Geo-information applications for off-reserve tree management

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List of abbreviations and acronyms

ANOVA	Analysis Of Variance
ASTER	Advanced Spaceborne Thermal Emission and Reflectance Radiometer
AVI	Advanced Vegetation Index
BG	BackGround
BI	Bare Soil Index
CIFOR	Center for International Forestry Research
CFM(U)	Collaborative Forest Management (Unit)
DA	District Assembly
DFO	District Forest Office
DN	Digital Number
EM	ElectroMagnetic
ETM	Enhanced Thematic Mapper
FAO	Food and Agriculture Organization
FC	Forestry Commission
FCD	Forest Canopy Density
FLEGT	Forest Law Enforcement, Governance and Trade
GIS	Geographical Information Systems
GORTMAN	Geo-information applications for Off-Reserve Tree Management
GPS	Global Positioning System
ITC	International Institute for Geo-information Science and Earth Observation
ITTO	International Tropical Timber Organization
IUCN	International Union for the Conservation of Nature
LSD	Least Significant Differences
MLFM	Ministry of Lands, Forestry and Mines
MOI	Material Of Interest
NGO	Non-Governmental Organization
NTFP	Non-Timber Forest Product
OASL	Office of the Administrator of Stool Lands
RIS(U)	Resource Information Systems (Unit)
RMSC	Resource Management Support Centre
RS	Remote Sensing
RUDEYA	Rural Development Youth Association
SI	Shadow Index
TBI	Tropenbos International
TI	Thermal Index
TM	Thematic Mapper
TOF	Trees Outside Forests
TUC	Timber Utilization Contract
UF	University of Freiburg (Albert-Ludwigs)
UG	University of Ghana
VLTP	Validation of Legal Timber Programme
WWF	World Wide Fund for Nature

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Preface

This document is a "synthesis report" that reflects on the efforts and the results of the "Geo-information applications for off-reserve tree management" (GORTMAN) project in Ghana.

This project was operating under auspices of Tropenbos International (TBI) and more specifically their Ghana Programme, TBI Ghana.

TBI Ghana pursues a demand-driven, basic and applied, research programme that aims to support improved policy formulation and management of forest/tree resources in Ghana. TBI Ghana simultaneously endeavours to support training that will build and improve research capacity of local institutions.

TBI Ghana fosters collaborative research and co-operation between relevant stakeholders including policy makers, forest owners, forest managers, forest fringe communities, individual researchers and academic institutions in Ghana and abroad.

For more information on TBI and TBI Ghana see www.tropenbos.org.

In December 2001 TBI Ghana invited interested parties to submit pre-proposals for possible projects within its programme. The deadline for pre-proposals was January 31, 2002. Among the organisations/institutions that reacted to this call there were three that submitted pre-proposals that had the following two elements in common:

» They focused on the so-called "off-reserve" forest and tree resources (that is: the forest and tree resources outside forest reserves);
» they intended to make use of "geo-information".

These three organisations/institutions were the University of Ghana (UG), the International Institute for Geo-information Science and Earth Observation (ITC) in The Netherlands and the Albert-Ludwigs University Freiburg (UF) in Germany.

TBI Ghana subsequently asked the three above-mentioned organisations/institutions to combine their three pre-proposals into one, comprehensive, final proposal, design/implementation of which would be the joint responsibility of the three partners. TBI Ghana moreover asked for a fourth partner to be involved in the future project, namely the intended beneficiary and end-user of the project's foreseen outputs, the Resource Management Support Centre (RMSC) of the Forestry Commission of Ghana. Their involvement would ensure the project's embedding in the forest sector's institutional framework/setting.

Extensive consultations between the four partners followed in the course of 2002 and these eventually resulted in submission of a final proposal to TBI Ghana in early 2003. The project eventually became operational in the middle of 2003 and was completed in the beginning of 2006.

The project was organised in such a way that the different partners all had their own work-packages (reflecting their specific professional interests and strengths) which to a large extent could be implemented independently and were their own responsibility. Tasks were roughly divided as follows:

» UG concentrated on the collection of data and the assessment of the various aspects of local stakeholders' use and management of off-reserve forest/tree resources;
» ITC concentrated on the collection of data and the assessment of the various aspects of off-reserve forest/tree resources' condition, distribution and their dynamics;
» UF concentrated on the collection of data and the assessment of the various aspects of one particular component of the off-reserve forest/tree resources: the so-called non-timber forest products (NTFP);

» RMSC ensured the institutional embedding of the project and the relevancy of its outputs, provided logistical support and professional input to the work of all other partners and participated extensively in the project's educational/training activities.

