumeration techniques than NTFPs and MRI may only include a limited number of species which are best known, traded in large quantities or may be experiencing overexploitation (e.g. as in the Ghana inventory, Falconer 1992a and b). Wong (2000) also contended that the greatest failing in tropical MRI is their exclusion of animals. This she attributed to the unamenability of animals, and also groups such as fungi, herbs etc, to the simple inclusion in traditional inventory. However, bushmeat is known to form a substantial part of the protein intake of rural and urban people particularly in West Africa (Falconer 1990, Falconer 1992b, Dijk 1999). Methodology for animal inventory is already well developed (Bibby and Moss, 1998). This study thus considers methods for inventorying plant NTFPs.

3.3.4 Yield assessment and product enumeration of NTFPs

Wong (2000) defined yield assessment as the quantification of the amount of a particular product that can be obtained from an area of forest. An estimation of the yield of a particular product requires the enumeration of certain characteristics of the individuals making up the parent population. Wong (2000) pointed out that in the context of NTFPs, yield is open to interpretation. She distinguished between total yield which measures the biological potential of the species and useful or commercial yield as that which is available for collection. What is actually collected and used by people was referred to as flow by Godoy et al. (1993). Wong (2000) found such a distinction to be necessary because it affects the conclusions that can be drawn from the study.

The measurement techniques used to quantify the product is known as product enumeration. NTFPs are parts of plants or animals and each part may require a different measurement technique. This implies that there may be a number of techniques which may be used for

NTFPs. Wong (2000) documented some enumeration methodologies from different NTFPs inventories. Table 3.1 shows the different enumeration methodologies as presented by Wong (2000).

Variable/ Product	**Methodology**	**Source**
Fruit yield per season	Ground level traps. 4 isolated trees selected, 15 1 m² plots randomly located beneath crown. Number of intact, predated, immature and mature fruit recorded every 7-10 days.	Peters (1996a)
Fruit yield per season	Fruit counted in situ on sample trees at frequent (weekly) intervals. Counted fruit left in situ and marked with paint to avoid repeat counts.	Peters (1990)
Fruits, leaves, etc	Randomised branch sampling. Branching pattern defined as numbered segments between branching nodes. Path from trunk to branch tip selected using random selection at each node. Fruit/leaf/etc. counts undertaken at distal end of path. Pooled result from several randomly selected branches is a non-destructive, precise and statistically reliable method of estimating fruit yield of tree. There are several refinements of method e.g. path selection proportional to size of available segments at a node, importance sampling etc.	Gregoire *et al* (1995), Jessen (1955), Nguvulu (1997)
Leaves	Pipe model. Non-destructive regression technique for estimating leaf biomass and area from branch cross-sectional area. Pipe model based on observation that transpiration rate of canopy is proportional to leaf area, sapwood cross-sectional area and conductivity of water transporting tissue. Therefore size of stem is proportional to leaf mass and area. So one can estimate leaf mass and area from measurement of stem cross-sectional area. Sample branches selected systematically to represent different branch heights. Regression analysis without constant.	Nygren *et al.* (1993)
Palm leaves	All leaves measured. Partially open leaves counted as fraction of open leaf. Leaf length measured monthly to track growth.	Cunningham (1988)
Palm stem increment	Leaf scars counted at monthly intervals. Stem growth quantified as height increment (cm) per leaf scar.	Olmstead and Alvarez-Buylla (1995)

Palm age	Count of leaf scars, assume constant rate of leaf production to give estimates of age and numbers of years to reach critical heights.	Pinard (1993)
Bulb size	Measurement of maximum width of largest leaf on each plant. Regression analysis performed on a random sample of 50 plants at each site indicated that the largest leaf's maximum width is strongly correlated to total leaf area. Total leaf area already shown to be an indicator of bulb size.	Rock (1996)
Bamboo biomass	Measure clump dimensions on orthogonal axes at ground level, 1 m and full canopy extent. Map these as concentric ellipses. Determine biomass as volume of cone projected upwards from the base of the clump. Site index = Sum of clump volume / clump density in plot. Site clump area = sum of clump area.	Widmer (1998)
Bushmeat weight	Opportunistic records of weights of captured animals in 3 villages used to supplement animal census.	Lahm (1993)

Table 3.1: Examples of techniques used for quantifying product yield (Adapted from Wong 2000)

Different methods have been used to quantify products available in the forest and there seems to be little standardisation of methodology. Table 3.1 for example gives three alternative methods for measuring fruit yields. The different methods in this case are used to contain differences in forest and tree structure and also the objectives of the study. Wong (2000) found marking and repeat counts as the only alternative for fruit which do not fall when ripe, when it is necessary not to disturb normal predation or it is thought that harvesting may stimulate fruit production or ripening. She reckoned that the choice of measurement technique is determined by the type of product, the characteristics of the source population, pragmatism and the objectives of the study. It is therefore very difficult to be prescriptive even for the most commonly studied NTFPs.

3.3.5 Production functions for NTFPs

NTFPs may be parts of a plant or animal. This implies that the extraction of the product may occur on the living plant or animal hence there should be functions that relate the quantity of the product to be extracted from an individual to a measured variable. A production function expresses the relationship between a measured variable on an individual and of the maximum quantity of the product that can be extracted from that individual without impairing its normal physiological processes. Studies of population dynamics of the exploited species become important in cases where the whole plant or animal is extracted.

All individuals sampled in an inventory cannot be enumerated for product yield because it may be costly, difficult and would require much time than the inventory would allow. Consequently sub-sampling for detailed measurements of yield on a smaller number of individuals is usually done (Wong, 2000). Sampling methods which are usually used for estimating yields of NTFPs are double sampling and multi-stage sampling. I will briefly explain what each sampling method entails.

Wong (2000) describes double sampling as product yield sampling independent of the main inventory. It is a form of multiphase sampling limited to two phases (Husch et al. 2003) and allows an estimate of a principal variable (product e.g. bark) by utilizing its relationship to a supplementary variable (e.g. diameter). Double sampling is perhaps the most frequently used for estimating yields of NTFPs and can use a range of different designs. Husch et al. (2003) describes the general procedure for double sampling. In the first phase, a large sample of individuals is taken on which the supplementary variable is measured. The second phase involves a random subsample selected from the previous sample, and on these sampling units measurements are taken of the principal variable. To illustrate this take a forest containing a tree species whose bark is utilised for medicinal purposes. A large sampling unit could be enumerated for density and diameter distribution of the trees. A small subsample of individual trees could then be enumerated for diameter and the quantity of bark that could be removed. The two samples are then independent and this is different from double sampling in which the main and subsample are mutually dependent as described by Husch et al (2003). The results are generally formed into models describing yields against size and the models are applied to the inventory data to provide bulked up estimates of total yield per unit area (Wong, 2000). The main constraints of double sampling as found by Wong (2000) are that it needs to be statistically sound, have some predictive variable in common with the main inventory and ideally should also have a similar spatial distribution to the main inventory though this is often not practical. Some examples of double sampling for NTFP yield are the survey of bark thickness for Prunus which was independent of the main inventory (Acworth *et al.*1998), animal inventories which use data of bodyweights derived from harvest records or secondary sources (Lahm 1993, FitzGibbon *et al.*1995) and berry yields measured on research plots and applied to static inventory in Finland (Raatikainen *et al.*1984).

In multistage sampling, a random sample is taken from the population (primary units) and each of these sampling units consists of smaller units (secondary units) which in turn could be made up of smaller units. A random subsample of secondary units is taken in each of the primary units selected and the procedure could be continued to the desired stage (Husch et al. 2003). Multistage sampling could also be employed with variable plot procedures and the data derived can be used to develop both general models and site specific conversion factors. Multistage sampling has the advantage of concentrating the measurements work close to the primary units chosen, rather than spreading it over the entire forest area to be inventoried. This becomes beneficial when it is difficult and costly to locate and access the ultimate sampling unit but comparatively easy and cheap to select and reach the primary units (Husch et al. 2003). However, Wong (2000) contended that detailed measurements may be constrained by restricted mobility of equipment. She also admonished adequate testing or supervision to ensure sufficient samples are obtained in rarer size classes to permit adequate replication for statistical analysis. For example larger sized trees may become very rare but contribute disproportionately to yield and in such case it may be necessary to augment the sample with additional observations in deficient size classes in order to obtain adequate replication for statistical analysis. Where the problem of inadequate sample size in rarer size classes is envisaged, double sampling has been found by Wong (2000) as a better alternative. Rai and Chauhan (1998) give an example of application of multistage sampling for bamboo.

Data from yield study could be applied to an inventory of population densities to give gross product yield of the study area. The simplest way to do this is by deriving a conversion factor, usually the mean amount per individual and to multiply this by the estimated total number of individuals in the population. Estimate of the harvestable yield could be made by considering accessible individuals or only those of a commercial size (Wong, 2000). Where yield of an individual is strongly related to size (e.g. for products derived from large trees, palms etc) some means of estimating yield as a function of size is generally used. The simplest means of doing this is by grouping individuals into size classes with a conversion factor for each class (Wong, 2000). In more complex forms regression equations are used to relate yield to some easily measurable indicator of size, e.g. diameter at breast height for trees. Jong and Bonner (1995) for example used a simple linear regression to estimate bark weight for Pacific Yew.

They assumed the tree bole is conical and bark area calculated as surface area of cone. The equation is given as: Bark volume = area x thickness. Thickness (cm) = 0.2 + (0.005 d), where d is diameter at breast height in cm.

Bark weight = volume x 0.4 (dry weight / green volume conversion factor).

If more data are collected over longer period of time, then it is possible to increase the sophistication and accuracy of the yield estimation models. An example of such models is the development of multiple regression models to predict yield for berry. Here long term studies based on recurrent forest inventory data or growth and yield plots (PSPs) have been used together with site and climate variables to develop multiple regression models to predict areal yields for berry (see Saastamoinen *et al.*1998). Wong (2000) observed that though high annual variability in tropical fruit has been repeatedly observed this has not as yet been accommodated in any yield functions for tropical species. She found it ideal for studies of yield of ephemeral products such as fruit, leaves or offspring to be undertaken over a number of seasons and include some measure of site quality and antecedent and concurrent climatic data, especially rainfall.

3.4 Growth and productivity studies

Sustainable utilization of NTFPs would require reliable data based on the dynamics of the target species. 'The ideal would be to have data on population dynamics (recruitment, mortality, migration etc.), the growth rates and patterns of individuals in the population and a measure of productivity for the product being harvested' (Wong 2000). The importance of investigating the life cycle of the species over long time periods has been emphasised by Peters (1994, 1996) and this could be obtained through growth and productivity studies. However, most tropical NTFP studies have been short-termed and this militates against the long-term work required for growth and productivity studies (Wong 2000). As pointed out by Wong (2000) the methodologies for determining the dynamics and growth of NTFPs are relatively few in spite of their diverse nature. This she attributed to methodology being largely borrowed from forestry and, as such, is most suitable for trees and perennial plants. I will briefly describe in the next few sections of this work some of the methods which have been used for NTFP growth and productivity studies.

3.4.1 Permanent sample plots

Permanent sample plots (PSPs) establishment have been the conventional means of determining productivity of timber. PSPs are usually permanently demarcated areas of forest, often 1ha each (square or rectangle), subdivided into 20m x 20m contiguous subplots and are periodically measured. PSPs are usually maintained over at least five years and often longer. In PSPs individual trees are tagged, mapped, identified and measured for size (diameter) at fixed points (breast height, marked by paint) at periodic intervals (2-5 years) over long periods of time (more than 15 years) (Alder and Synnot 1992). According to Wong, (2000), PSPs are ideally suited to long-lived trees being managed for timber which accumulates very slowly (e.g. mm per year). The objective of the PSP protocol is the quantification of timber at many life stages of the target species as possible. Thus studies of phenology, seed, seedling and sapling dynamics are often omitted from timber PSPs because of the long intervals between enumerations and also because it is the growth performance of established trees that is the primary concern. Synnot (1979); Alder and Synnot (1992) have dealt with PSP practices in tropical countries in detail. However, Wong (2000) discovered that several studies have adapted tree PSP protocols for use with NTFPs. Contrary to timber PSPs which are more interested in adult tree growth rates, she found most NTFP studies to be more concerned with phenology (especially fruit and seed yields), and early establishment. Thus phenological observations are included in the protocols of these studies and use of very short observation periods (a week is common) to capture fruit dynamics. Double sampling and multi-stage sampling are often employed in NTFP-PSP studies to reduce cost and time for the inventory. Nested sub-plots (multi-stage design) are often used for seedlings and saplings while phenological observations are made on a sample of adult trees. The small size of plots means that there are sometimes insufficient adults for phenological observations because of small plot size and in such situations the sample of adults can be increased through double sampling (Wong, 2000). Peters et al. (1989), Peters (1990), Peters and Hammond (1990), Peters (1996b), Phillips (1993), Olmsted and Alvarez-Buylla (1995) are some examples of NTFP PSP studies on neotropical fruit trees, shrubs and palms. Wong (2000) has listed the protocols for fruit production used by these studies. Valkenberg (1997) also used PSPs to assess the growth of non-tree species, such as rattan. Wong (2000) found NTFP PSP studies to last for one to two years and this is short to acquire enough data to better predict dynamics in growth and productivity of the target species. However, some few long-term autecological studies have been done on palms (e.g. (Piñero and Sarukán 1982, Piñero *et al.*1982, Piñero *et al.1*984, Oyama 1990).

3.4.2 Experimental harvests

An experimental harvest is a form of experimental design to compare the productivity and dynamics of different harvesting intensities with unexploited controls. Experimental harvest studies tend to determine the impact of harvesting intensity and technique on productivity and dynamics of exploited populations (Wong, 2000). As experimental design, a distinction is made between the treatment plot and the measurement plot. The treatment plot is made larger than the measurement plot so that a buffer zone, which is treated but not measured, is created around the measurement plot. This is done to reduce the influence of conditions of the untreated area outside the plot on the measured plots (Alder and Synnnot, 1992). Experimental harvest designs must also have adequate replication of treatments and a control (Wong, 2000). The experimental approach has been used on a range of products heavily exploited on commercial bases e.g rattans (Valkenberg 1997, Ros-Tonen *et al.* 1998), palms (O'Brien and Kinnard 1996, Gómez 1998).

3.5 Sustainable harvest levels

Overexploitation has characterised most NTFPs utilised on commercial bases because sustainable harvest levels of the species in most cases are not known or adhered to. The concept of what is sustainable has been defined differently by different authors. For instance Hall and Bawa (1993) defined sustainable NTFP extraction in ecological terms as the level of harvest which has "no long term deleterious effect on the reproduction and regeneration of populations being harvested in comparison to equivalent non-harvested natural populations. Furthermore, sustainable harvest should have no discernible adverse effect on other species in the community, or on ecosystem structure and function." Although this definition includes all the ideals of sustainability, its demands were found to be impractical by Boot and Gullison (1995) in that natural forest exist as a mix and it is virtually impossible to remove anything without creating any noticeable changes. Hence they suggested a more pragmatic indicator of sustainable harvest which requires that there is no loss in species and no irreversible changes in ecosystem processes. According to Wong, (2000) the ideals of sustainability are translated into certain principles in practical terms. She stated that "a central premise used to determine the allowable harvest level is that harvest quotas for wild populations should not exceed a level that can be supplied by the population in perpetuity without damaging its vitality". She also observed that managers of natural forest have often taken this to mean that annual harvests should be constant and available in perpetuity. However, for yields to be made sustainable adjustments must be made to the extent and intensity of harvesting in accordance with the state of the resource but constant supplies are an artefact of the management regime. The productivity of many species that produce NTFPs is highly variable from year to year. Consequently, Wong (2000) regarded the concept of constant annual yields as inappropriate but defining a 'sustainable harvest' for many NTFPs would require innovative interpretations of detailed ecological knowledge supported by novel methodologies for studies of productivity and its successful exploitation. Many agree that exploitation of NTFPs be based on productivity and inventory data (e.g. Peters 1990, 1991, 1994, Hall and Bawa 1993, Shanker et al. 1996, Gould *et al.* 1998) and have led to the development of some quantitative and non-quatitative methodologies for 'sustainable harvest'. Wong (2000) has described some of these methods e.g. rapid vulnerability assessment, periodic harvest adjustments, matrix models etc. Matrix models seem to be frequently applied (Olmsted and Alvarez-Buylla, 1995; Pinard, 1993; Peter, 1990, 1991) and I will in the next section review and describe the application of matrix models as a tool to determine 'sustainable harvests.'

3.6 Matrix Models for predicting sustainable harvesting levels

A model is an abstraction or simplified representation of some aspects of reality (Vanclay, 1994). The long term productivity of exploited species depends on continued recruitment of new individuals as well as the productivity of the adults (Wong, 2000). This makes it imperative to investigate the effect of harvesting on the population dynamics of exploited species across the life cycle in order to establish the levels of harvesting that would have minimal impact on the population of the species to ensure sustainability (Peters, 1994, 1996a; Wong, 2000). Models are used to predict the life cycle dynamics of the species as a first step to determine the sustainability of harvesting levels (Wong, 2000). Wong (2000) noted that although growth and yield models are well developed for timber species, such models have only been recently adopted for NTFPs (see Olmsted and Alvarez-Buylla, 1995; Pinard, 1993; Peter, 1990, 1991).

Matrix model, a method of modelling the demography or life cycle of an organism, is the most widely used technique for determining sustainable harvesting levels for NTFPs (Wong, 2000). This technique was first devised by Leslie (1945) for use with animal populations. The method was later adopted for use by Lefkovitch (1965) to estimate finite population growth rates for insect. Usher (1966) also used matrix model to model tree population in a forest using diameter classes. Other investigators have recommended the use of matrix models for estimating sustainable harvest levels of NTFPs (Hall and Bawa, 1993; Peters, 1994, 1996a and Martin, 1994).

A matrix model uses the life cycle dynamics of a population to estimate future population of the species. According to Wong (2000) life cycle dynamics of a population consists of the action of growth, fecundity and mortality on the population. For each life stage there is a net effect of growth and mortality between time intervals with fecundity providing young ones. The data is arranged into a matrix as a life table model (see Peter, 1996a) to simulate the state of future populations. Life table models are composed of a square transition matrix describing the behaviour of the population and a column state vector, which gives the number of individuals in each life stage at any one time. Multiplying the transition matrix by the column vector yields the state of the population at one step into the future. Repeating the process with the column vector for time 1 gives the state for time 2, etc. The rows in both matrixes represent life stages in the organism with the first row representing seeds and the last, decrepit adults. The transition matrix is the square with the columns also representing life stages. The first row of the matrix is fecundity and the data represents the numbers of seeds produced by an average individual of each life stage. This is usually size-dependent in adults and it is obviously 0 for younger stages. The principal diagonal in the matrix is the probability of remaining in the same life stage from one iteration to the next and is calculated from growth and mortality rates. The sub-diagonal represents the probability of movement into the next higher stage at each iteration. Harvesting of different plant parts is simulated by changing fecundity (if fruits or seeds are removed) or mortality (if sap, leaves etc. are removed) and the model is run to determine if the population can withstand harvesting (Peters 1996a).

Sustainability is judged by deriving the dominant latent root (l) of the transition matrix which represents the intrinsic population growth rate. Stable populations have $l = 1$, growing populations are represented by $l > 1$ (getting denser) and diminishing populations by $l < 1$. Theoretically the maximum sustainable harvest from the population will be at the highest positive l when the population should be stable (Vanclay, 1994 quoting Usher 1966) and would ideally be $l = 1$. Peters (1996a) inferred that a population with $l \geq 1$ should be able to maintain itself under various degrees of exploitation with only minimal management inputs, while one with l <1 will require a greater intensity of management to ensure long-term sustainability of harvesting. Sensitivity analysis of l to changes in mortality or fecundity is also used to gauge the relative resilience of the population to different patterns and intensities of exploitation (Peters 1996a). However, there are reservations about this type of modelling. Vanclay (1994) hinted that the life history of plants can influence the value of l, such that, in an undisturbed forest, pioneer and light demanding species should have l <1, whilst shade tolerant species should have l >1. It is also not clear if l values are characteristic of a species, the present state of the forest or an artefact of the method.

Life cycle models require enumeration of flowers, fruit, seed stores and seedlings as well as consideration of the dynamics of processes such as pollination, fruit dispersal, fruit and flower predation, seed longevity and germination. Permanent sample plots (PSPs) with frequent observation intervals are necessary to capture flower and fruit production as well as germination which are often seasonal or periodic. Wong (2000) noted that most life-cycle PSPs for NTFPs have focused on few fruits and have been conducted for short periods (approximately 1-2 years). She thus criticised the adequacy of time period used for such studies as phenology and germination are highly variable, both between seasons and spatially within a single season.

Boot and Gullison (1995) have also criticised the use of uncalibrated matrix models for NTFPs in that they are empirical and need to be calibrated for all management scenarios and also iterated that the demographic data used were collected over short periods and the models do not incorporate density dependence functions.

In spite of their advantages of being relatively simple to construct, analyse and interpret and their suitability for modelling the dynamics of populations that are harvested without introducing a large change in the ecosystem (cf. Peters, 1990); matrix models may have the following drawbacks:

- not mechanistic (mechanistic models are individual based and appropriate for modelling the effects of harvest that cause large changes in the population and ecosystem structure);

- require many more data and greater understanding of the system. E.g. processes that determine mortality and recruitment;
- function within the range of conditions for which it has been parameterized and calibrated;
- must be calibrated for entire range of parameter space that will be modelled and this makes it impossible and impractical (Boot and Guillison, 1995).

4. Research site description

4.1 Location and demography

The Goaso forest district lies between latitudes 6° 27’ North and 7° 00’ North and longitudes 20° 23’ West and 2° 52 West. The total land area of the district is 2187.5km² with forest reserves covering 779.4km².

The population of the district is estimated at about 188,143 (projected from the 2000 census of 174,026 at a growth rate of 2.6%per annum). Farming is the economic activity of the area, employing about 70.1% of the labour force. Farmers grow mainly cocoa, oil palm, food stuffs and fruit crops. The main industrial activity is wood processing by saw mills which employ about 5.9%, services sector employs 9.6% and commerce 14.4% of the labour force (Asunafo district Assembly, planning unit, 2003)

4.2 Soil and Vegetation

The district is dominated by soil type locally classified as forest ochrosols. The forest ochrosols are by far the most extensive soils within the forest zone of Ghana. Typical forest ochrosols are mainly red and well drained on the upper horizons while the middle horizons are brown and moderately well drained. Forest ochrosols tend to be fertile, thus support the growth of tree crops like cocoa and also food crops. However, most of the nutrients are concentrated within the top 30-40cm where accumulation of organic matter has occurred over the years through the decomposition of plant biomass. Hence soil fertility easily decline through erosion and leaching if the soil is exposed directly to rain, wind and sun.

The vegetation is a semi deciduous forest type. There are six contiguous forest reserves which have been conserved over the years as permanent forest estate. Farming activities outside the reserves have modified the original forest vegetation into a mosaic of cocoa farms, arable lands and patches of secondary forests. Secondary forest proportion is on the decline partly due to the spread of *Chromolaena odorata* which colonises lands after clearing for crop production. *Chromolaena odorata* tends to grow faster than native pioneer species thus preventing natural regeneration of trees where it colonises. Wider areas of *Chromolaena odorata* fields exist in the off-reserve areas.

The district experiences the wet to semi-equatorial type of climate with mean monthly temperatures uniformly spread and ranging between 25° C and 30° C. The rainfall pattern is the double maxima type characteristic of southern Ghana with annual mean values ranging between 125cm and 175cm. The major rains occurs between April and July and the minor in September and October. There is a spell of drought in mid August and a prolonged dry season between November and March. Relative humidity is generally high ranging between 70% in the dry season and 80% in the rainy season.

4.3 Land use

Land use in the Goaso forest district is mainly forest and agriculture. The forests are mainly forest reserves and outside these forest reserves are the agricultural lands (off-reserves). I will briefly describe food crop and cash crop production in the agricultural lands.

Food crop is generally produced by small holder farmers on subsistence bases. Land preparation is through slash and burn. Here forestland or fallow land is slashed, trees felled and the debris burnt. Mixed cropping is usually practised (see Figure 4.1).

Figure 4.1: Early stage of a typical food crop farm in the study area.

Thus most monocrops (cash crops e.g. cocoa, oil palm) start as mixed cropping. Monocrop of maize and other crops are on a small-scale. When the farmer intends to use the land for cash crop production, e.g. cocoa, cocoa seedlings would then be interplanted with staple crops like plantain, cocoyam, cassava, maize etc. The food crops mature earlier and as they are harvested more space is created for the growing cocoa trees till the food crops recede, leaving a monocrop of cocoa, oil palm or fruit trees. Where only food crops are grown the land is left to fallow after all crops are harvested. The fallow period however, may differ from individuals but it is believed to have become shorter as agricultural lands have become scarce.

4.4 Major land cover types in off-reserves

The major land cover types identified in off-reserve areas of the Goaso forest district were classified into the following:

4.4.1 Annuals

Annual croplands consist of lands currently under production food crops or which show clear signs of recently harvested crops. Here, crops such as maize (*Zea mays)*, cassava (*Manihot esculenta*), plantain (*Musa paradisiaca*), and cocoyam (*Xanthosoma sagittifolium)* are mostly grown. These crops are mostly grown in mixed cropping but they could also be grown as mono crops. Cocoa seedlings may also be part of such a mixed cropping system. It should be noted that these crops are not always strictly annual, for example plantain and cassava can be left on the land for more than one year. However their characteristics in terms of tree cover are similar to real annual crops. In these lands, a few trees are observed because the crops do not cope well with much shade. Only large or highly important trees whose shade the crops could tolerate are left in the field. According to Amanor (1996) the trees farmers retain in their farms are usually the tree species that have some value to them.

4.4.2 Cocoa Farms

This land cover is characterised by mainly cocoa trees with bigger and taller trees, often forest species, left to provide some shade for the cocoa trees. Fruit trees such as *Citrus sinensis, Persia americana,* and *Magnifera indica* are often found in this land cover type. A minimum of two stories is observed, i.e., cocoa and fruit trees at the lower and bigger shade trees on the upper storey. In general many shade trees may be found in older cocoa farms than new ones. Farmers view was that the newer varieties of cocoa tolerate lesser shade and that could do better with lesser or no shade.

4.4.3 Shrub fallow

This is the 'young' fallow, it may be in rotation or not. Few trees are regenerating, some poles might be seen but especially shrubs (e.g. *Chromolaena odorata*) are dense and vigorous. The land may have been under fallow for about 1 to 5 years.

4.4.4 Tree fallow

Tree fallow has not been used for 5 or more years. Often such fallow lands may be intentionally left for people to collect their forest and wood products or may be forestland in transition or sacred groves. Tree fallow consist of a dense vegetation of young regenerated trees and a few old bigger trees. Secondary forest or patches of forest lands were included in this group.

The classification above was made according to cover types encountered using systematic cluster sampling. However, the sampling may have missed other cover types such as grasses or bare areas which may not be common in the area. The use of remote sensing technique could provide a more detailed classification of the cover types in the area.

5. Methods

5.1 Selection of species for the inventory

The species inventoried were first selected based on interviews conducted in six communities in the Goaso forest district. The communities were Ahwiawia, Gyasikrom, Chief Camp, Asuopere, Keyasi Camp, and Ntesere. These communities were randomly selected for the interviews. The selection was not meant to give a representative data of the study area but to give a fair overview of the species exploited as NTFPs. The survey took the form of door to door semi structured interviews. Males and females of randomly selected households of each selected community were interviewed. Goaso and Mim markets were also surveyed for traded NTFPs. The aims of the community and market survey were to obtain from local people NTFPs for subsistence use, income generation and to seek local knowledge on the ecology, distribution as well as history of availability of the species in off-reserves. Information on ecology, distribution and history of availability was to help in selecting appropriate methods and design for the assessment of the species. Based on the criteria of subsistence use and income generation, the species in table 5.1 were selected for the inventory.

The species were then divided according to their distribution. *Calamus deeratus* (rattan), Raphia and *Bambusa vulgaris* (bamboo) were found to be distributed mainly in patches along streams and rivers. Adaptive cluster sampling with a systematic base was designed to inventory the three species. A systematic base was used to allow comparison of the efficiency of systematic sampling and adaptive cluster sampling methods because systematic sampling is often used in forest inventories. The other species (consisting of trees and shrubs) were found to be scattered in other land cover types. The land cover types were identified as tree fallow, shrub fallow, cocoa farms and annuals. Detailed description of these cover types has already been given in chapter four. Systematic cluster sampling was designed to inventory the tree NTFP species as well as timber species. Before describing the sampling design, I would like to give a brief overview of the sampling methods.

Scientific Name	**Local Name**	**Habitat**	**Use**
Calamus deeratus	Demere	Patches around streams and rivers	Baskets, furniture
Raphia hookeri	Adobe	Patches around streams and rivers	Baskets, drying mats
Bambusa vulgaris	Pampuro	Patches around streams and rivers and long roadsides	Construction, handicrafts
Tetrapleura tetraptera	Prekese	Forest, Farmlands, Fallowlands	Spice, medicinal
Ricinodendron heudelotii	Wama	Forest, Farmlands, Fallowlands	Curving, medicinal, oil from seeds
Daniellia ogea / Guibourtia ehie	Hyedua	Forest, Farmlands, Fallowlands	Incense
Christiana africana	Sesedua	Forest, Farmlands, Fallowlands	Curving
Nauclea diderrichii	Kusia	Forest, Farmlands, Fallowlands	Curving
Spiropetalum heterophyllum	Ahomakyem	Forest, Farmlands, Fallowlands	medicinal
Rauwolfia vomitoria	Kakapenpen	Forest, Farmlands, Fallowlands	medicinal
Alstonia boonei	Nyamedua/Sinuro	Forest, Farmlands, Fallowlands	Medicinal, carving
Kola nitida	Bise	Forest, Farmlands, Fallowlands	Food
Strombosia glaucescens	Afena	Forest, Farmlands, Fallowlands	Construction
Margaritaria *discoidea*	Pepea	Forest, Farmlands, Fallowlands	Construction
Ficus exasperata	Nyankyeren	Forest, Farmlands, Fallowlands	Medicinal, Abrasive cleaners
Spathodea campanulata	Kuokuonisuo	Forest, Farmlands, Fallowlands	Medicinal
Chrysophyllum albidum	Akasaa	Forest, Farmlands, Fallowlands	Fruit

Table 5.1: Species selected for the inventory

5.2 Sampling methods

Sampling is usually preferred in forest inventory to complete enumeration due to reasons which have been explained by many authors (e.g. Schreuder et al. 1993, Johnson 2000). The sampling method and the design used in an inventory depend on the distribution of the species, the budget and the objectives of the inventory. This section gives an overview of some sampling methods which have been traditionally used for timber inventories and have been adapted for NTFP inventory as well as some novel sampling methods suggested to be efficient for NTFP inventory.

5.2.1 Systematic sampling

In systematic sampling, the sample units are spaced at fixed intervals throughout the population. According to Husch et al (2003), systematic sampling designs are widely used in forest inventory because they have a number of advantages:

1. They provide reliable estimates of population means and totals by spreading sample over the entire population. Thus systematic sampling provides a more representative sample than random sampling of the same size, especially when sampling a complex population. Since the complexity of a population usually increases as population size increases (e.g. sampling larger heterogeneous landscapes), systematic sampling would usually provide a more better relative representativeness of such populations than would a simple random sampling of the same size (Johnson, 2000). Johnson (2000) however, maintains that systematic sampling might not produce a representative sample of a population with periodicity[2].
2. They are usually faster and cheaper to execute than designs based on random sampling because the choice of sampling units is mechanical, eliminating the need for a random selection process.
3. Travel between successive sampling units is easier since fixed directional bearings are followed, and the resulting travel time is usually less than that required for locating randomly selected units.

[2] Periodicity occurs in a population if some trend occurs in a more or less regular manner. E.g. where topography and/or altitude controls species distribution and development. The interval of selection of sampling units in a systematic sample may follow this trend, thus making it unrepresentative.

4. the size of the population need not be known since units are chosen at a fixed interval after an initial point has been selected;
5. Mapping could be carried out concurrently on the ground since the field party traverses the area in a systematic grid pattern.

In forest inventory work, the systematic distribution of sampling units can be used with fixed area plots or strips, or points and lines in probability proportional to size (PPS) sampling. However, because the selected sampling units are not independent of each other, a systematic sampling is fundamentally different from simple random sampling (Johnson, 2000). Husch et al (2003) maintains that for the mean of a systematic sample to be unbiased, some form of random selection must be incorporated in the sampling process and that the only randomisation possible is the selection of one of the fixed sets of systematic samples. The set will depend on the selection of the initial sampling unit in the population. The initial sampling unit can be randomly selected out of the entire population of units or it may be randomly selected from the first *k*[3] units in the population. In either case, once the first unit is selected, all additional units are selected at an interval k. They ascertained however, that many forest inventories start a set of systematically distributed sampling units at some easily accessible, arbitrarily chosen point (point specified by the designer of the inventory), assuming negligible bias in the resulting estimate of the mean. According to Johnson (2000), this arbitrary chosen position is in most cases the midpoint of first k sets of sampling units. He illustrated that in most line-plot timber inventories sampling lines are drawn parallel to the tract boundary, a cardinal direction, or so as to cross, at right angles, the major streams and ridges within the tract. The first of these sampling lines is located at half the sampling line spacing from the left-most point on the tract boundary, which is usually the westernmost point. The first plot on that line is located at the point that is half plot interval from either the upper (usually the northern) or the lower (usually the southern) tract boundary. The position of the set of plots is fixed by this process.

5.2.2 Cluster sampling

In cluster sampling, sampling units consist of a group of smaller units (recording units) located around a centre in a fixed configuration. The group of subplots (clusters) forms the sampling unit (Husch et al 2003). The clusters can take on a multitude of different

[3] k represents the interval of selection of sampling units.

configurations, depending on the number of subplots, the distance between units, and the geometric distribution. Husch et al. (2003) has illustrated some of the common cluster configurations. The configuration used in any specific situation depends largely on the nature of the sampling problem and the universe of interest. Multistage sampling can be applied to cluster sampling. When the sampling process is limited to drawing primary clusters (cluster locations selected from a set of locations), it is referred to as simple, one-stage, or single-stage cluster sampling. However, in two-stage cluster sampling a subsample of clusters is selected from primary clusters and this subsample measured. There is no limit to the number of stages that can be used if subsample units are available to form clusters (Johnson, 2000). In either single or two-stage cluster sampling etc, the number of clusters per location and the number of subunits in clusters may be similar or differ. For example probability proportional to size (PPS) sampling could be used at the subunit. As noted by Johnson (2000) equal-sized clusters provide advantages in some cases but equality of cluster size is not essential. The method of selecting cluster locations may be random or systematic.

Johnson (2000) offers the following reasons that make cluster sampling procedure attractive for an inventory:

- When the area to be inventoried is large and /or sampling units are widely dispersed and/or difficult or impossible to identify or locate single sampling units;
- When time and costs associated with travelling between and location of single sampling units becomes excessive.

This study used single-stage cluster sampling with equal cluster size and I provide statistics for single-stage cluster of equal size as given by Husch et al. (2003). However, Cochran, (1977) provides procedure for analysis of two-stage cluster sampling and unequal clusters sizes.

Let n = number of clusters

M = number of subunits per cluster

y_{ij} = value of parameter (e.g. volume) for jth subunit of the ith cluster

$y_i = \sum_{j=1}^{M} y_{ij}$ = total for jth cluster

$\bar{y}_i = {}^{y_i}\!/\!_M = \sum_{j=1}^{M} {}^{y_{ij}}\!/\!_M =$ mean of subunit of ith cluster

$\bar{y} = \sum_{i=1}^{n} y_i / n =$ estimated sample mean cluster

$\bar{\bar{y}} = \sum_{i=1}^{n} y_i / nM = \bar{y} / M =$ estimated mean subunit

The variance among subunits has two components and is estimated by

$$s^2 = \frac{(n-1)s_b^2 + n(M-1)s^2_w}{nM-1}$$

where s^2_b is the variance between clusters and is estimated by

$$s^2_b = \frac{\sum_{i=1}^{n} (\bar{y}_i - \bar{\bar{y}})^2}{n-1}$$

and s^2_w is the variance within clusters is estimated using

$$s^2_w = \frac{\sum_{i=1}^{n} \sum_{j=1}^{M} (y_{ij} - \bar{y}_i)^2}{n(M-1)}$$

Statistical efficiency of cluster sampling

Statistical efficiency of is measured by the magnitude of the standard error of the mean or total and the cluster sampling design must strive to keep this value as small as possible (Johnson, 2000).This can generally be achieved by using sampling units that include within themselves as much of the heterogeneity of the population as possible to minimise the differences between the sampling units. In conventional timber inventory, this can be accomplished by using either large sample plots, or if plot size is to be held constant, by using rectangular rather than circular plots. By covering larger areas, large plots include more diverse conditions (e.g. differing stand densities) than small plots. Rectangular plots include more conditions than similarly sized circular plots because they are less compact and extend laterally across greater distances (Johnson, 2000). According to Johnson (2000) this idea of including population heterogeneity within the clusters and keeping heterogeneity between the clusters at a minimum must be applied to cluster sampling design so that fewer sampling units would be needed to meet an allowable standard error requirement. Intracluster correlation is used to measure the degree of homogeneity within clusters and it is an important statistic to determine the efficiency of cluster sampling or the optimal cluster size (Schabenberger, 1991). Secondly, the cluster configuration must be such that field operations are kept as simple and convenient as possible. This implies that the units making up a cluster should be in relatively close proximity to one another. This requirement is found to conflict with the earlier condition since the elements are rarely randomly distributed and elements that are close to one another are more likely to be similar than elements that are far from one another (Johnson, 2000). Hence when designing a cluster configuration, trade-offs must be made. Whether statistical efficiency or sampling convenience dominates the trade-off depends on the situation (Johnson, 2000). Calculating autocorrelation between and within clusters could be a tool to help in the trade-off decision.