ITC was coordinator of the project.

Upon completion of their individual tasks, each of the partners produced a series of outputs such as reports, maps and databases. What still needed to be done, however, was to bring all these individual bits and pieces of work of each of the partners together into one document that would reflect upon the efforts and results of the project as a whole in a comprehensive and especially coherent way.

This document begins by sketching the context within which the project was undertaken, (including research problem, objectives/research questions, intended beneficiaries, etc.). This is followed by a short introduction to some of the concepts of remote sensing because use of this technology was one of the more important aspects of the project. Subsequently methods/materials employed for data collection/analysis are described. This is followed by a presentation of the most important outcomes/results of the project. The latter are finally discussed vis-à-vis the research questions.

Introduction

1.1. Project's context

Ghana's moist/tropical high forest resources contribute substantially to the country's national economy through the production of timber and the trade of this commodity. In the 1920s to 1940s Ghana's government already brought 20-25 percent of land in the so-called "high forest zone" under its exclusive control by declaring it as "forest reserve".

Rationale behind the establishment of forest reserves was initially an environmental one as the reservation of part of the forest resources was basically aimed at maintaining a "forest climate" in support of the growing of cacao in the same area (Kotey *et al*., 1998). In later years, however, timber production became the main focus in forest reserve policy-making and management.

Ghana's high forest resources also have an important role to play in local economies through local people's subsistence use and sale of many non-timber forest products. These high forest resources also provide various environmental/ecological services such as biodiversity conservation, soil and water conservation and sequestration of carbon. Although – in essence – equally important, above-mentioned forest functions are difficult to value in economic terms and are therefore considered to be of less interest by government.

The land outside the forest reserves has now mostly been converted to agricultural land. These so-called "off-reserve" areas, however, still contain substantial numbers of trees. One finds isolated trees left standing in agricultural fields, young/old secondary forest regenerating from abandoned agricultural land, strips of riparian vegetation along streams and patches of left-over old growth forest treasured as, for example, sacred groves. These trees contribute significantly to rural people's livelihoods through, for example, provision of small timber, firewood, food, medicine, shade trees for cacao, etcetera. These trees also contribute substantially to the national economy. Currently more timber is coming from the off-reserve areas than from the forest reserves (Kotey *et al*., 1998).

The off-reserve tree resources, however, are under substantial and increasing pressure. Once brought under cultivation, the use of land is intensive, which goes hand-in-hand with shorter fallow periods and the removal of trees to reduce competition with crops. Tightened controls on-reserve have brought down logging considerably in those areas. This has caused a shortfall of timber and thus an over-capacity in the timber industry, which timber companies try to compensate by increased logging activities off-reserve. Part of these activities is legal, but because of poor law enforcement much illegal logging also takes place.

Forest legislation is currently such that timber exploitation, be it on-reserve or off-reserve, is controlled by the government. As such both logging companies as well as individual farmers require a permit from the forestry authorities before any timber tree can be removed. Approximately 75% of royalties associated with off-reserve logging goes to the government. The remaining 25% of royalties goes to paramount chiefs and traditional councils because ownership of the land, and with that the forest/trees on it, is vested in them. Individual farmers who tend the land, including the trees on it, receive – at best – only minimal compensation for damage done to crops during logging. Individual farmers therefore have no real incentive to retain timber trees on their land. The 1995 "*Interim Measures to Control Illegal Timber Harvesting Outside Forest Reserves*" gave farmers the right to veto logging and to crop damage compensation. Enforcement of these interim measures, however, is rather poor in practice and the above-mentioned rights of farmers are often denied to them by the authorities involved. In order to avoid or reduce damages and losses farmers engage chainsaw operators to illegally remove adult timber trees or kill these themselves through fire or ring-barking (Figures 1.1.a and 1.1.b). Seedlings and saplings of timber trees are removed before they reach a harvestable size. Farmers basically state that only those timber trees that have a clear function/use within the farming system or farmers' livelihoods are allowed to grow into sizeable dimensions.

Fig. 1.1.a. Setting fire to timber trees.

Fig. 1.1.b. Ring-barking timber trees.