The next section will describe adaptive cluster sampling as a form of cluster sampling in which the number of sampling units per cluster depends on the observations made.

5.2.3 Adaptive cluster sampling

Adaptive cluster sample designs are in marked contrast to conventional sampling designs, in which the probabilities for selecting samples do not depend on any observed population characteristics.

Density of rare and clustered populations is difficult to estimate precisely using conventional sampling designs. For such rare and clustered populations, adaptive cluster sampling has been found to be appealing because survey efficiency could be maximised compared with more conventional designs such as simple random sampling (Thompson and Seber, 1996; Christman, 1997; Brown, 2003). The purpose of adaptive strategies is to take advantage of population characteristics to obtain more precise estimates of the population parameters with a given amount of effort. According to Thompson and Seber (1996) many populations of animals and plants have aggregation tendencies due to such factors as schooling, flocking, dispersal patterns, and environmental patchiness. Often, the location and shape of the aggregations cannot be predicted before a survey, making traditional means of increasing precision such as stratification insufficient. For such populations, adaptive sampling strategies have been found theoretically to provide a way to dramatically increase the effectiveness of sampling effort (Thompson, 1990, 1991). Subsequently there have been various applications of adaptive cluster sampling in the field of biology, ecology and environmental studies (e.g. smith et al. 1995, Keith 2000, Vasudevan et al. 2001, Smith et al. 2003). Yue et al (2004) also applied the adaptive cluster sampling procedure to assess the density of ant nets in the city forest of Freiburg. They found adaptive cluster sampling to be more efficient than simple random sampling. However, few applications have been done in forestry to assess plant populations. For example, Acharya et al (2000) assessed rare tree species in Nepal using systematic adaptive cluster sampling and found that for clustered species the efficiency for density estimation increased as much as 500% but for unclustered species it decreased by 40%. Besides Acworth (1999) used adaptive cluster sampling to assess the density of *Prunus africanus* in Cameroon and found it more efficient than random sampling. The relative efficiency of the adaptive cluster procedure to conventional sampling methods has been found to depend on certain factors and these are considered in the next section.

5.2.3.1 Factors influencing efficiency of Adaptive cluster sampling

The relative efficiency of adaptive cluster sampling to conventional sampling methods depends on several characteristics of the population, the design, and cost (Thompson and Seber, 1996). The following characteristics tend to increase the efficiency of adaptive cluster sampling relative to simple random sampling:

- The within-network (or within cluster) variance is close to population variance, which occurs when the population is clustered or having aggregation tendencies (Thompson, 1990; Smith et al., 1995; Thompson and Seber, 1996)
- The population is rare. This implies that the number of units in the population is big relative to the number of units satisfying the condition for neighbourhood sampling. Also the study region is big relative to the area in which the animals or plants would be encountered (Thompson and Seber, 1996).
- The expected final sample size is not much larger than the initial sample size. With a larger initial sample, the ratio of the expected final sample size to the initial sample size tends to be smaller. In a situation where units in a population satisfying the condition for neighbourhood sampling are all detached from each other, adaptive cluster sampling would be less efficient relative to simple random sampling. In this situation the within-network variance is zero and adaptive sampling adds only edge units. These increase the sample size but do not contribute to the precision of the estimators (Thompson and Seber, 1996);
- The cost of observing units in clusters or networks is less than the cost of observing the same number selected at random throughout the study region;

- The cost of observing units not satisfying the condition is less than the cost of observing units satisfying the condition;
- In some cases, cost savings may be achieved by basing the condition additional sampling on an easy-to-observe auxiliary variable so that the variable of interest does not need to be measured on edge units (Thompson and Seber, 1996).

As has been described above the efficiency of adaptive cluster sampling depends on degree of rarity and clustering of the population, which is unknown prior to sampling, and the final sample size is random, which adds uncertainty to survey planning. However, if and when a population is sufficiently rare and clustered for adaptive cluster sampling to be efficient remain an open question (Smith et al., 2003). This implies that adaptive cluster sampling if misapplied could result in failure to achieve the desired efficiency or a final sample size that exceeds a survey's budget. Excessive final sample size can result when the biological population is not as rare as or is more widely distributed than anticipated resulting in a situation which practitioners of adaptive cluster sampling refer to colloquially as encountering "the cluster from hell" (Smith et al., 2003). Thus the choice of the neighbourhood and critical value is important in adaptive cluster sampling. If the critical value is set too low when sampling a particular population the final sample size will be excessively large because the networks that are formed will span many units (Brown and Manly, 1998). If the critical value is too large there may be no adaptive selection of units if no unit in the initial sample has a value that reaches the critical value. Similarly, if the neighbourhood definition is too large the final sample size will be excessively large and if it is too small there may be little adaptive selection of units. Brown (2003) maintained that there is no clear definition of how to choose the neighbourhood and critical value. Many works have thus focussed on limiting the final sample size using different strategies (Brown and Manly, 1998; Thompson and Seber, 1996; Salehi and Seber, 1997). The next section will seek to review some of these strategies.

5.2.3.2 Strategies for limiting sample size and dealing with unexpected exigencies

As has been revealed in the previous sections, adaptive cluster sampling tends to be most efficient when the population is rare and clustered and the final sample size tends to be proportionally not too much larger than the initial sample size. Practically however, one could underestimate the abundance and range of the population in setting the condition for extra sampling making a rigorous adherence to the adaptive procedure adding more units than time or cost allow. The exact design unbiasedness of the adaptive sampling estimators depends on inclusion in the sample of the neighbourhood of every sample unit satisfying the condition. If sampling is curtailed prematurely, biases may arise (Thompson and Seber, 1996; Su and Quinn, 2003). The same problem arises in conventional sampling when the entire selected sample cannot be obtained. For example where inaccessibility of an area makes it impossible to measure plots in those areas in a forest inventory and biases arise if the completed part of the sample is not representative of the population as a whole. The following guidelines and suggestions have been offered as ways of limiting the total sampling effort in adaptive cluster sampling:

- Stratification of the study area into a number of strata. The study area is stratified into a number of strata ahead of the survey. The neighbourhood definition and critical values are modified if necessary based on the results in the strata already completed e.g. time spent, abundance observed, variance estimated or other criteria (Thompson and Seber, 1996; Brown, 1996a). Each stratum could have a different design and design unbiased estimators of the stratum population total and of estimation of variance depend on the design used in that stratum. The stratified estimate of the population total is the sum of the individual stratum estimates, and the estimate of its variances is the sum of the individual stratum variance estimates (Thompson and Seber, 1996). Selehi and Seber (1995) also suggested two-staged design where the population is partitioned into primary units. Within a selection of a primary unit, secondary units are selected by adaptive sampling. More primary units can be added to the sample if a large critical value has been used and few units have been adaptively selected. However, Su and Quinn (2003) ascertained that stratification could supplant the anticipated efficiency that ordinary adaptive cluster sampling was intended to provide;
- Using poststratification. This is where the data is stratified during the estimation stage. The initial conventional probability sample would provide an unbiased estimate of the population mean if no adaptive sample were planned at all. Thus priority is given to the initial sample. It is always desirable for cost purposes to do adaptive sampling in sequence whenever a unit satisfies the condition, with travel beginning generally from one side of the study area to the other. If at some point of the survey it is determined

that time remains only to finish the initial sample, then all adaptive sampling should stop at that point and the initial sample should be completed. For estimation purposes the population could be post stratified so that one stratum is represented by the adaptive part of the survey and the other stratum is represented by the part of the population sampled conventionally. An adaptive cluster sampling estimator is used in the first stratum and a conventional estimator in the second. The two estimates, along with the two estimate of variance can be combined as in traditional stratified sampling. In general, if the condition for extra sampling is modified one or more times during the survey then the region should be post stratified, with each stratum representing an area within which a given condition was used. The separate stratum estimates may then be combined as stratified estimates. This procedure would be exactly design unbiased had the strata been delineated ahead of time (Thompson and Seber, 1996);

- Selection by order statistics. Where prior knowledge of the population is too weak for the selection of a suitable condition on which to base the extra sampling, the condition can be based on order statistics. This is where adaptive sampling could be carried out in the vicinity of units with the highest values in the initial sample rather than in the vicinity of every observation exceeding a prespecified level. For example, units with highest values in a group of every five initial units are adaptively sampled. Brown (1996a, b) suggested the surveying of all the initial units in the sample and the critical value is set based on the values obtained e.g. the top 10 percentile is used as the critical value (Thompson, 1994). The disadvantage of this approach is that units in the initial sample that do have a value greater than the critical value have to be revisited to conduct the adaptive selection of neighbouring units. In many ecological surveys, such as sampling in a dense forest, this may be impractical or costly (Brown, 2003). Su and Quinn (2003) also maintained that having a criterion based on the data may make adaptive sampling more feasible by regulating the number of adaptive units added to the sample. They however noted that this condition now changes the criterion for adaptive sampling with each sample and hence the networks of neighbouring units meeting the criterion vary from sample to sample thus making the efficient Horvitz-Thompson estimator no longer unbiased. However, Thompson, (1996) provides unbiased estimator similar to the less efficient Hansen-Hurwitz estimator;

- Brown (1994) describes a way of controlling sample size in an adaptive sampling in which selection of units for the initial sample continues sequentially until a specified sample size is reached. A unit is selected each time and observed with associated adaptive additions. If the cumulative total number of units in the sample is below a specified sample size limit, the next initial unit is added and associated adaptive additions carried out. This continues till the cumulative total sample size equals or exceeds the sample size limit. The final sample size can then vary only by the cluster associated with the last selected sample unit. However, this strategy of sequential selection of initial sampling units as observed by Thompson and Seber (1996) introduces a bias into the estimates of the population total. Although this method controls the overall sampling effort, the need to sequentially select initial units at random preludes using the most efficient travel path between selected units in the study area.

- ‘Partition neighbourhoods’. This can be used to limit the potential size of the networks by partitioning the study area into regions or blocks and use a rule that no cluster can spread into a neighbouring block, hence any adaptive addition to the sample stop at these partition boundaries (Thompson, 1994; Thompson and Seber 1996);
- Neighbourhoods can consist of systematic grids of units rather than contiguous units, so that the resulting networks will be constrained to be spatially sparse (Thompson and Seber 1996);
- Utilizing information from a pilot survey as described by Salehi and Seber (1995).

5.2.3.3 Estimators of Adaptive cluster sampling

There are two estimators of adaptive cluster sampling method:

- Horvitz-Thompson (HT) - An estimator using initial intersection probabilities;
- Hansen-Hurwitz (HH) - An estimator using numbers of initial intersection.

The two estimators have been extensively examined. The main difference between the HT and HH estimators is that the HT estimator is based on inclusion probability of each unit *i* in the population whiles the HH estimator is calculated by taking a simple random sample of size n_1 from a population of w_i values (Thompson, 1990; Salehi, 2003). Thompson (1990) presented modified HT and HH estimators designed for unbiased use in the adaptive cluster method. The modified HT estimator has been found to have smaller variance estimates and thus more efficient than the modified HH estimator. The two estimators are however, more efficient than simple random sampling (Salehi, 2003; Yue et al., 2004). The formulas for the estimators are presented below.

Horvitz-Thompson estimator (HT)

The following notations as used by Thompson and Seber (1996) will be used:

- Let N be the number of sampling units in the population;
- y_i be observations made in sample unit i. E.g. the number of raphia palms in unit i;
- A_i be the network for unit i;
- m_i be the number of sampling units in A_i;
- C be the condition when satisfied, that sample unit's network is added to the sample;
- a_i be the total number of sampling units in networks of which sample unit i is an edge unit. If unit I satisfies C then $a_i = 0$. If unit i does not satisfy C then $m_i = 1$.
- n_1 be the number of networks in the sample.

The partial inclusion probability of unit i in the sample is

$$p_i' = 1 - \left[\binom{N - m_i}{n_1} \Big/ \binom{N}{n_1} \right]$$

An unbiased estimator of the population mean is given by

$$\hat{m} = \frac{1}{N} \sum_{i=1}^{N} \frac{y_i I_i'}{p_i}$$

where I_i is an indicator variable that takes the value of 1 if the initial sample intersects with A_i and 0 otherwise.

The variance can be calculated from

$$\mathrm{var}(\hat{m}) = \frac{1}{N^2} \left[\sum_{j=1}^{K} \sum_{k=1}^{K} \frac{y_j y_k}{a_{jk}} \left(\frac{a_{jk}}{a_j a_k} - 1 \right) \right]$$

where y_k is the sum of the y values for the kth network, K is the total number of distinct networks in the population, k is the number of distinct networks in the sample, j_k is another indicator function that takes the value of 1 if the initial sample intersects with the kth network and 0 otherwise. a_j, a_k is the probability of intersection of the jth and kth networks with the initial sample respectively.

Hansen-Hurwitz (HH) estimator

An unbiased estimator of the population mean is given by

$$\tilde{m} = \frac{1}{n_1}\sum_{i=1}^{n_1} w_i$$ where w_i is the mean of the m_i observations in A_i.

The variance is calculated from

$$\mathrm{var}(\tilde{m}) = \frac{N - n_1}{Nn_1(n_1 - 1)}\sum_{i=1}^{n_1}(w_i - \tilde{m})^2$$

For complete derivation of formulas for the estimation of the population mean and variance, reference is made to Thompson (1990) or Thompson and Seber (1996).

5.2.4 Ranked set sampling

Statisticians have over the years recognised the need to explore more cost-effective sampling procedures for estimating variables of interest difficult to measure with the more traditional simple random sampling. These cost-effective methods are said to have observational economy and tend to be more desirable in environmental and other applications because of their ability to provide same information with fewer observations (Ross and Stokes, 1999). Ranked set sampling which was originally suggested by McIntyre (1952) can provide observational economy where the variable of interest is difficult to measure but it is possible to make an economical assessment of the rank order of potential outcomes.

The ranked set sampling technique consists first of drawing n random samples from the population, each of size n, and ranking each of the n samples by visual judgement or other process. Then the smallest observation from the first sample is chosen for measurement, as is the second smallest observation in the second sample. The process continues in this way until the largest observation from the nth sample is measured, producing a total of n measured observations, one from each order class. The entire cycle is repeated m times until a total of mn^2 observations have been drawn from the population but only mn have been measured. These mn observations are referred to as the 'ranked set sample' (see Figure 5.1). Accurate judgement ordering of a large number of observations would be difficult in most experimental situations (Stokes, 1980). To minimise ranking error, Stokes (1980) suggested an increase in the sample size by increasing m, the number of replications rather than n. Since the cost of choosing and ordering observations is presumed to be negligible in comparison with measurement, estimators based on a ranked set sampling of size mn are comparable with those from random samples consisting of the same number of measured observations, namely mn rather than mn^2.

As an illustration, consider a set size of n = 3 with m = 4 cycles. This could be illustrated as in Figure 5.1, where a row represents a judgement-ordered sample within a cycle and the units for quantitative analysis are circled. Although 36 samples were randomly selected in 4 circles, only 12 were measured and analysed as the ranked set samples.

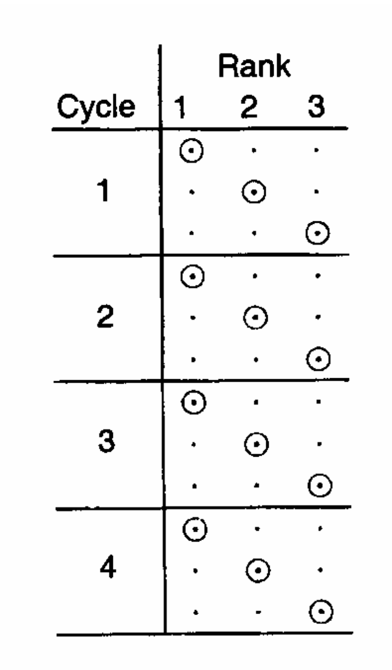


Figure 5.1: A ranked set sample design with set size n = 3 and number of sampling cycles m = 4.

Although 36 sampling units have been selected from the population, only the 12 circled units are actually included in the final sample for quantitative analysis

Application of Ranked set sampling

McIntyre (1952) applied ranked set sample to successfully estimate mean pasture yields without actually carrying out the time-consuming process of mowing and weighing the hay for large a number of plots. The method seemed not to have been applied till about the middle of the 60's when Halls and Dell (1966) used the technique to estimate the mean height of trees in a forest. In recent years however, ranked set sampling has seen more applications and in environment and ecology. Example of application of ranked set sampling among others, Halls and Dell (1966), Gore et al., (1994), Johnson et al. (1993), Patil et al. (1993) and Cobby et al. (1985). Chen (1999) sees a potential for the method to be applied in other areas such as industrial statistics and sociology. Stokes and Sager (1988) also found ranked set sampling as a potential technique for estimating volumes of trees in a forest and also data collection for determining the consumer price index. The application potential and observational economy of ranked set sampling could be the reasons for the upsurge of interest in literature as observed by Ross and Stokes (1999), e.g. Stokes and Sager (1988), Patil et al. (1993) Patil et al. (1994), Bohn and Wolfe (1992, 1994), Kvam and Samaniego (1994), Hettmansperger (1995), Stokes (1995), Chen and Bai (1998), Chen (1998a, 1999). Yu and Lam (1997) observed that ranking of units may not be done perfectly in most situations of rank set sampling. Many studies have investigated the implications of imperfect ranking on the relative precision of the ranked set sampling procedure. For example, using judgement order statistics Dell and Clutter (1972) showed that regardless of ranking errors the ranked set sample estimator of the population mean is unbiased and at least as precise as simple random sample estimator with the same number of quantifications. Others have considered studies where ranking is done using a numerical covariate or a concomitant variable (David and Levine, 1972; Stokes, 1977). Nevertheless, ranked set sampling would require more theoretical development as well as application to NTFP problems (Wong, 2000).