With the continuing disappearance and degradation of the off-reserve tree resources has come increased recognition about their importance and with that the need for more supportive policy-making and more appropriate planning/ management related to them. The latter, however, makes it imperative to have relevant and accurate information about the tree resource-base itself, its users, its functions and uses, its management, etcetera. This type of information, however, is something that is missing to a large extent. Illustrative in this respect is that a complete inventory of off-reserve tree resources has taken place only once (in 1995) and then only for timber trees (Affum-Baffoe, 2001). Partly this is because of methodological problems with the inventory of the resources and partly this is because such inventories would put too much strain on limited human/ financial resources. As such priorities in this respect are put on the forest reserves. Even in the limited number of off-reserve inventories undertaken focus has always been much on timber trees, which means that information on the non-timber tree species, their specific functions/uses, their place/role in land-use systems and implications thereof for their protection/management is even more scarce.

The Forestry Commission recognizes the current shortcomings as regards “information” on the off-reserve tree resources and has expressed the intention to address this situation. The GORTMAN project aims to assist them with that.

1.2. Project’s objectives, research questions and hypotheses

1.2.1. General objective

The general objective of the GORTMAN project was ultimately formulated as follows:
To provide information for the improved use/management of the off-reserve tree resources in Goaso Forest District.

1.2.2. Specific objectives

The specific objectives of the GORTMAN project were subsequently formulated as follows:

- » To compare operational methods for the assessment of off-reserve tree resources condition and distribution;
- » to provide information on off-reserve tree resources condition and distribution, dynamics and functions/uses;
- » to explore several different incentive mechanisms for their potential to stimulate improved use/management of off-reserve tree resources by local stakeholders;
- » to increase the capacity of local institutions (especially FC/RMSC) in the application of geo-information for tree resources policy-making and management.

The above specific objectives reflect upon the element of information provision within the project, but also upon the elements of methodology development and capacity building related to it.

1.2.3. Research questions

The GORTMAN project set out to answer the following research questions:

- » Q.1. To what extent can remote sensing technology be used for the assessment of off-reserve tree resources condition and distribution?
- » Q.2. What is/are the most appropriate operational method(s) for the assessment of off-reserve tree resources condition and distribution?
- » Q.3. What is the off-reserve tree resources condition and distribution and what factors influence these?
- » Q.4. How has off-reserve tree resources’ distribution changed over the last 10 to 15 years and is there a certain pattern of change?
- » Q.5. What are the main functions/uses of off-reserve tree resources for/by local stakeholders?
- » Q.6. What are the main sources (=land cover types) of tree products for local stakeholders?

- » Q.7. What are potential incentive mechanisms for improved use/management of off-reserve tree resources by local stakeholders?
- » Q.8. What – in particular – is the role and importance of non-timber forest products from off-reserve lands for local stakeholders and could this possibly serve as an incentive mechanism?

1.2.4. Hypotheses

The GORTMAN project was guided by the following hypotheses:

- » Off-reserve tree resources density distribution can be mapped using remote sensing technology.
- » There is a relation between both the quantitative as well as the qualitative aspects of the off-reserve tree resources and the prevailing land-use system with its various components such as annual/perennial cropping, fallowing, tree cropping, etc.
- » Off-reserve tree resource destruction and degradation are related to settlement expansion and a changing land-use system.
- » The functions/uses of trees for local stakeholders determine their presence/abundance and local strategies for their conservation.
- » Non-timber forest products could serve as an incentive mechanism for improved use/management of off-reserve tree resources by local stakeholders.

1.3. Project's study area

The GORTMAN project's area of work was Goaso Forest District, Brong Ahafo Region, located between 6°47'48" and 7°06'44" N and 2°17'53" and 2°38'46" W (Figure 1.2). TBI Ghana selected Goaso Forest District as a study area for its projects because it is one of the richest forest districts in Ghana with forest reserves covering 1/3 of its total area of 2,188 km^2. This clearly offered good opportunities to the programme for studying issues related to timber extraction and forest protection together with their socio-economic dimensions.

Goaso Forest District, however, was also a suitable site for the GORTMAN project because its off-reserve areas can be considered representative for many such areas in Ghana, given that they are under intense pressure from agriculture and legal/illegal timber logging and that the land/tree tenure system is typical for many parts of the country.

Goaso Forest District is located in Ghana's high forest zone and its forest can be characterized as "moist semi-deciduous – northwest subtype" (Hall & Swaine, 1981). Their current condition is being described as "degraded" by Hawthorne & Abu Juam (1995).

Goaso has a "humid tropical" climate, with an annual rainfall between 1250 – 1750 mm. The pattern of rainfall is bi-modal, which means that rain comes in two peak periods. The first of these periods is April – July and the second period is September – October. There is thus a long dry spell between November and March and a short one in August. Temperatures are fairly uniform throughout the year with monthly averages ranging between 26° and 29° C. Relative humidity in the dry seasons is between 70 % and 75 % and in the wet seasons between 75 % and 80 %.

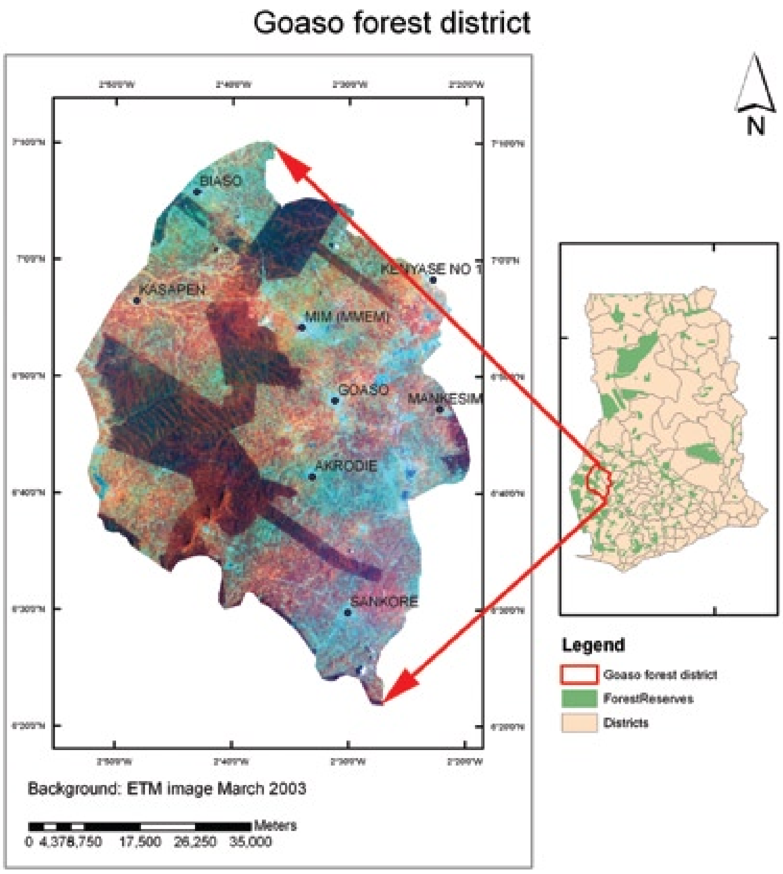


Fig. 1.2. Map of Ghana with location of study area (arrow on the left).

Fig. 1.3.a. Cultivation of food crop: cocoyam.

Fig. 1.3.b. Cultivation of tree crop: cacao.

Goaso's topography is "gently undulating lowland" ranging between 100 and 300 m above sea level. Soils are mainly of the "forest ochrosol" type, which are red(dish) and well drained in the upper horizons and brown(ish) and moderately well drained in the middle horizons. Fertility of these soils is reasonably good, supporting the growth of food and tree crops. Most nutrients, however, are concentrated within the top 30 – 40 cm where accumulation of organic matter has occurred over time and fertility therefore easily declines through erosion and leaching if the soil becomes exposed to water, wind and sun.

Goaso's predominant land use is rain-fed agriculture. Crops that are most commonly grown are annual/perennial food crops such as maize, cocoyam, cassava and plantain and perennial tree (=cash) crops such as cacao and oil palm (see Figures 1.3.a. and 1.3.b).