Although ranked set sampling is described as part of this study, it was not applied in the sampling design. A land cover map or a classified satellite image was needed to make objective ranking of plots according to cover types possible. However, no suitable cover map for the study area was available.

5.3 Sampling designs for the Inventory

The species inventoried by the study were grouped into two according to their distribution. *Calamus deeratus*, raphia and bamboo were found to be distributed in patches around streams and rivers. These species were also found to be clumped species. Adaptive cluster sampling was used for these species because it was found to be the appropriate method in view of the given characteristics of the species. The method was thus designed and tested for its efficiency for inventorying the three species in a pilot study and used in a subsequent main inventory. The tree species used as NTFPs (Table 5.1) but are scattered on the different cover types were inventoried using systematic cluster sampling. This method was found to be the most desirable due to the large size of the study area and the funds available for the inventory. I will describe the two designs in the next sections.

5.3.1 Adaptive cluster sampling with a systematic base

Adaptive cluster sampling with a systematic base was designed to inventory the three species; bamboo, rattan (*Calamus deeratus*) and raphia palm, distributed in patches around water bodies. A systematic base was used so that the efficiency of the systematic sampling design could be compared with the adaptive cluster design. The area was stratified using streams and rivers as basis on the assumption that the species to be inventoried are concentrated in patches around streams and rivers and any bias here is negligible. Two percent of the streams and rivers in the study area were selected randomly using Arcview (see Figure 5.2)

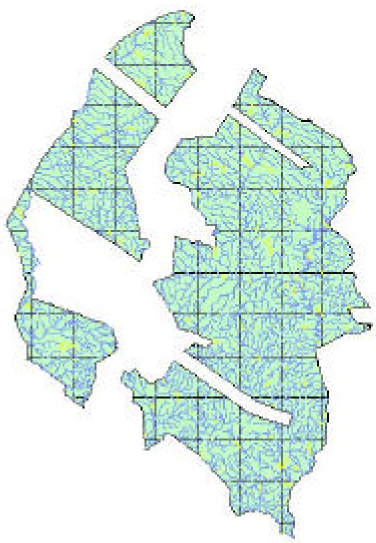


Figure 5.2: Selection of streams and rivers for the inventory.

The yellow lines in the figure represent streams and rivers selected.

At a randomly selected starting point on each selected stream or river, 50m x 50m plots were located on both sides of the stream or river. Systematic plots of the same configuration as the first were then laid along the stream on both sides of the starting point at 500m interval. Sampling along each stream was done with a rule that if no observations were found in five consecutive plots, the site is abandoned. A total of 63 systematic plots were observed. Where an observation of any of the species of interest is made, 50m x 50m adaptive adjoining plots are made till a network of plots with zero observation edge units is formed (Figure 5.3)

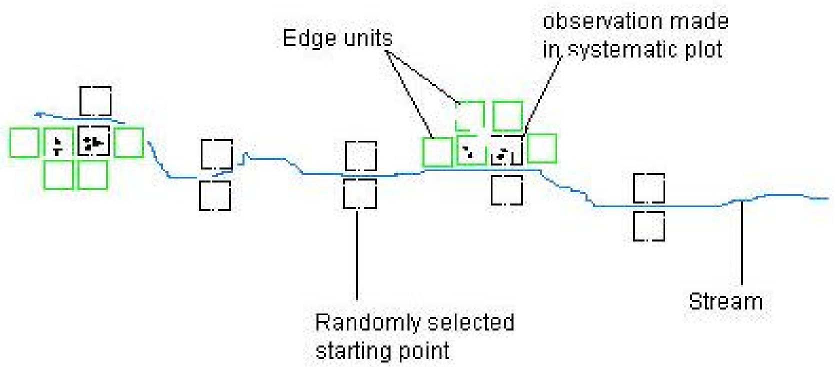


Figure 5.3: Illustration of the sampling design for the systematic adaptive cluster sampling.

Plots with green outline are the adaptive plots.

The number of clumps of bamboos, the base area of each clump, number of culms in each clump and the average diameter of culms in each clump were taken. The base area of each bamboo clump was determined by measuring the orthogonal clump base dimensions. The number of culms in each clump was counted and this was used to form a linear regression model to determine whether the clump base area could be an appropriate predictor of the number of culms in a bamboo clump. For rattan and raphia palms, the numbers of plants were grouped into mature and immature. In the case of the rattan (*Calamus deeratus*) canes less than 3m length were considered immature while those of 3m length or more were considered mature. With the raphia, palms of less than 3m height were considered immature while those above 3m lengths were considered mature. Estimates were calculated using the Hansen-Hurwitz estimator. Although the Hansen-Hurwitz estimator is less efficient than the Horvitz-Thompson estimator, they are both superior to simple random sampling (Yue et al 2004). Since the objective of the study was to compare the efficiency of adaptive cluster sampling with systematic sampling, which is based on simple random sampling, any of the two estimators could be appropriate. The data was analysed using Excel.

5.3.2 Quantifying the number of culms in a bamboo clump

Bambusa vulgaris occur in clumps and the sizes of clumps vary. A measure of the clump dimensions at canopy extent has been used by Widmer (1998) to estimate bamboo biomass. The culms are however the utilisable parts of bamboo and their numbers in a clump could also be essential in quantifying bamboo. Counting the number of culms in a clump could be time-consuming and tedious but determining the clump base area on orthogonal axis could be relatively easier and faster. Therefore a valid linear regression model using base area of bamboo clump as a predictor variable and the number of culms as the response variable could make the estimation of the number of culms in bamboo clump relatively easier. To make a linear regression model for estimating number of culms in a bamboo clump, clump base area was determined by measuring clump base dimensions on orthogonal axis (Figure5.4) and the number of culms in each counted. 55 bamboo clumps were enumerated and the data was used to form a linear regression model to test the validity of using bamboo clump base as a predictor of number of culms in the clump.

For the linear regression model to be valid it must satisfy the assumptions that the standardised residual values have no outliers, data points are independent and the residues must be normally distributed. There are no outliers when the minimum and maximum standardised residual values do not exceed ±3. The Durbin Watson estimate was used to check for independence of residues. Values around two means the data points are independent, values near zero means strong positive correlations whiles values around four means strong negative correlation. A histogram and a normal distribution plot are used to envisage if residues are normally distributed.

Figure 5.4: Determining the base area of bamboo clump

5.3.3 Systematic cluster sampling design

Tree resource off-reserve was assessed using systematic cluster sampling. This method was chosen because the area was large and time and cost associated with travel between single sampling units could be excessive. The area was also found to be of mosaic land cover and an initial stratification according to the cover types could have made sampling more efficient. However, in the absence of a land cover map of the off-reserve areas, a systematic grid was used.

A 7km by 7km square grid was overlaid on a geo-referenced map of the Goaso district. Global position system (GPS) coordinates of all grid points in off-reserve areas were taken. A Garmin II GPS was used to locate each of the grid points. At each grid point a 50m x 50m plot was demarcated and all tree species above 10cm diameter at breast height (DBH) were measured with a diameter tape. Diameter of trees with large buttresses was measured 30cm above the buttress. Land cover type within sample plots were identified and grouped into Cocoa farms, Annuals, Shrub fallow and Tree fallow. Three other satellite plots were made such that four 50m x 50m plots lie at the corners of a 100m square (Figure 5.6). Plots and cluster configurations were chosen considering tree population variability within off-reserve areas so as to include as much as possible population heterogeneity within clusters but reduce travel time between cluster plots. This was done so as to improve the statistical efficiency as already described by Johnson (2000). For plots which fell on tree fallows, a 10m x 10m plot was made from a corner of each of the 50m x 50m plots to access regeneration (see Figure 5.5). Regeneration could not be observed in shrub fallows as they were mostly covered by *Chromolaena odorator* that suppressed any regeneration. In annual and cocoa farm, tree regeneration is treated by farmers as weed and is removed during weed control. Tree species with DBH less than 10cm to saplings of 1m high and above were considered as regeneration. In all 128 plots were sampled. The data was analysed using Excel and presented with descriptive statistics.

Post stratification of the cluster plots according land cover types resulted in single units of different clusters occurring in different land cover types making the number of plots per cluster vary. The sample sizes of the different land cover types were thus different resulting in different precision levels in each cover type. Thus pre-stratification using a land cover map could be more appropriate and efficient.

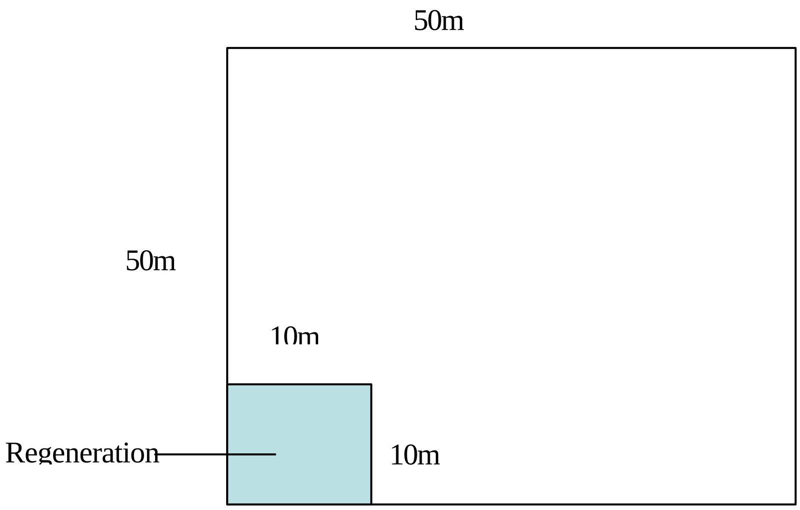


Figure 5.5: Plot configuration for regeneration

Also autocorrelation between and within clusters or intracluster correlation coefficient was not considered because the most efficient design in this case was not an objective of the inventory and financial constrains could not allow that.

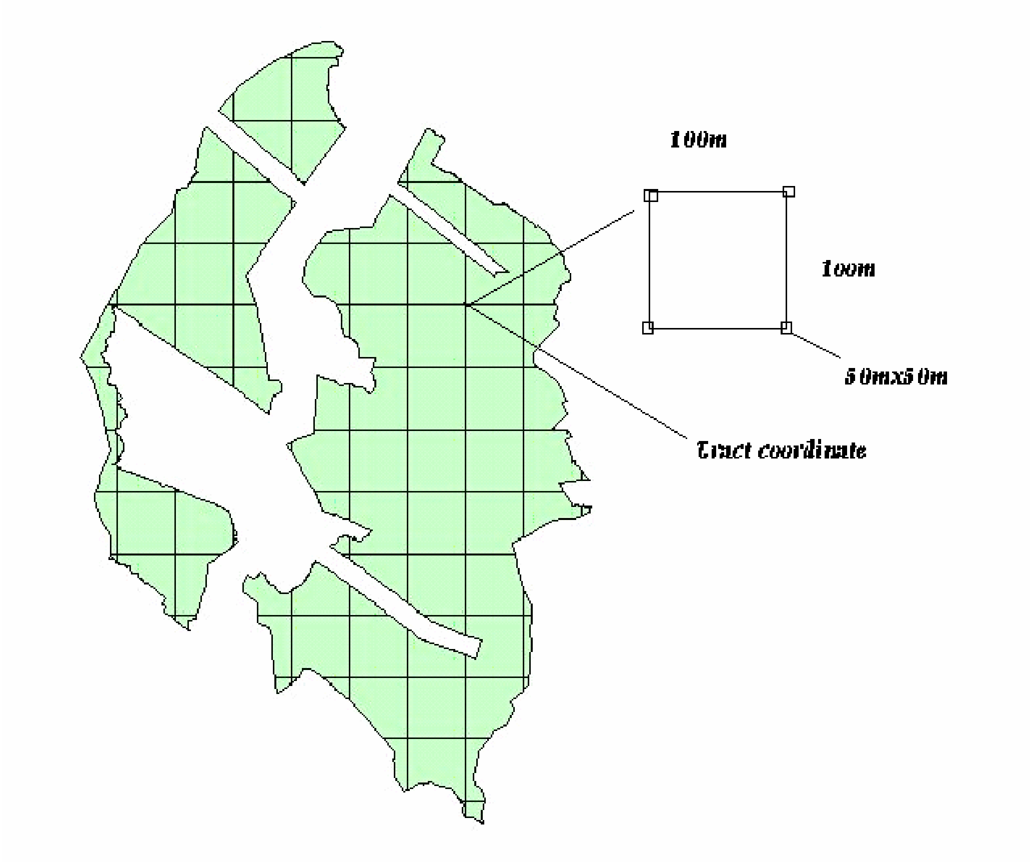


Figure 5.6: The systematic cluster design

5.4 Confidence limits

In forest inventory, sample data is used to obtain a point estimate of a population parameter. When the population is sampled several times, different values of the same statistic are obtained but yet they are all estimates of the same population parameter. The variation between the individual estimates is due to sampling error. Sampling error is the result of some samples per chance having more of larger units whilst others having more of smaller units. (Fowler et al., 1998). This means that in a collection of small samples drawn from the same population, some values of the statistic underestimate the parameter and others overestimate it. Sampling error is a reflection of the random variation inherent in any sample. To consider the variation in estimates of the same population parameter, estimates are usually represented as an interval estimate instead of a point estimate. This interval is quoted with a probability level at which we can be reasonably confident that the population estimate lies in this interval. The interval is thus referred to as confidence interval. The width of the interval is an indicator of the precision of the estimate; the smaller the width the more precise the estimate and the wider the width the more imprecise the estimate. The width of the confidence interval depends on the following factors:

- the sample size (n). Larger sample size usually yields smaller error and hence a smaller width of the interval;
- variability among the units (measured by the standard deviation). The greater the variability the greater the width of interval;
- the level of confidence. The greater the confidence the greater the width of the interval (Rees, 2001).

The confidence interval has a lower and upper boundaries referred to as confidence limits that define the width of the interval. The confidence interval (CI) is expressed by

$$\text{CI} = p \pm t.s_p$$

Where $p =$sample mean, t = value of t for a chosen probability level (Student's t distribution), $s_p =$standard error of the mean given by $s_p = \frac{s}{\sqrt{n}}$ where s = standard deviation and n= number of samples.

6. Results

The first part of the results of this study compares the efficiency of adaptive cluster sampling method with systematic sampling method for inventorying 3 species. The result of a linear regression model as a means of quantifying the number of calms in bamboo clumps is also presented. The second part deals with the abundance of other species scattered in other land cover types. The results are presented with tables and graphs.

6.1 Efficiency of systematic sampling method and systematic adaptive cluster sampling

Efficiency of a sampling method may be described as the ability of the method to yield relatively lesser variation in the estimates of the population when sampling is repeated. This may be referred to as statistical efficiency. Statistical efficiency could be measured by the sampling error. Theoretically statistical efficiency could be improved by increasing sampling intensity. Increasing sampling intensity would lead to more time being required for the inventory and hence higher cost and uneconomic. Therefore a sampling method would be more suitable for inventorying a population if the sampling error and time required for the inventory are relatively lower. I present in this section results of this study comparing both statistical and economic efficiencies of systematic and adaptive cluster sampling for inventorying the 3 NTFP species considered.

6.1.1 Comparison of efficiency of systematic sampling and adaptive cluster sampling for inventorying bamboo, *Calamus deeratus* and raphia palms

Sampling error was used as a measure of the efficiency of the sampling methods. It is also an indicator of the precision of the estimates. At a given confidence level (95% in this study) sampling error depicts the probability of estimates deviating from what has been estimated if sampling were repeated a number of times. Thus the lower the sampling error the more reliable is the estimate and vice versa. Table 6.1 shows estimates and their sampling errors using systematic sampling and adaptive cluster sampling method for inventorying 3 NTFP species.

Table 6.1: Comparison of efficiency of systematic sample design with adaptive cluster sample design.

Species	Systematic Sampling			Adaptive Cluster Sampling			Relative efficiency
	Mean/ha	CI	E%	Mean/ha	CI	E%	$\frac{E\%S}{E\%A}$ [4]
Bamboo	2	0.4-3.3	76.8	2.8	2.5-3.0	8.75	8.77
Calamus deeratus	10.5	0-22.6	114.6	11	10-13	12.86	8.91
Raphia	30.8	15-47	51.5	29	28-30	6.35	8.12

(Confidence Interval (CI) is at 95% probability)

This table compares the statistical efficiency of systematic sampling with systematic adaptive cluster sampling for inventorying bamboo, Calamus deeratus and raphia palms. Sampling error (E %) was used as the basis of comparison. For all the 3 species adaptive cluster sampling design was about 8 times efficient relative to systematic sampling design.

Time used for inventory is a function of the cost of the inventory and hence the importance of time when considering efficiency of inventory methods. Inventory method with a high statistical efficiency but requires relatively much time to execute could be impractical because of budget constrains. On the other hand if an inventory method that requires relatively less time (cheaper) may not be suitable if it yields unreliable estimates of the population. Therefore a balance should be struck between statistical efficiency and economic efficiency when choosing a method to inventory a population. Whether the balance tilts towards statistical efficiency or economic efficiency depends on the purpose and the budget of the inventory. Table 6.2 presents the time analysis of using systematic and adaptive cluster sampling to inventory the 3 species.

Time for plot measurement includes travel time, plot demarcation and enumeration. Travel time for adaptive plots was assumed to be zero since adaptive plots were contiguous to systematic plots and to each other. t_D shows the extra time used for adaptive plots and No.

[4] E%S = Sampling error from the systematic sampling design, E%A= Sampling error from adaptive sampling design

systematic plots t_D is the corresponding number of systematic plots that could be sampled with the extra time for adaptive sampling.

Table 6.2: Analysis of time needed for systematic and adaptive cluster sampling method

Species	Mean time/sys Plot (min)	$t_D = t_A - t_S$ (min)	No. Sys plots t_D	% t_D	$E\%_S$	$E\%_{S+D}$	$E\%_A$
Bamboo	55	564	10	16.2	76.8	74.6	8.8
Calamus deeratus	52	205	4	6.2	114.6	113.8	12.9
Raphia	55	2450	45	71.2	51.5	41	6.4

6.1.2 Efficiency of the systematic cluster sampling design for inventorying tree resources off-reserve

The systematic cluster sampling method was used to inventory tree resources off-reserve. Although the efficiency of the method for assessing off-reserve tree resource has been mentioned here, the most efficient systematic cluster design was not an objective. The method was applied to give an overview of tree resources off-reserve. The tree species were classified under commercial and non-commercial species and their densities estimated. Basal area was only estimated for commercial timber species because it could be used to envisage the volume of wood. Table 6.3 shows the results of estimates of tree resources off-reserve using the systematic cluster method.

Table 6.3: Tree density and basal area of commercial and non-commercial tree species

Estimate	**Commercial timber species**		**Non-commercial species**
	Density (tree/ha)	Basal Area (m^2/ha)	Density (tree/ha)
Mean	24	5.2	26
Sampling error (%)	14	34	15.9

The sampling errors for tree density were appreciable given the heterogeneous nature of off-reserves. Sampling error for basal area of commercial species was high.

6.2 Quantifying the number of culms in a bamboo clump

A regression model makes indirect estimates of variables of interest that are difficult to measure in a direct manner. A linear regression model was tested to investigate the validity of predicting the number of culms in bamboo using orthogonal base area of the clumps. Figure 6.1 shows the scatter plot of clump base area against the number of culms with a regression line.

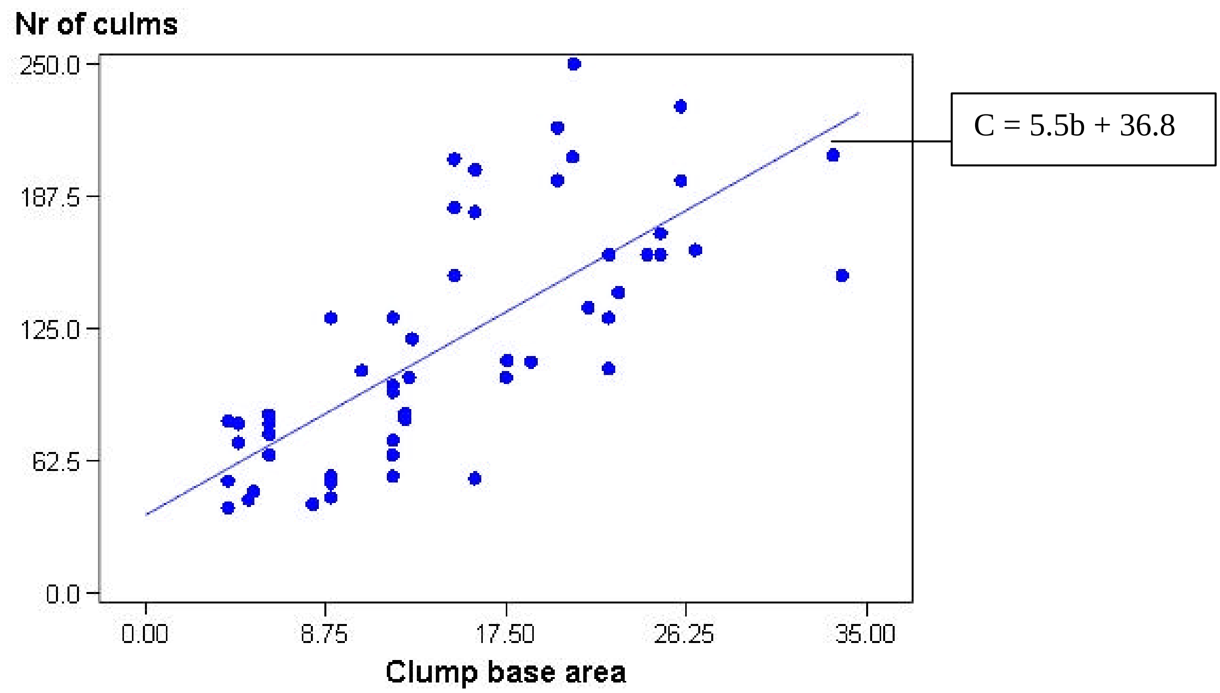


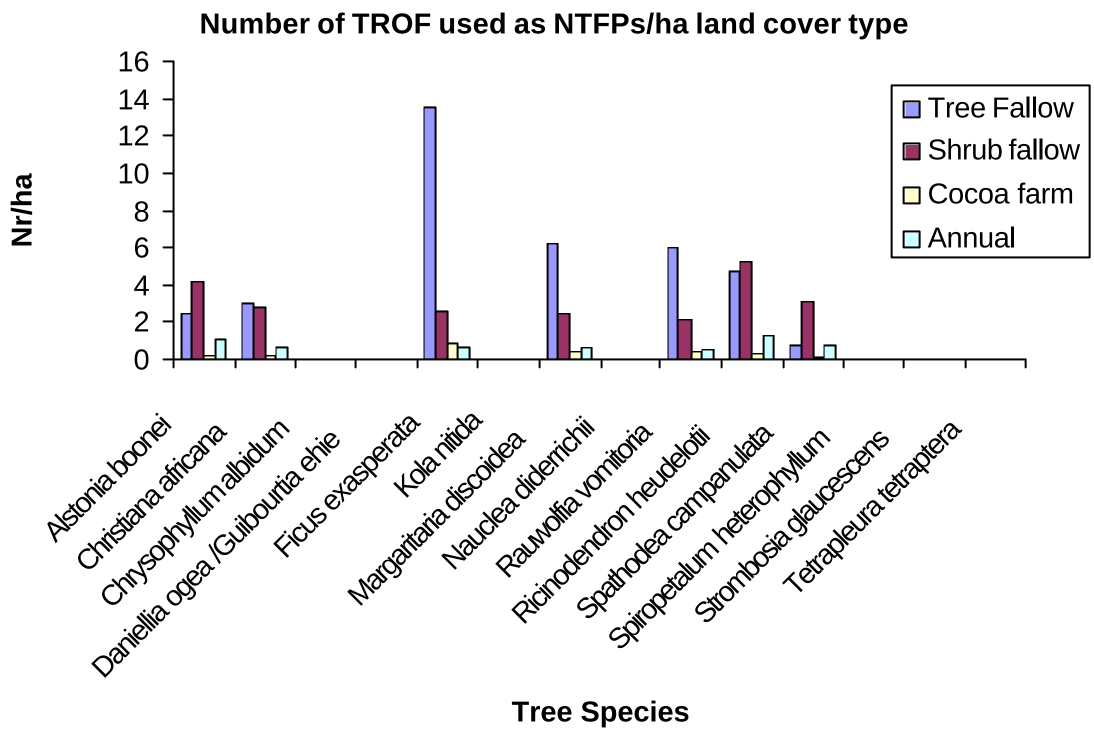
Figure 6.1: A scatter plot of bamboo clump base area against number of culms with a regression line

Clump base area showed a linear relationship between the base area of bamboo clumps and the number of culms (with a correlation coefficient about 74%). The analysis of variance was significant at 5% and that base area of bamboo clump explains about 55% of the variation in the number of culms in the clump. The residue analysis showed no outliers with normal distribution but showed positive correlation (see appendix) rather than independence.

6.3 Abundance of tree species in off-reserve

Abundance of species in an area is a fundamental ecological parameter and a critical consideration when making management and conservation decisions. For a species under utilisation, its abundance could be an indicator of the level of utilisation or its capability to cope with disturbance in the ecosystem. To estimate the abundance of tree species used as NTFPs and those for commercial timber species, a systematic cluster sampling method was used. The cluster units were also grouped into the different cover types in which they occurred to give an overview of the abundance of the tree species in the different off-reserve cover types. For commercial timber species basal area was also estimated to provide an overview of volume of timber in the different land cover types. Basal area of tree species used as NTFPs was not calculated because parts of the tree rather than the wood are mostly used. However, basal area for tree species used for carving or other activities related to the use of wood could be used for estimating the product volume. Figure 6.2 shows the density of the different tree species used as NTFPs in the different land cover types.

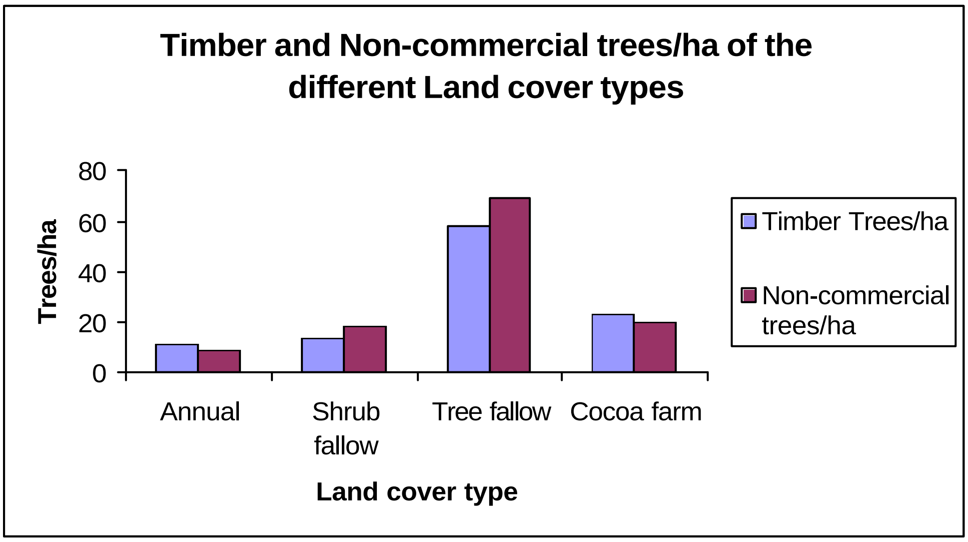
Figure 6.2: Density of Tree species used as NTFPs in different cover types.



Higher density of most species occurred in tree fallows and shrub fallows. *Ficus exasperata* was the most abundant in tree fallows whiles *Ricinodendron heudelotii and Alstonia boonei* were relatively abundant in shrub fallows. Tree species such as *Chrysophyllum albidum, Daniellia ogea/Guibouurtia ehie, Nauclea diderrichii, Spiropetalum heterophyllum, Strombosia glaucescens and Tetrapleura tetraptera* had negligible density or were not encountered. Such species may have become very rare in off-reserves.

Figure 6.3 shows the density of timber and non-commercial tree species in the different land cover types.

Figure 6.3: Density of Timber and non-commercial tree species in the different cover types

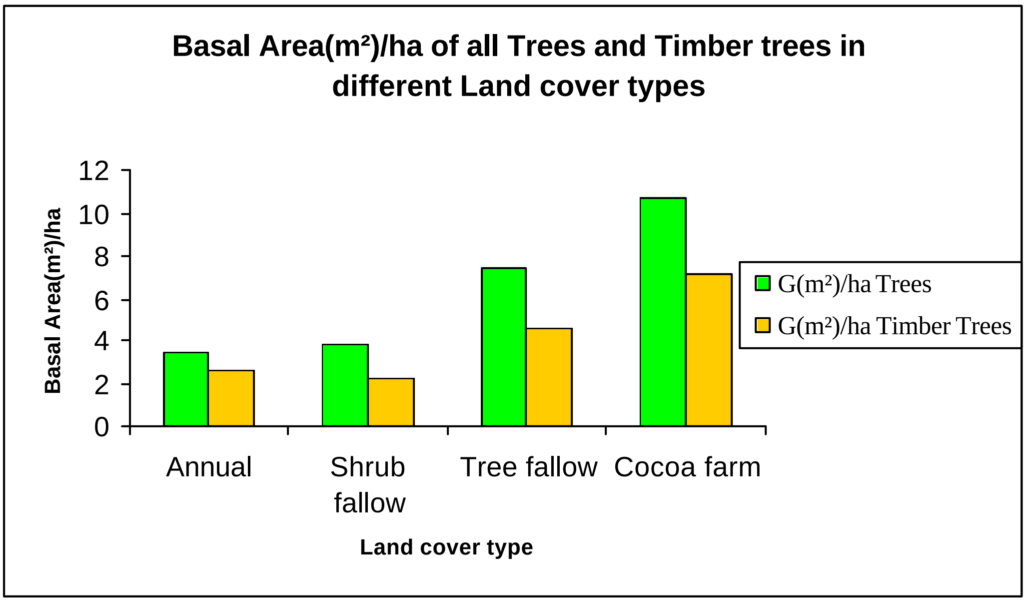


Density of non-commercial species was higher than timber species in tree and shrub fallows. The density of timber species was however, slightly higher than non-commercial species in cocoa farm and annual. Density of both timber and non-commercial tree species was highest in tree fallow. Within the cover types with agricultural crops, cocoa farm tends to harbour more trees.

Off-reserve timber trees are more open to utilisation than timber trees in forest reserves. Timber trees of harvestable sizes could be abundant in cover types where the trees are well protected. Basal area of timber trees could be an indicator of the relative sizes of timber trees in the off-reserve cover types. Figure 6.4 shows the proportion of timber trees in the basal area of each cover type.

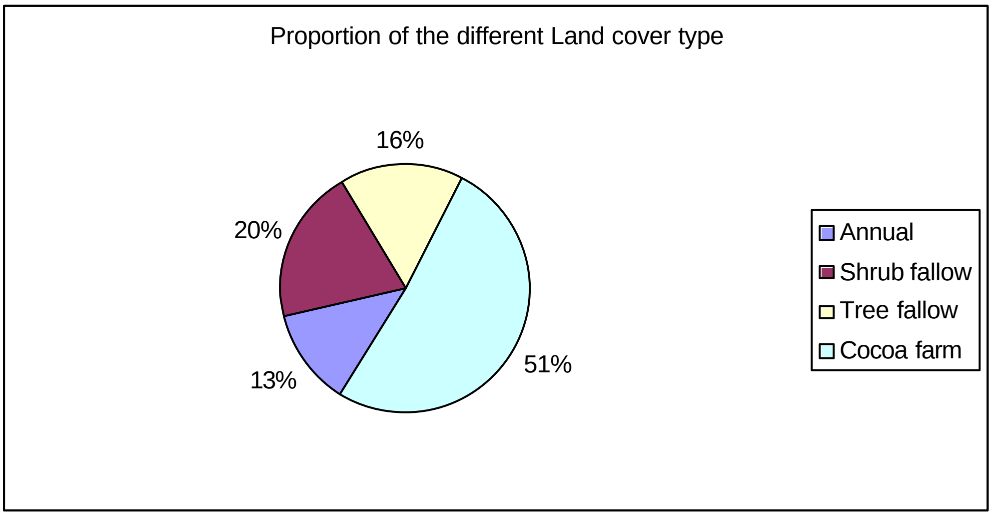
To determine the spatial influence of each cover type and its significance in managing tree species off-reserves, a crude estimate of the proportions of the different land cover types was made using the proportions of systematic plots that occurred in each cover type. Figure 6.5 shows the proportions of the land cover types using this method.

Figure 6.4: Proportion of timber trees in basal area of the different cover types



Although tree fallow had the highest timber tree density, the basal area of timber trees in cocoa farm was the highest. Timber trees in cocoa farms are thus better protected.

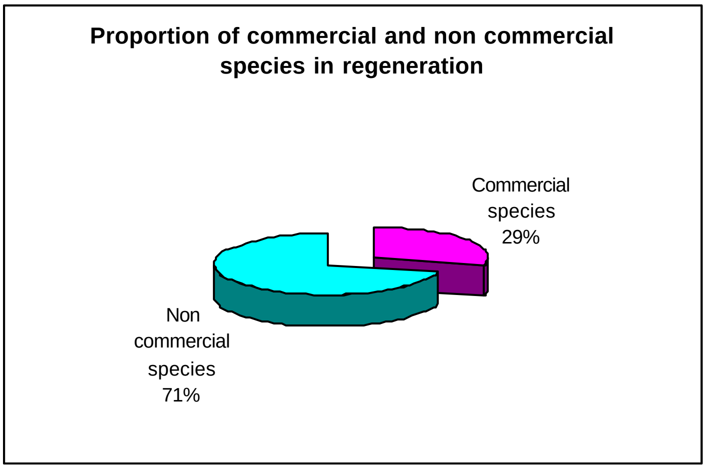
Figure 6.5: Proportion of cover types estimated from number of systematic plots in the different cover types



Cocoa farm was found to be the major cover type using this crude estimate. However, satellite image classification would give more accurate proportions of the cover types.

Species regeneration is an important indicator of the survival of the species and for envisaging the future tree species composition and diversity. Regeneration was only observed in tree fallows and the species grouped commercial and non-commercial species. Figure 6.6 is a pie chart showing the proportions of commercial and non-commercial species in regeneration.

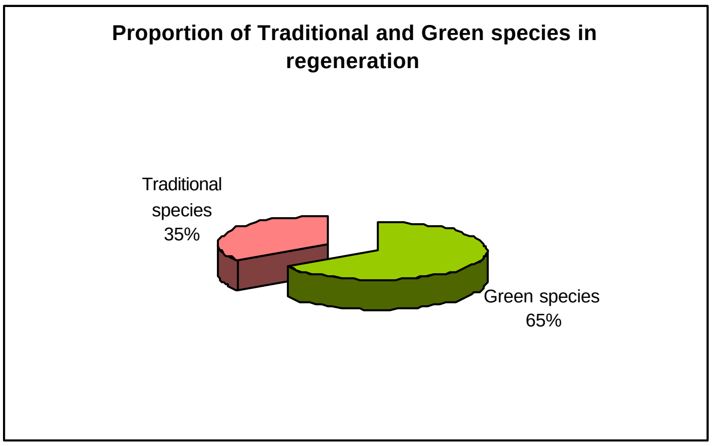
Figure 6.6: Proportion of commercial and non-commercial species in regeneration



Non-commercial species formed the major proportion of regeneration although the ratio of commercial and non-commercial species was almost the same (14:17).

Traditional commercial species have been exploited over the years because they are well known and most preferred. Traditional commercial species are thus more intensively exploited than newly introduced commercial species known as lesser used species (LUS). The lesser used species are also referred to as green species[5] according to the commercial species star rating system. The proportions of the traditional commercial timber species (scarlet, red and pink species) and the green species in regeneration could provide an indication of the future commercial species composition off-reserve. Figure 6.7 provides the proportions of the traditional commercial species and the green species in the regeneration.

Figure 6.7: Proportions of traditional and green species in regeneration of commercial species



The green species constituted greater proportion of the regeneration.