Land preparation is basically of the slash and burn type and cropping mostly mixed. Mono-crops such as cacao and oil palm usually also start in a mixed cropping system with their seedlings inter-planted with food crops such as the ones mentioned above. The reason for this is twofold: firstly the young plants of the tree crops require some shade which is provided by the food crops and secondly the tree crops take time to become productive and the food crops provide the farmers with some return during this period. Over time, however, the food crops recede and eventually only the mono-crop remains. In areas where only food crops are grown, land is left to fallow after a couple of years. Land, however, is getting scarce nowadays and as a result fallowing periods shorten. The average fallow period is now 4 – 6 years whereas previously it was up to 10 years (farmers pers. comm.). Once thresholds of cultivation intensity and soil impoverishment are crossed, weeds such as *Chromolaena odorata* (local name: *acheampong*) and grasses such as *Pennisetum purpureum* and *Imperata cylindrica* tend to encroach fields, rendering further cultivation at least impractical and sometimes even impossible.

Cacao (*Theobroma cacao*) has been the traditional cash crop of the area since the 1940s. Droughts/bushfires, diseases and low producer prices in the late 1970s and early 1980s, however, led to the destruction, degradation and/or abandonment of many cacao farms. Many farmers switched to increased food crop production and marketing in response, whereas especially oil palm (*Elaeis guineensis*) emerged as an alternative cash crop. Since the beginning of the 21st century, however, a renewed interest in cacao is emerging. The market for food crops is finite and the prices for food crops fluctuate greatly, which makes their production a more risky and less interesting option than it initially seemed. The market for cacao, on the other hand, is growing and prices are increasing. Government, moreover, is actively promoting cacao production again through, for example, guaranteed pricing and the subsidized provision of fertilizer and pesticides. New hybrid plant varieties, less susceptible to diseases, are thereby replacing the old ones.

The population of Goaso Forest District was approximately 174,000 in the 2000 census. Most people (about 70 %) belong to the "Akan" ethnic group, but there is also a good representation (about 15 %) of people belonging to the "Mole-Dagbani" ethnic group. The latter originate in northern Ghana, but have over time settled in the district in order to work in cacao farming and timber logging/processing.

Land in Goaso Forest District is owned by the Mim, Goaso, Kukuom and Akrodie stools (a "stool" literally means the "seat" of a chief).

The district's main economic activity is farming with 70.1% of people working in this sector. 5.9% of people work in the timber logging/processing, 9.6% in "services" and 14.4% in "commerce".

Farming land, however, is getting scarce (due to population growth and tenure issues). With that the traditional system of fallow cultivation is becoming unsustainable and uneconomical (also see above) and especially young people are now moving from rural to urban areas in search of other opportunities.

The three biggest towns or urban areas of the district are Goaso, Mim and Sankore. Goaso thereby has about 15,000 inhabitants, Mim about 22,500 and Sankore about 5000. Goaso is the capital of the district and its administrative and commercial centre with reasonably good facilities in terms of education, healthcare, finance and communication. Goaso is more or less located in the centre of the district and is linked by good/tarred roads to Sunyani (in the north), Kumasi (in the east) and Western Region (in the south). Many villages, however, are more difficult to reach, especially so in the rainy seasons. Mim and Sankore are local centers for timber logging/processing and attract labour and economic activities associated with that.

1.4. Stakeholders in off-reserve tree use/management

The stakeholders most actively and directly involved in off-reserve tree use/management in Ghana are the following:

- » Forestry Commission (FC) (and units including the RMSC and DFO);
- » Loggers/chain-sawers;
- » Farmers/communities.

FC, RMSC and DFO are the designated/formal managers of the off-reserve tree resources. Loggers/chain-sawers and farmers/communities are its users and its de-facto/informal managers. See Figure 1.4.