[5] Green species were previously non-commercial species but have been recently added to the list of commercial species. Commercial tree species are given star (colour) rating according to their rarity or imminent threat of extinction. The star ratings are scarlet, red, pink and green. Scarlet species are under imminent threat of economic extinction, Red species are those for which current rates of exploitation present a significant danger of economic extinction, Pink species are significantly exploited, but not yet so as to cause concern for their economic future and Green species are less exploited and relatively abundant.

7. Discussions and Conclusions

The result of the study is discussed in two parts. The first part deals with the efficiency of the methods applied and the second part with abundance and distribution of the species and implications for their management in the off-reserves.

7.1 Efficiency of systematic sampling and systematic adaptive cluster sampling methods for inventorying bamboo, Calamus deeratus and raphia

Table 6.1 shows that the sampling errors of the systematic sampling for the three species were high. This might be accounted for by conversion of the species habitat to agricultural fields which may have caused fragmentation in their distribution and hence making the conventional systematic sample inappropriate for their inventory. The three species also occur in clumps which further worsen the suitability of the systematic sampling method for their inventory. The adaptive cluster sampling method gave relatively low sampling errors for all the three species because the distribution characteristics of the species tend to favour the use of this method. This confirms the assertion of Thompson and Seber (1996) that adaptive sampling method tends to be more suitable for species with clumping distribution characteristics.

Table 6.2 shows the time analysis of the sampling process. Total time per plot included walking/travel time, time for plot demarcation and enumeration. It could be seen from table 6.2 ($\%t_D$) that about 16%, 6.2% and 71% of the total time for systematic method were added to the adaptive sampling method for bamboo, *Calamus deeratus* and Raphia respectively.

Although much time was used to measure adaptive plots in the case of raphia, about 71% more than the systematic sampling, a significant reduction of the sampling error was made (51.5% to 6.4%). An error of about 51% using systematic sampling would make the results very unreliable. The extra time used for adaptive sampling (t_D) could have been used to sample 10, 4 and 45 systematic plots on the average for bamboo, *Calamus deeratus* and raphia respectively. However, if these extra systematic plots were added to number of systematic plots already sampled, it could have reduced the sampling error (E %) from 76.8%, 114.6% and 51.5% to ($E\%_{S+D}$) 74.6%, 113.8% and 41% for bamboo, *Calamus deeratus* and raphia respectively. Hence notwithstanding the extra time for adaptive sampling even in the case of raphia (about 71% more), significant reduction of the sampling errors were made using adaptive cluster sampling than with systematic sampling for all the three species and could be worth the cost if appreciable sampling efficiency is desired. Given the very high coefficient of variation of the sampling units, it will require enormous number of systematic plots to reduce the sampling error to the level of the adaptive cluster sampling for all the three species considered.

The time for adaptive sampling in the case of raphia was comparatively higher and lowest in the case of *Calamus deeratus*. Raphia palms were found to be distributed in belts and were less clustered resulting in sampling more adaptive plots. It is therefore not surprising that the systematic sampling method was more efficient with sampling error of 51.5% in the case of raphia. This again confirms that the efficiency of adaptive cluster sampling method depends on the density and clustering degree of the species being inventoried as asserted by Talvitie et al. (2006). Bamboo and *Calamus deeratus* were more clumped and hence lesser numbers of adaptive plots were sampled.

The very high relative efficiency of adaptive cluster sampling design over the systematic sampling may give it an edge over systematic sampling for inventorying the three species in off-reserve areas. However, adaptive cluster sampling may have performed better than systematic sampling because the distribution of the species may have been fragmented by farming activities. For one to see the full picture of the relative efficiency of the two methods in inventorying the three species, it is recommended that the methods be tested in the forest reserves where disturbance of the species habitat may be minimal.

The means for the species were very low and hence their population density. The low population density of the species might be due to habitat destruction. Conversion of the species habitats to agriculture fields seems to seriously hamper their regeneration. Even though there is a regulation for farmers to leave some 10m strip around streams and rivers, this is not strictly adhered to. It was realised from the field that farmers would farm into the stream or river so far as the valley is low and flooding could be avoided. When the land is to be used for crops which could thrive in flooded areas, clearing is done into the stream or river destroying the habitats of the species. The low population density conforms to the assertion of the communities that the species are now scarce, especially rattan, in off-reserves due to farming activities. Although locals use such plant species for one thing or another, much attention is not paid to the preservation of such plants off-reserve. These plants may serve as common pool resources and that those who own lands on which the plants are found may not benefit much from the resources. Hence when there is possibility for the land to be used for crop production which the land owners think could give them more benefits, the land is readily converted without taken into consideration the presence of those species which are of importance to members of the community (see Figure 7.1). Those who may need the resource have no chance to preserve the resource if they are not the owners of the land. However, the species may be protected by land owners if used for commercial purposes. An example is the use of raphia palms for commercial alcohol production in certain areas of Ghana.

Figure 7.1: A converted field with remnants of raphia palms

7.2 Efficiency of the systematic cluster sampling design for inventorying tree resources off-reserve

Results from Table 6.3 show an estimate of 24 trees /ha with 14% sampling error and 26 trees/ha with 15.9% sampling error for commercial and non-commercial tree species respectively. Given the heterogeneity of the study area, the efficiency of the design was appreciable and could be appropriate for tree density estimation in the study area. However, with basal area of 5.2m²/ha the sampling error was about 34% for commercial tree species. The sampling error was high for basal area of commercial tree species because the sizes of commercial tree species tend to vary from one cover type to another and even within cover types in the study area. Whiles cocoa farms, especially older ones, may harbour mostly larger trees; larger commercial trees in tree fallows, shrub fallows or annuals may be removed. This will result in a high coefficient of variation between the samples and hence higher sampling error. When the data was post stratified according to the different land cover types, single cluster units of different clusters occurred in different land cover types making the number of plots per cluster vary. The sample sizes of the different land cover types were thus different resulting in different precision levels in each cover type. For the design to be more efficient in inventorying and estimating tree parameters in the different land cover types, pre stratification of the area according to the different land cover types would be necessary. This stratification would require a good land cover map of the study area. Also to obtain the most efficient design, a pilot study could be done to test the minimum distance for autocorrelation within and between the clusters. The minimum distance for autocorrelation could be kept between clusters and increased within clusters. When this is done heterogeneity within clusters could be increased but keeps heterogeneity between clusters at a minimum leading to an increase in statistical efficiency as described by Johnson (2000).

7.3 Quantifying the number of culms in a bamboo clump with regression model

Figure 6.1 shows a linear relationship between the base area of bamboo clumps and the number of culms (with a correlation coefficient about 74%). The analysis of variance showed that the relation was significant at 5% level and that base area of bamboo clump explains about 55% of the variation in the number of culms in the clump. The residue analysis showed no outliers with normal distribution but showed positive correlation (see appendix) rather than independence. Although the relation was significant at 5% level, base area of bamboo clump was not a good predictor of the number of culms in a clump. The error margin of the regression model was high and thus may not accurately predict the number of culms in a bamboo clump for practical purposes. The high error margin might be due to stumps of harvested culms which form part of the base areas of the clumps but were not counted. This implies that given the same base area, a bamboo clump with some culms harvested and a non-harvested clump may vary significantly in the number of culms. The model may thus tend to underestimate non-harvested clumps and overestimate harvested ones. Other predictor variables may thus be needed to make the model effective.

7.4 Significance and potential of selected NTFPs

The species selected for the inventory play some vital role in the lives of local people. Though some may have lost their importance, others are still relevant to rural lives and may have some potential for income generation. This section discusses the significance and potential of the species selected for the inventory through literature and personal observations.

7.4.1 Importance of the selected NTFPs to local people

The general importance of NTFPs has already been reviewed in this study. This section looks at the importance of the species selected for the study as pertains to Ghana.

The species selected play some important roles in the lives of local people. Rattan is used for weaving baskets, mats and making furniture. Baskets are important to farmers and fishmongers as a container for carrying head loads. Farmers carry farm produce in baskets from farms to the home or the market. Cocoa farmers use baskets to gather cocoa pods in the farm and to carry the fermented beans onto platforms for drying. For fish mongers, the ventilated basket becomes essential for carrying and transporting smoked fish to the market. Rattan is also used for weaving mats for drying cocoa beans. These were the main products of rattan identified in the Goaso district. However, rattan furniture, shopping and laundry baskets and serving trays are produced mostly in the cities where there is probably market for them and this agrees with the assertion of Oteng-Amoako and Obeng-Darko (2002). However, the raw material is taken from the rural forest areas.

Leaflets, petiole as well as the whole raphia palm plant are used for different purposes. The mature leaflets of raphia palm are used for making thatch. The tender leaves are employed in the production of raffia, a fibre, used in a number of woven articles e.g. mats, hats etc. The bark of the petiole is used for making mats for drying cocoa beans and for other purposes. The palm could be tapped (Figure 7.2) just before flowering to obtain palm wine (the sap from the palm).

Figure 7.2: A raphia palm being tapped for palm wine

Palm wine is sweet when fresh but undergoes fermentation when left to stand. The fermented palm wine could be distilled to produce alcoholic beverages. The use of raphia palm to produce alcoholic beverage was rare in the Goaso district. Although some people are engaged in this activity, oil palm trees are mostly used. This might be due to the low densities of raphia palms in the off-reserve areas where accessibility may be relatively easier or the availability of oil palm trees from oil palm plantations.

Bamboo is mostly used for construction of huts, barns and also as stakes on farms. Recently however, bamboo is being used for scaffolding instead of *Triplochiton scleroxylon* (Wawa) planks. Bamboo is also combined with rattan to make furniture (Figure 7.3) both for local market and export.

The level of usage of the plants named above was low in the Goaso district. Although rattan continues to be an important raw material, its availability in the off-reserve areas of the Goaso forest district is limited. Calamus deeratus which is the least preferred among the five known utilisable species of rattan in Ghana (Oteng-Amoako and Ebanyele, 2001) was the only species obtainable in subsistence quantities off-reserve of the Goaso forest district. This implies that forest reserves continue to be sources of supply of rattan for local or urban harvesters who harvest large quantities. Even though there has been promotion of rattan and bamboo as alternative resources to wood, there has however not been a complimentary development of the resource base. Inventories of rattan even within the reserves have been ad hoc and no prudent management had been in place. The issuing of permits by the district office to collectors or harvesters had been the only means of managing rattan resources within forest reserves (Falconer, 1994). The lack of extensive inventory data and measures of annual increment of harvestable canes means that it is impossible to be confident about the sustainability of future supplies. There is thus the likelihood of overexploitation of rattan resources even within the forest reserves (Oteng-Amoako and Obiri-Darko, 2002).

Raphia palm use was found to be subsistence in the Goaso forest district. The bark of the petioles of raphia palm may still be used to weave mats for drying cocoa beans; other uses such as using leaflets for making thatch may be losing significance. This is because many may prefer the use of aluminium roofing sheets which are more durable to the raphia thatch which needs to be maintained regularly to prevent leakage. Even though the argument for such a change may be convenience, it may sometimes be the connotation of 'backward and primitive' which may be linked with the use of such products or may be seen as poor people's goods (Gronow, 2003). Rural dwellers therefore replace the thatch with aluminium roofing sheets where they have the financial capability to do so. Notwithstanding its undurability, raphia thatch provides a cooler room under the warm tropical conditions than the aluminium roofing sheets which conducts heat faster. For the rural poor raphia thatch is still an alternative roofing material. The substitution of raphia thatch with aluminium roofing sheets could make raphia lose its conservation in areas where other uses are not common.

Although bamboos have versatile uses, especially in Asian countries, its use in Ghana has been traditionally restricted to few areas such as construction of huts, barns, and fences, platforms for drying cocoa beans and recently in making scaffolds, handicrafts and furniture. Although bamboo utilization is being promoted as alternative resource to wood, bamboo usage in the Goaso district and Ghana in general is still rudimentary.

Tree species like *Nauclea diderrichii* (Kusia), *Chritiana Africana* (Sesedua), *Ricinodendron heudolotii* (Wama) and *Astonia boonei* (Sinuro) are among the species used extensively in the woodcarving industry. *Nauclea diderrichii,* also a timber species, is used mostly for carving mortar, an important utensil in most Ghanaian homes for pounding fufu. The use of such tree species for mortar carving would still continue so far as there is no machine to replace mortars and Ghanaians continue to eat their traditional fufu. In the Goaso forest district there might be a few mortar carvers but it was observed that community members were not prepared to give the identity of carvers for fear of causing their arrest by forestry officials. Carvers were expected to obtain permit and pay for the trees they use but this is usually not done and the trees were mainly sourced illegally sometimes through informal price negotiations with farmland owners in off-reserves. Illegal sourcing within forest reserves cannot be ruled out (Cudjoe, 2005). Other tree species mentioned above are used mostly for carving stools, dolls, mask etc. Although woodcarving was not observed as important activity in the Goaso forest district, trees used for these activities could be sourced from the area.

Tetrapleura tetraptera (Prekese) is a tree whose fruit is used as a spice in dishes, jams, candies, alcoholic beverages etc. The bark, leaves, roots and fruits are believed to posses important medicinal properties. In spite of these and other potential uses, Prekese had remained at the subsistence level of usage, usually popular with the Akans of Ghana as a spice in soups. Recently however, the Centre for Biodiversity Utilization and Development (CBUD) in Kumasi has been promoting its usage and conservation.

Other species are mostly used for medicinal purposes are *Rauwolfia vomitoria*, *Alstonia boonei*, *Spathodea campanulata*, *Kola nitida* and *Spiropetalum heterophyllum*. Leaves, seeds, bark and roots of these plants are believed to possess medicinal properties and are used by local people to cure various diseases. Medicinal plants continue to play a role in the health of local people as they may still rely on plant medicine as the first step of curing illnesses. Most often medical doctors are consulted after plant medicine has failed to provide a cure. However, the efficacy of most of these medicinal plants has not been scientifically documented. The Centre for Scientific Research into Plant Medicine in Ghana has been tasked with making scientific investigation into the efficacy and preparation of medicine from medicinal plants.

7.4.2 Potential of the selected NTFPs for income generation

Rattan has the potential of generating income for rural forest fringe communities in Ghana. Forest fringe communities could collect and sell rattan to weavers as well as making products from rattan for sale. Presently carriage and storage baskets are the only rattan products from rural communities. Oteng-Amoako and Obiri-Darko (2002) ascertained that the increase in the number of hotels, restaurants and other service centres as well as the number of expatriates and foreign businesses could give a boom to local trade in quality rattan products in Ghana. However, some form of training in making other rattan products in forest fringe communities would be necessary to ensure that value is added through some local form of processing so that a fair proportion of the product value accrues to the people who live close to the resource and have a stake in its management. Promotion of such processing would require a sustainable resource base to supply quality rattan for processing. Oteng-Amoako and Obiri-Darko (2002) have already enumerated some interventions to make the rattan industry in Ghana and Africa in general to realise its potential. These include sustaining the resource base, improving the quality of rattan products through technology transfer and effective marketing at both local and international levels.

The use of raphia palm for making alcoholic beverages has a potential for income generation. Although this was not found as a major activity in the study area, it could be an income generating activity if enough raphia palms were available. Research into securing the resource base of raphia palms through species selection and enrichment planting as well as improving processing of the alcohol could help realise its income generating potential.

Bamboo is now being utilised for furniture (see Figure 7.3) and scaffolding as substitute for wood.

Figure 7.3: Bamboo furniture

Bamboo utilisation in Ghana may increase in the future as timber resources decline. However, for bamboo to play a supplementary role to wood there is the need to assess the bamboo resource base and to invest in technology to enhance its utilisation.

Tree species for carving may also be in high demand. Growth in tourism and trade in Ghana could increase demand for carvings. However, the resource base on which an increase in demand would thrive has dwindled leaving the potential of carving activities as income generating activity uncertain. The resource base of these tree species could be improved through establishment of plantations. The interest of local people of the study area in such income generating activities may be low. This could be attributed to factors such as limited supply of species which could supply raw materials for income generating activities, lack of the requisite skills for those activities, lack of market for the products or a combination of these. This study did not investigate this and could be interesting to research into.

7.5 Distribution and abundance of the species

This section discusses the results of the study with regards to the abundance and distribution of the species in the different cover types. It also explores the implications of the abundance and distribution of the species on their utilisation and management.

7.5.1 Factors influencing spatial distribution of the selected NTFPs

The NTFP species inventoried would be divided into two. The non woody species comprising Calamus deeratus, bamboo and raphia while tree species used as NTFPs would be here classified as woody species. The non woody species were found to be mostly distributed in patches along streams and rivers while the woody species were scattered in the other land cover types. The main factors found to influence their distribution were farming activities, utilisation and their accessibility.

Off-reserve areas were mainly to be used for agricultural purposes and expansion of agricultural activities, especially cocoa production, over the years have reduced off-reserve forest cover in the study area. This increase in agricultural activities off-reserves has invariably affected the distribution of species used as NTFPs. Once the forest land is cleared and burnt some of the NTFP species are lost. For instance there are four other known important commercial species of rattan in Ghana but Calamus deeratus was the only species found off-reserves. Calamus deeratus tend to be riparian and its habitat is not totally destroyed by farming activities although it is affected to some extent. Farmers are required to leave some 10m strip of land around natural watercourses as a kind of protection for those water bodies. Where such strips are left they become habitat for species such as Calamus deeratus, raphia and bamboo which could thrive in such habitats. However, farmers do not strictly obey this regulation and sometimes clear all vegetation around the stream or river so far as the valley is low and flooding could be avoided. This breaks the strips around the streams or the rivers causing some fragmentation in the distribution of the species. Raphia mostly occur in marshes and the strips within which they occur could be cleared when the land owner intends to use the land for growing crops which could thrive under waterlogged conditions (Figure 7.1).

The woody species are not restricted to any particular habitat but are scattered across the landscape. When forest land is converted into a farm, the decision to preserve or fell a tree depends on the farmer. The number of trees preserved on a farm also depends on the farmer's knowledge of the usefulness of those trees or the ability of his crops to tolerate the shade provided by the trees. Thus the distribution and density of the woody species used as NTFPs across cover types such as annuals, cocoa farms as well as shrub fallows may vary greatly (Figure 6.2). It could be noted from the figure that *Ficus exasperata* was the most predominant and widely distributed of the species in all the four cover types. Rauwolfia vomitoria was also found in all the four cover types but more dominant in tree fallows.

Species like *Alstonia boonei* was more prevalent in cocoa farms indicating probably its suitability as a shade crop for cocoa and its importance for medicinal and other uses. *Asltonia boonei* has already joined the lesser used species (LUS) and its utilisation for timber could reduce its density especially in the tree fallows. Nauclea diderrichii, *Kola nitida* and *Chrysophyllum albidum* occurred only in limited numbers in cocoa farms. *Nauclea diderrichii* and *Chrysophyllum albidum* are also utilised for timber and may have been overexploited in the other cover types. *Kola nitida* may have been planted or retained in the cocoa farms by farmers. *Tetrapleura tetraptera* occurred in limited numbers in annuals, shrub fallows and cocoa farms. Farmers might have preserved the trees on their farms for their spicy fruits. The density of the species in general could be said to be low. This deviates from the assertion made by Falconer (1992a and b) and Towson (1995a and b) that off-reserves provide the bulk of NTFPs. The reason might be due to changes in the vegetation of off-reserves areas over time mainly caused by conversion of more forest lands into agriculture and the spread of *Chromolaena odorata* which prevents regeneration of trees and other species in fallow lands.

Utilisation of the species may also affect their distribution. NTFPs off-reserves may be classified as both private property and open-access resources in terms of tenure and access. Open-access implies that the resources are accessible to all, have no recognised users and are not easily controlled. However, the NTFP resources may be controlled by land owners where utilisation assumes commercial dimensions. In such a situation the resource assumes a private property status. Uncontrolled usage could lead to overexploitation of the resources. This is especially true where the resources are easily accessible through access roads and paths. It was observed on the field that bamboo clumps which were near roads or paths were mostly harvested while clumps further away from roads were not harvested. In the case of Calamus deeratus, harvesters could harvest them in spite of their distances from roads or paths due to the relative ease of transporting the canes.

7.5.2 Management of NTFP resources off-reserves

Off-reserve lands belong to stools, clans, families and individuals as has been described in section 2.2.3. The complex land tenure system in most parts of Ghana makes it difficult to manage resources off-reserves. The forest service of Ghana has therefore no management plans for off-reserve resource in general. Non-timber resources off-reserves are viewed as open access resources which all members of communities could utilise. However, the resources are found on lands belonging to individuals or families. This implies that the land owner determines the fate of the resource and not the user and could limit access where he desires to do so. For resources like bamboo, rattan and raphia, members of communities could possibly harverst without permission from the land owner, especially where the harvesting of the resource does not affect crops or any use to which the land owner has put the land. The fate of the resource is in the hands of the land owner because he could use the land for other purposes such as crop production which could lead to the destruction of the resource. Preservation and management of non-timber resources off-reserves would therefore first be determined by the interest of the land owner. If the land owner utilises the resource or finds it important, then he will protect it and try to control usage.

In forest resource management various degrees of deliberate human interventions, including activities aimed at safeguarding and maintaining the resource base, are established. Such activities include controlling harvesting by setting yield limits which allow the species to recover from harvesting, allowing enough time between harvesting for regeneration of the species or engage in enrichment planting to increase the density of the species where natural regeneration fails. An open access resource would be difficult to manage because of the difficulty in monitoring and enforcing such interventions. For species like bamboo or rattan, only matured individuals could be utilised and regeneration from stumps is possible. Such species may be said to be self-regulatory and harvesting per se may not adversely affect their population density. However, instances of repeated bushfires could affect population density and the size of the culms. On the other hand, harvesting all matured individuals at the same time could negatively affect the ability of rattan to produce seeds and to form new colonies through seed dispersal and thus could affect their population density. For species like raphia or tree species which regenerate only through seeds, harvesting all matured individuals each time would certainly lead to the extinction of the species. Thus some form of harvesting controls would be needed to maintain such species but these controls could not be enforced in off-reserves. The worst scenario occurs when the whole piece of land on which the species occur is converted through slash and burn. The species could completely disappear from the converted land. To manage off-reserve NTFPs the land owner must be interested to preserve the species through the benefits he derives from them.

7.6 Commercial and non-commercial tree species off-reserve

Commercial tree species are referred to here as species exploited for commercial wood production. Non-commercial species could be used as NTFPs or for other purposes.

7.6.1 Management of timber resources off-reserves

Although lands off-reserves belong to individuals, timber trees off-reserve are owned by the government. This claim of timber trees off-reserves by the government means that no recognition was given to forest off-reserve as a land use form and farmers or landowners could not benefit from timber resources as far as the resource comes from naturally grown forest. This also partly created some incentives for the conversion of forestlands off-reserve to grow cash crop like cocoa because even leaving the land as a forest gave them not enough direct benefits. However, some see higher levels of cocoa production as deliberately guided by policy to grow the country's economy through export of cocoa. In the study area, cocoa farms seem to cover the major part of off-reserves (Figure 6.5). Fortunately cocoa trees tolerate some shade making cocoa farms a refuge for some appreciable number of trees off-reserves because the trees are not easily accessible to concessionaires or chain saw loggers. However, recent observations from the field indicated that the farms with new cocoa hybrids have fewer trees. The new hybrids according to the farmers tolerate lesser shade and they were advised by extension officers to reduce the number of shade trees in their farms. This situation may lead to a further decline of tree resources off-reserves and needs to be investigated. The complex land tenure system in Ghana and the tradition that timber resources occurring naturally on the land belong to the chiefs, who are custodians of the land, make ownership of timber resources off-reserve complicated. The trees which farmers tender on their farms do not belong to them but to the chiefs who collect royalties when they are harvested. The farmer however, determines the fate of the tree and aggrieved farmers tend to destroy trees instead of protecting them (see Figure 7.4). The issues of land tenure and ownership of tree resources off-reserves need to be resolved in a way that would make the farmer who tenders the tree on his farm the centre of attention.

Figure 7.4: A young *Milicia sp*[6] ring barked in a cocoa farm

[6] Milicia sp (Odum) is highly valued in Ghana for its dense hard timber.

Killing of trees by farmers would affect tree density off-reserves.

7.6.2 Density and distribution of timber and non-commercial tree species in off-reserve land cover types

Timber tree density was found to be highest in tree fallows, followed by cocoa farms while annuals and shrub fallows were almost the same (Figure 6.3). Tree fallows have undergone longer fallow and were expected to have higher tree density among the cover types. However, the density of non-commercial species in tree fallows was found to be higher than timber species. This could be explained by the fact that the timber species are mostly harvested by concessionaires and also chain saw loggers. Utilisation of timber species off-reserve is only guided by a minimum girth of 70cm. This implies that all timber trees with girth of 70cm and above could be harvested so far as they are accessible to the concessionaire. Chain saw logging activities are considered illegal and therefore they do not follow any harvesting size regulation. Timber trees in tree fallows may be the most accessible as the there is lesser possibility of conflict arising from their utilization. Harvesting trees in tree fallows may not cause any damage to crops and concessionaires may not need to negotiate with the farmer or land owner. Concessionaires or chain saw loggers may have less access to timber trees in cocoa farms due to the possibility of damaging the cocoa trees. Law demands that concessionaires negotiate with farmers for access to timber trees where utilisation may cause damage to the farmer's crops although this may not always be the case. This restricts the utilisation of timber trees in areas with agricultural crops especially cocoa farms. This explains why in spite of higher timber tree density of tree fallow; the basal area of trees in cocoa farms is the largest (Figure 6.4) because the trees tend to be protected and are larger in size.

Annuals and shrub fallows tend to have similar tree densities because shrub fallows were annuals that were just undergoing fallow. Similar crops which tend to tolerate the same amount of shade were planted in them and hence their similar tree densities. The densities of timber and non-commercial species in annuals and shrub fallows were almost similar giving an indication that farmers would retain trees on their farms based on their importance to them and that timber species may not be selected against non-commercial species. The proportion of timber and non-commercial species in cocoa farms is similar because the farmer also selects the species to preserve in the farm.

The farmer is central to what kind and number of trees present in off-reserve agricultural fields. The interest of the farmer thus becomes imperative in the preservation of both commercial and non-commercial tree species in off-reserves.

7.6.3 Tree species regeneration off-reserve

In the four cover types identified in the off-reserve areas, regeneration was found only in tree fallows. Regeneration could not be found in annuals as they were under food crop production and any regeneration may have been removed through weed control measures on farms. In cocoa farms the closed cocoa canopy allows little light to reach the soil and thus hampers regeneration. Even where openings occur in the cocoa canopy and some regeneration occurs or for species which could still regenerate under little light, farmers remove them through weed control measures. In shrub fallows however, the presence of *Chromolaena odorata* was found to be the main obstacle to regeneration. *Chromolaena odorata* (dispersed by wind) germinates and grows faster and therefore smother any regeneration. Shrub fallows are thus mostly covered with *Chromolaena odorata* with little or no regeneration occurring and that trees retained during the previous farming period occur in them. Result of proportions of commercial and non-commercial tree species in the regeneration measured in tree fallows is shown in Figure 6.6. It could be seen from the figure that the non-commercial tree species form 71% of the regeneration although the number of commercial species and non-commercial species encountered in the regeneration were almost the same (14:17 respectively). The low level of regeneration of commercial species might be due their selective harvesting. Removal of larger timber species may reduce the proportion of their seeds in the soil seed bank because more potentially seed producing individuals are removed and this is likely to reduce their proportion in the regeneration. This is also seen from the high proportion (65%) of the green species (Figure 6.7) in the regeneration of commercial species although similar numbers of greens and traditional species were observed in the regeneration. Albizia zygia and Blighia sapida were particularly common in the regeneration. The conversion of tree fallows into agriculture, hampering of regeneration in shrub fallows by *Chromolaena odorata* and further removal or destruction of trees may cause a decline in tree density off-reserve. The capability of off-reserves in the study area to provide a sustained level of tree resources is thus bleak. The traditional commercial species may in the near future become scarce or rare off-reserves if nothing is done to avert the current situation.

7.7 Conclusions

This study was conducted in off-reserve areas of the Goaso forest district with the objectives of developing efficient methods of inventorying selected NTFPs, inventory the selected NTFPs obtainable off-reserves to determine their abundance and distribution, explore the potential of the NTFPs for income generation and investigate some factors which affect their distribution. The following conclusions could be drawn from the study:

- **Efficiency of the sampling methods for inventorying the species**

  This study found systematic adaptive cluster sampling method to be relatively more efficient for inventorying bamboo, *Calamus deeratus* and raphia palms than systematic sampling. Adaptive cluster sampling could therefore be a suitable method for inventorying the three species. This finding supports the theory of Thompson and Seber (1996) that adaptive cluster sampling is more efficient for sampling clumped or rare species than conventional methods. Adaptive sampling increased sampling intensity but travel/walking time was reduced making adaptive cluster sampling also relatively more cost efficient than systematic sampling of similar intensity. Although adaptive cluster sampling was relatively more efficient for inventorying the three species, its application for other species or similar species in other ecological areas should be done with caution by considering the distribution characteristics of the species. Beginning the inventory with a pilot study could be useful in deciding on the optimum design. The methods were tested in off-reserves of the study area but further work needs to be done to establish the relative efficiency of systematic adaptive cluster sampling for inventorying the three species as well as other clumped or rare NTFP species in the forest reserves. The use of remote sensing could also be an option for quantifying species such as bamboo in the study area.

  The systematic cluster sampling was efficient for tree density considering the level of heterogeneity in the study area. However, the design tended to be inefficient for basal area because tree sizes seem to vary greatly between and within the different cover types. When the systematic cluster sampling method was post-stratified according to the cover types, single cluster units of different clusters occurred in different land cover types making the number of plots per cluster vary. The sample sizes of the different land cover types were thus different resulting in different precision levels in each cover type. Pre-stratification of the study area according to cover types could improve the efficiency of the systematic cluster sampling. A land cover map of the area would be necessary for stratification according to the cover types. However, a land cover map of the study area was not available for this study. A stratified systematic cluster sampling method could be tested for its efficiency in the different cover types once a land cover map of the study area is available.

Estimating quantities of bamboo

The study used a regression model of the orthogonal base area of bamboo clumps to estimate the number of culms per clump. The analysis of variance showed that the regression was significant at 5% level and that about 55% of the variation in culm numbers in a bamboo clump is explained by the clump base area. The residue analysis showed no outliers with normal distribution but showed positive correlation rather than independence. Bamboo clump base area was thus practically not a good predictor of the number of culms in a bamboo clump. Stumps of harvested bamboo culms formed part of the clump base area but were not counted may have contributed to weakening the model. It would be interesting to investigate other predictive variables which could make such regression model effective in estimating the number of culms in a bamboo clump.

- **Abundance of the selected species off-reserves**

The study also found the densities of the selected species to be generally low. The quantities of the selected NTFPs in the study area are low to support commercial utilisation. For non-commercial tree species, *Ficus exasperata* was found to be the most abundant in all the cover types whiles *Albizia zygia* was the most abundant among the commercial tree species. Farmers may have special preference for these species on farms or those species have special adaptations to regenerate or disperse. For tree species used for carving, e.g. *Nauclea diderrichii*, their utilisation may have reduced their densities off-reserve. The low densities of the selected NTFPs were contrary to the assertion of Falconer (1992) that off-reserves contribute the major portion of NTFPs. Changes in the land cover over the years from mainly forest lands to agriculture may have accounted for the deviation. There would be the need to create these resources off-reserves and to protect patches around water bodies as habitats for *Calamus deeratus*, raphia palms and bamboo.

Potential of the selected NTFPs for income generation

The species selected were found to be used mainly on a subsistence basis. Uses of some of the NTFPs have been substituted with industrial products (e.g. raphia palm leaflets as thatch substituted with aluminium roofing sheets) causing a reduction in their significance for income generation. Raphia palms however, could be used for alcohol production but this would require an improvement in the resource base in terms of quantity and quality of the palms. Bamboo would also have a potential for income generation as its uses are being diversified. Bamboo could be planted where it would be accessible to improve the bamboo resource base and invest in technology to improve its utilisation. The resource base for the selected species in the study area was low to support high levels of income generating activities. There is the need for improvement of the resource base of the NTFPs off-reserve and to train local people to utilise the NTFPs for income generating activities. Research is however needed to establish the relative economic viability of such NTFP income generating activities for their economic as well as ecological sustainability.

Factors affecting the distribution of NTFPs off-reserve

Calamus deeratus, raphia palms and bamboo were found to be mainly distributed in patches around water bodies and their distribution was tied to this habitat. Conversion of this habitat into agriculture may have caused some fragmentation of the species distribution off-reserve. Signs of utilisation were found on bamboo clumps or raphia palms closer to roads or paths. However, those farther from roads and paths were not utilised. Such bamboo clumps were found to contain overgrown culms. Accessibility was found to be a factor for the level of utilisation and hence the distribution. For Calamus deeratus, clumps farther from roads or paths were even harvested because it is relatively easier to transport the harvested canes. Tree species used as NTFPs were scattered across the different cover types. Farmers' preference for those tree species and the level of utilisation were found to be factors for their distribution. Farmers willingness to retain certain species on their farms shows the importance of the species to them and where the usefulness for the species become limited they are likely to be ignored or destroyed.

This study has sought to design and test adaptive cluster sampling as an inventory method for bamboo, raphia palms and *Calamus deeratus* in an area for which no such other study had been done. By this the study has contributed to knowledge on the relative efficiency of adaptive cluster sampling for inventorying the three species and thus helps to provide baseline information for the management of the species. The study also gave firsthand information on the abundance and distribution of the three species as well as other tree species used as NTFPs or timber in the study area of which no such work had been done.

8. Summary

This study was conducted with the objectives to develop assessment method for selected non-timber forest products (NTFPs) in off-reserve areas of the Goaso forest district, Ghana. In this frame the relative efficiency of adaptive cluster sampling method for inventorying selected NTFPs was investigated. The study also inventoried the selected species, explored their potential for income generation and sought how factors like accessibility influence their spatial distribution and abundance.

Literature on the significance of NTFPs to local people echoed the need for the inclusion of NTFPs in forest management. The different methods of assessing NTFPs were reviewed to establish that methods for timber inventory which were inefficient for NTFPs have been adapted for NTFP inventory and thus the need for methods which would be more efficient for NTFPs. Adaptive cluster sampling method which has been suggested to be efficient for clumped and rare species was developed and tested.

Community and market survey was conducted first to select important NTFPs obtainable in off-reserves of the study area. The importance here was based on the use of the NTFP for subsistence and/or income generation. Six communities in the study area were randomly selected and a random number of households in each community were interviewed. Two main markets in the study area were also visited to obtain an overview of NTFPs used for income generation. The survey sought to include local knowledge on ecology, harvesting techniques and history of abundance of the selected species in the inventory design. Through the results obtained the species were grouped into two, based on their distribution. Three species, *Calamus deeratus*, bamboo, and raphia palms were mainly found to be distributed in patches around streams and rivers and tree species or shrubs scattered across the mosaic off-reserve cover types. A pilot inventory was conducted and the results factored into the design of the main inventory.

Adaptive cluster sampling with a systematic base was designed to inventory the three species distributed around water bodies. A systematic base was used to allow comparison of the efficiency of systematic sampling and adaptive cluster sampling methods because systematic sampling is widely used in forest inventories. Arcview was used to randomly select 2% of

streams and rivers in the study area. Using an initially chosen random point, 50m x 50m plots at 500m interval were systematically made along each selected stream or river. A total of 69 systematic plots were measured. Where any of the species of interest was found, 50m x 50m contiguous adaptive plots were made till no species of interest was observed in the edge units. Bamboo clumps were enumerated by counting the number of clumps, measuring the base area and counting the number of culms. A linear regression model was formulated to determine the validity of using the base area of a bamboo clump to predict the number of culms. The number of plants of *Calamus deeratus* and raphia palms were counted and grouped into mature and immature plants. Estimates were calculated using the Hansen-Hurwitz estimator. The relative efficiencies of adaptive cluster and systematic sampling methods, for inventorying each of the three species, were determined by comparing their sampling errors for each species.

To obtain an overview of the abundance and distribution of the other NTFP species in the study area, a systematic cluster sampling was used. Systematic cluster sampling method was used because of the relative cost efficiency of cluster sampling when inventorying larger areas. A 7km x 7km square grid was overlaid on a geo-referenced map of the study area. At each grid point four 50m x 50m plots were systematically made at the corners of a 100m x 100m square. A total of 128 plots were measured. The land cover type within which each plot occurred was identified and the diameter of all tree species above 10cm diameter at breast height (dbh) or at 30cm above the buttress were measured with a diameter tape. Each tree species was identified with its local and scientific name and grouped into commercial and non-commercial species. Where a cluster unit fell in a tree cover, 10m x 10m subplot was made at a corner of the 50m x 50m plot to access regeneration. Tree species of less than 10cm dbh to saplings of 1m height and above were recorded as regeneration.

The results showed that adaptive cluster sampling was about eight times more efficient as systematic sampling for all the three species inventoried. However, because the efficiency of adaptive cluster sampling depends on the density and clustering degree of the species which is usually not known before the start of the inventory, application of adaptive cluster sampling cannot be transferred easily from one area to another. The method should be applied with circumspection and pilot studies could be used to obtain the desired information about the species before main inventories are undertaken. The study also suggested testing of adaptive cluster sampling in the forest reserves because densities and degree of clustering of the species could be different within the reserves. Although statistically significant relation was found to exist between the base area of bamboo clump and the number of culms, base area of bamboo clumps was not found to be practically good predictive parameter of the number of culms in a bamboo clump. The validity of the linear regression model may have been weakened by stumps of harvested culms which formed part of the base area but were not counted.

When the inventory with systematic cluster sampling method was post stratified according to the cover types, single cluster units of different clusters occurred in different land cover types making the number of plots per cluster vary. The sample sizes of the different land cover types were thus different resulting in different precision levels in each cover type. A land cover map would be required for pre-stratification to make it more efficient.

The densities of the species were found to be low. Change in the land cover due conversion of the species habitats to agriculture may have accounted for this. Based on the inventory results, the capability of the off-reserves to provide sustained levels of the selected NTFP species was bleak as regeneration capability of the species could be hampered by agricultural conversion and the spread of *Chlomolaena odorata*.

9. Zusammenfassung

Diese Untersuchung wurde mit dem Ziel durchgeführt, Verfahren zur Aufnahme von ausgewählten „non-timber forest Products" (NTFPs) in den nicht geschützten Gebieten des Goaso Forest District, Ghana zu entwickeln. Auf diese Weise wurde die Effizienz des adaptiven Klumpenstichprobenverfahrens zum Inventarisieren von ausgewählten „non-timber forest Products" (NTFPs) in den nicht geschützten Gebieten des Goaso Forest District, Ghana überprüft. Im Rahmen der Arbeiten wurde eine Inventur der ausgewählten NTFPs und Baumarten durchgeführt und ihr Potential als Verdienstquelle evaluiert. Zudem wurde untersucht wie verschiedene Faktoren, z. B. die Zugänglichkeit, die räumliche Verteilung und Häufigkeit der NTFPs beeinflussen.

Literatur über die Bedeutung von NTFPs für die lokale Bevölkerung betont die Notwendigkeit des Einbezugs von NTFPs in die Management Entscheidungen. Die verschiedenen Verfahren zur Aufnahme von NTFPs wurden überprüft. Dabei zeigte es sich, dass die Verfahren zur Inventur von Holz für die Aufnahme von NTFPs ungeeignet waren. Diese herkömmlichen Verfahren mussten deshalb für die Inventur von NTFPs angepasst wurden. Adaptive Klumpenstichprobenverfahren, die für geklumpte und seltene Spezies sich als effizient gezeigt haben, wurden im Rahmen der Arbeit weiter entwickelt und geprüft.

Zu Beginn der Untersuchung wurde eine Gemeinde- und Marktumfrage durchgeführt um die im Untersuchungsgebiet relevanten NTFPs zu identifizieren. Sechs Gemeinden (Ahwiawia, Gyasikrom, Chief Camp, Asuopere, Keyasi Camp und Ntesere) wurden im Untersuchungsgebiet zufällig ausgewählt, und eine zufällige Anzahl von Haushalten in jeder Gemeinde interviewt. Zusätzlich wurden zwei der wichtigsten Märkte, die sich im Untersuchungsgebiet befinden besucht, um einen Überblick über die NTFPs zu bekommen, die als Einkommensquelle benutzt werden. Die Umfrage strebte an, auch örtliche Kenntnisse über Umwelt, Erntetechniken und Entwicklung des Vorkommens der ausgewählten Spezies in das Inventurdesign aufzunehmen. Die NTFPs wurden nach ihrer Wichtigkeit für die Subsistenzwirtschaft und als Einkommensquelle ausgewählt.

Durch die erhaltenen Ergebnisse wurden die Spezies je nach Verteilung in zwei Gruppen geordnet. Drei Spezies, Calamus deeratus, Bambus und Raphiapalmen befanden sich vor allem in der Nähe von Strömen und Flüssen. NTFP relevante Baumarten und Büsche verteilten sich über die vielgestaltigen Bedeckungsformen der nicht geschützten Gebiete. Eine Pilotinventur wurde durchgeführt und die Ergebnisse wurden als Faktoren in das Design der Hauptinventur übernommen.

Adaptive Klumpenstichprobenverfahren mit einer systematischen Verteilung wurden entwickelt, um die drei Spezies zu inventarisieren, die sich rund um Augewässer verteilten. Eine systematische Verteilung wurde verwendet, um Vergleiche der Wirksamkeit von systematischen Stichprobeverfahren und adaptiven Klumpenstichprobenverfahren zu ermöglichen, da systematische Probenverfahren in Waldinventuren weit verbreitet eingesetzt werden. Arcview wurde benutzt, um zufällig 2% der Ströme und Flüsse im Gebiet der Studie auszuwählen. Ausgehend von einer zu Anfang zufällig gewählten Stelle wurden systematisch entlang jedes ausgewählten Stroms oder Flusses 50m x 50m Plots in Intervallen von 500 m eingeteilt. Insgesamt wurden 69 systematische Plots aufgenommen. Wo eine der interessierenden Spezies gefunden wurde, wurden 50m x 50m angrenzende adaptive Plots aufgenommen, bis keine der interessierenden Spezies in den Randeinheiten beobachtet wurde.

Bambusklumpen wurden ausgezählt, indem die Anzahl der Klumpen gezählt, die Bodenfläche gemessen und die Anzahl der Stämme gezählt wurde. Ein lineares Regressionsmodell wurde formuliert, um die Validität zu bestimmen, mit der die Bodenfläche eines Bambusklumpens die Anzahl der Stämme vorhersagte. Die Anzahl der Calamus deeratus Pflanzen und Raphia Palmen wurde gezählt und in ausgewachsene und Jungpflanzen gruppiert. Schätzungen wurden mit Hilfe des Hansen-Hurwitz Schätzers gerechnet. Eine effizientere Schätzung könnte durch den Horvitz-Thompson Schätzer erreicht werden, dessen Anwendung jedoch wesentlich aufwändiger ist. Da beide Schätzer dem Zufallsstichprobenverfahren überlegen sind und das Ziel der Anwendung lediglich der Vergleich der Effizienz des adaptiven Klumpenstichprobenverfahrens mit der des systematischen Stichprobenverfahrens war, waren beide Schätzer gleichermaßen geeignet. Die relative Effektivität des adaptiven Klumpenstichprobenverfahrens und der systematischen Stichprobenverfahren für die Inventur jeder der drei Spezies wurde bestimmt, indem ihr Stichprobenfehler für jede Spezies verglichen wurde.

Um einen Überblick über die Verteilung und Häufigkeit der anderen NTFP Spezies im Untersuchungsgebiet zu bekommen wurde eine systematische Klumpenstichprobe benutzt.

Das Systematische Klumpenstichprobenverfahren wurde wegen der relativen Kosteneffektivität von Klumpenstichproben bei der Inventur von größeren Gebieten benutzt. Ein 7km x 7km Quadrat Gitter wurde über das Untersuchungsgebietes gelegt. An jedem Gitterpunkt wurden systematisch vier 50m x 50m Plots an den Ecken eines 100m x 100m Quadrates gemacht. Insgesamt wurden 128 Plots gemessen.

Der Bodenbedeckungstyp, in dem die jeweilige Probefläche vorkam wurde identifiziert. Folgende Bodenbedeckungstypen wurden ausgewiesen: Alte Brachen mit Baumbestand aus natürlicher Regeneration (tree fallow), jüngere Brachen mit Strauchregeneration (shrub fallow), Ackerland (annuals) und Kakao-Plantagen (cocoa farm). Diese Klassifizierung entstand aufgrund der bei der Inventur vorgefundenen Flächennutzungen.

Innerhalb der Probeflächen wurde der Durchmesser aller Baumarten über 10cm Durchmesser auf Brusthöhe (BHD) oder 30cm über der Brettwurzel mit einem Durchmessermaßband gemessen. Jede Baumart wurde mit ihrem lokalen und wissenschaftlichen Namen erfasst und in Handels- und Nicht-Handels-Spezies gruppiert. Dort wo eine Klumpeneinheit in einen Wald oder Sekundärwald fiel, wurde ein 10m x 10m Subplot an einer Ecke des 50m x 50m Plots angelegt, um die Verjüngung aufzunehmen. Baumarten mit weniger als 10cm BHD bis hin zu jungen Bäumen von mindestens 1m Höhe wurden als Verjüngung aufgenommen.

Die Ergebnisse zeigten, dass das adaptive Klumpenstichprobenverfahren für alle drei Spezies ungefähr achtmal so effizient war wie das systematische Stichprobenverfahren. Da jedoch die Wirksamkeit des adaptiven Klumpenstichprobenverfahrens von der Dichte und dem Klumpungsgrad der Spezies abhängt, der gewöhnlich vor dem Beginn der Inventur nicht bekannt ist, kann die Anwendung des adaptiven Klumpenstichprobenverfahrens nicht einfach von einem Bereich auf den anderen übertragen werden. Die Methode sollte mit Umsicht angewandt werden und Pilot Studien können benutzt werden, um die gewünschten Informationen über die Spezies zu erhalten, bevor große Inventur unternommen werden. Das adaptive Klumpenstichprobenverfahren sollte auch in den geschützten Waldgebieten getestet werden, weil Dichte und Klumpungsgrad der Spezies innerhalb der geschützten Waldgebieten anders sein könnten. Bodenfläche von Bambusklumpen stellte sich nicht als guter Vorhersageparameter für die Anzahl von Stämmen in einem Bambusklumpen heraus. Die Validität des linearen Regressionsmodells könnte durch Stümpfe von geernteten Stämmen geschwächt worden sein, die einen Teil der Bodenfläche einnahmen aber nicht gezählt wurden. Wenn die Inventur mit systematischer Klumpenstichprobe nach dem Bodenbedeckungstyp poststratifitiert wurde, kamen Klumpeneinheiten von verschiedenen Klumpen in unterschiedlichen Bodenbedeckungstyp vor, die Anzahl der Plots pro Klumpen war dadurch unterschiedlich. Der Stichprobeumfang für verschiedene Bodenbedeckungstypen war unterschiedlich, was zu unterschiedlichen Genauigkeiten führte. Eine Bodenbedeckungskarte wäre nötig für die Prästratifizierung, um die Methode effizienter zu machen.

Die Dichten der Baumarten stellten sich als gering heraus. Veränderungen in den Bodenbedeckungstypen aufgrund der Umwandlung der Lebensräume der Arten in landwirtschaftliche Flächen könnten dies erklären. Somit hängt die Verteilung der Arten hauptsächlich von dem Interesse der Bauern ab, diese auf ihren Flächen zu halten und zu nutzen. Die Verteilung der Baumarten wird außerdem durch ihre Zugänglichkeit bestimmt: Je leichter zugänglich eine Ressource ist, desto eher wird sie übernutzt.

Die Nutzung der NTFPs deckte vor allem den Eigenbedarf der Bevölkerung. Das Interesse die NTFPs als kommerzielle Einkommensquelle zu nutzen war gering, da die Anzahl an Arten, die als Rohmaterial nutzbar waren, begrenzt war und es an Fachkenntnis für die kommerzielle Erschließung der NTFPs mangelte. Darüber hinaus fehlte der Markt für diese Rohmaterialien und die aus ihrer Weiterverarbeitung entstandenen Produkte. Diese Beobachtungen konnten im Rahmen der vorliegenden Arbeit jedoch nicht näher untersucht werden. Eine Folgestudie wäre daher anzuraten.

Die Inventurergebnisse zeigen, dass in den nicht geschützen Gebieten im Forstdistrikt Goaso, keine Nachhaltigkeit der ausgewählten NTFP Spezies gewährleistet ist. Ein Grund hierfür könnten landwirtschaftliche Umwandlungen und die Ausbreitung von Chlomolaena odorata sein, die die Regenerationsfähigkeit der Spezies hemmen.

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Appendix

Regression

Variables Entered/Removed(b)

Model	Variables Entered	Variables Removed	Method
1	Clump base area(a)		Enter

a All requested variables entered.

b Dependent Variable: Nr of culms

Model Summary(b)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics			
					R Square Change	F Change	df1	df2
1	,740(a)	,547	,538	38,933	,547	63,996	1	53

a Predictors: (Constant), Clump base area

b Dependent Variable: Nr of culms

ANOVA(b)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	97004,599	1	97004,599	63,996	,000(a)
	Residual	80337,510	53	1515,802		
	Total	177342,109	54			

a Predictors: (Constant), Clump base area

b Dependent Variable: Nr of culms

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	36,780	11,416		3,222	,002
	Clump base area	5,487	,686	,740	8,000	,000

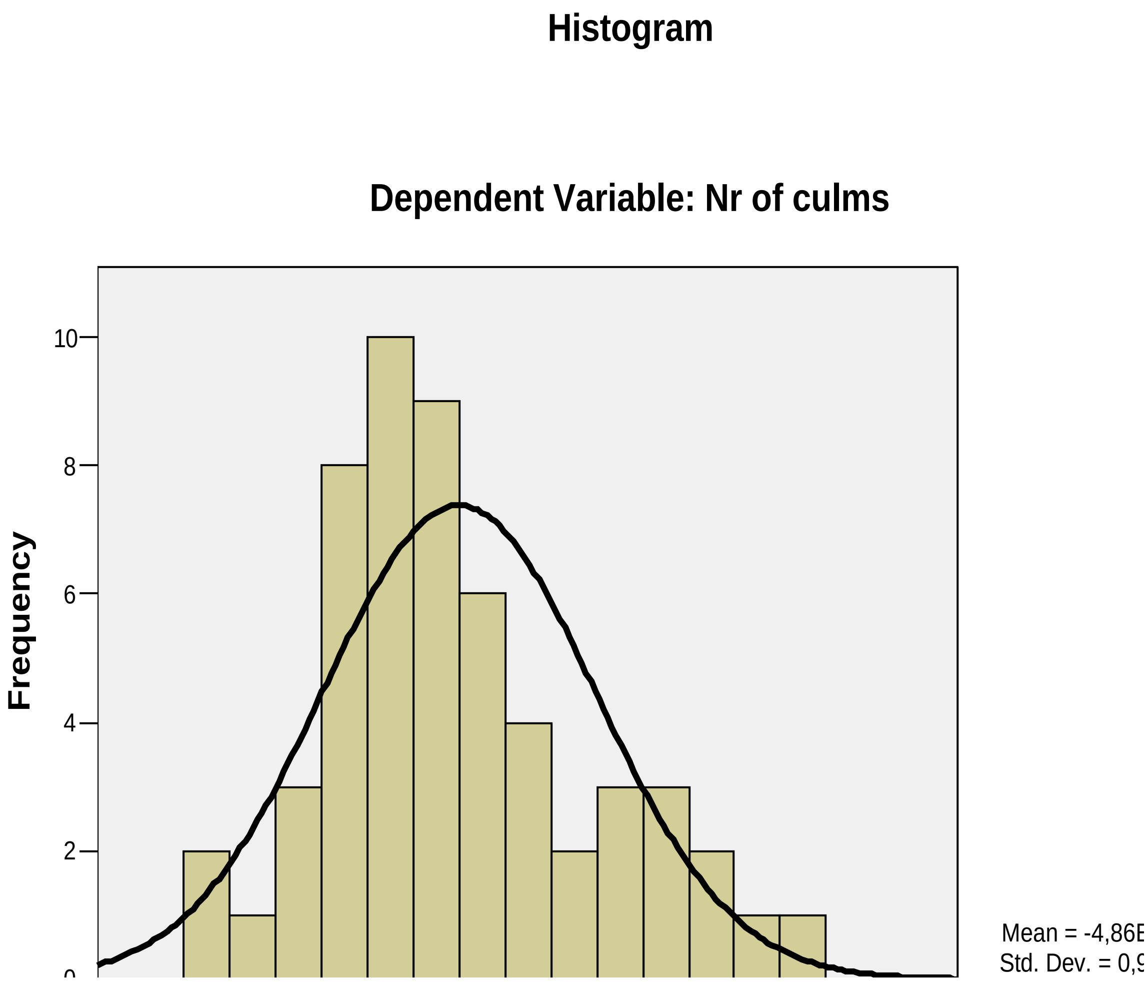
a Dependent Variable: Nr of culms

Residuals Statistics(a)

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	58,73	222,48	117,87	42,384	55
Residual	-72,476	99,081	,000	38,571	55
Std. Predicted Value	-1,395	2,468	,000	1,000	55
Std. Residual	-1,862	2,545	,000	,991	55

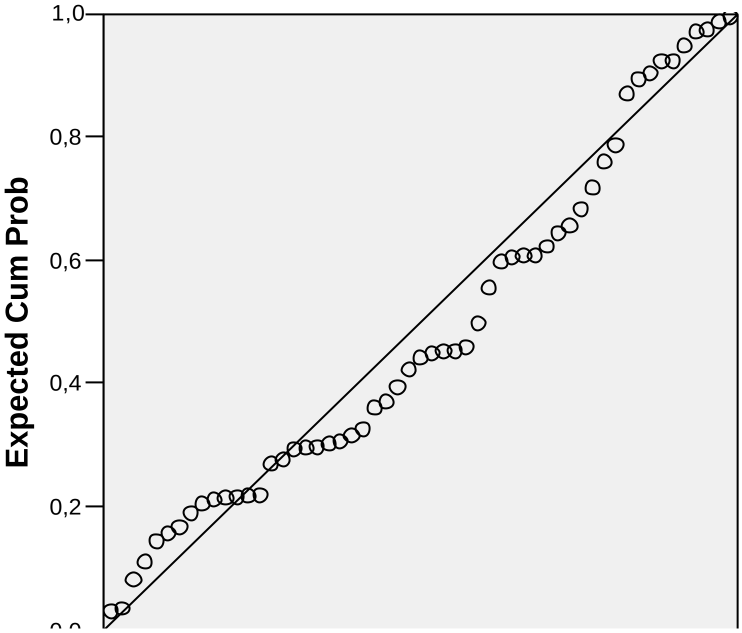
a Dependent Variable: Nr of culms

Charts


Histogram
Dependent Variable: Nr of culms
Frequency
10
8
6
4
2
Mean = -4,86E
Std. Dev. = 0,9

Normal P-P Plot of Regression Standardized Residual

Dependent Variable: Nr of culms



Scatterplot

Dependent Variable: Nr of culms