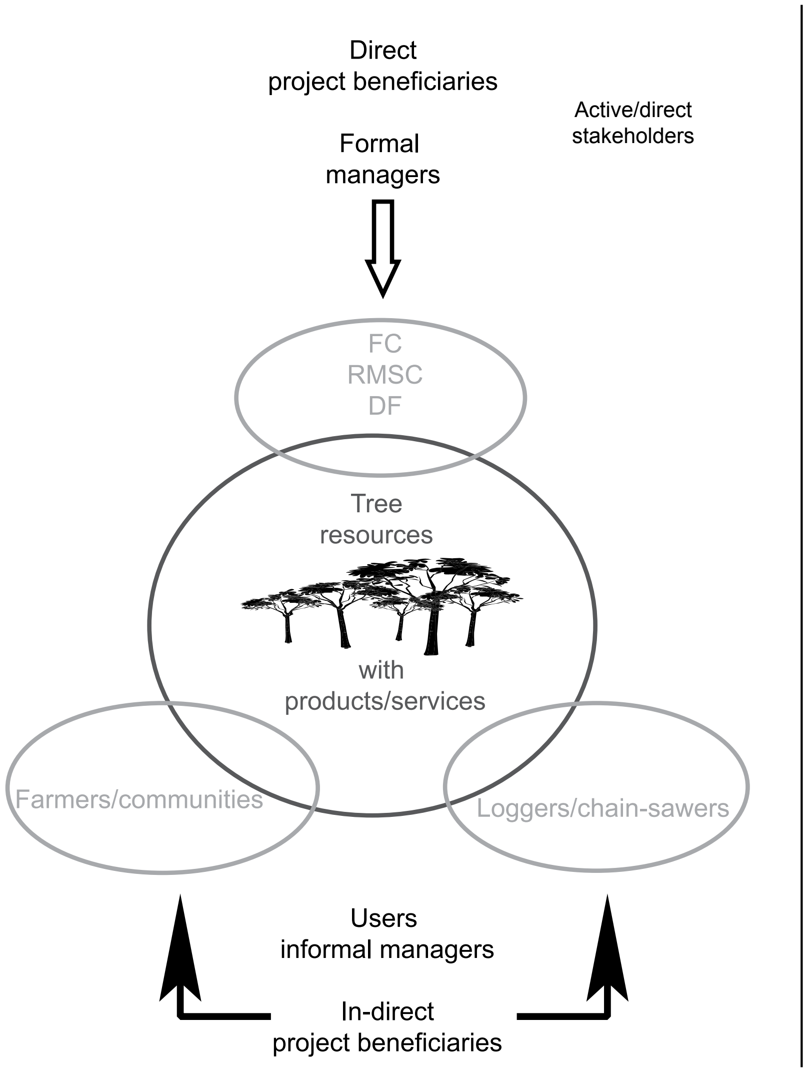


Fig. 1.4. Stakeholders in off-reserve tree use/management and project beneficiaries.

In addition to the above one can also identify a number of stakeholders that are more passively and indirectly involved.

These are:

- » Ministry of Lands, Forestry and Mines (MLFM),
- » Office of Administrator of Stool Lands (OASL),
- » District Assemblies (DAs) (=local government),
- » Traditional Authorities.

1.4.1. Forestry Commission

The Forestry Commission (FC), under the Ministry of Lands, Forestry and Mines is the main forestry authority in the country and responsible *for the regulation of utilization of forest and wildlife resources, the conservation and management of those resources and the formulation/coordination of policies related to them*.

Chiefs and councils, through a combination of statutory and customary law, are essentially the land- and forest/tree-holding authorities in the off-reserve areas. Government, however, has by legislation given itself the right to all the timber trees. Government therefore grants the "concessions" or "timber utilization contracts" (TUCs). The FC takes 40% of royalties associated with exploitation of off-reserve timber trees (with the other 35% of government's share of royalties going to the District Assembly and the Office of the Administrator of Stool Lands) to cover its management costs.

1.4.2. Resource Management Support Centre

The Resource Management Support Centre (RMSC) is a separate – specialist – unit within the FC. Their official mission is t*o develop (effective, efficient and affordable) forest and wildlife management systems and to facilitate and monitor their implementation through active cooperation with stakeholders*.

Some of their somewhat more concrete/tangible activities are:

» To monitor and report on the state/condition of Ghana's forest and wildlife resources;
» to assist forest districts with the preparation of management plans for their permanent (=reserved) forest and wildlife resource areas;
» to support the formulation of forest and wildlife policy.

1.4.3. District Forest Office

The District Forest Office (DFO) is the executing/operational unit of the FC. Among its activities are:

» Protection of forest reserves (from e.g. fire and illegal farming);
» control of logging (on-reserve and off-reserve);
» revenue collection (on-reserve and off-reserve);
» control of NTFP extraction from forest reserves.

1.4.4. Loggers/chain-sawers

Logging takes place within the framework of so-called "timber utilization contracts" (TUCs), a concept/system introduced in the 1997 "*Timber Resources Management Act*". TUCs (both on-reserve as well as off-reserve) are granted to contractors by the FC, usually without consultation with stools, farmers/communities or local government.

Besides TUC contractors, there are also chainsaw operators that extract timber trees. Most of these, unlike TUC contractors, convert the timber trees to lumber on the spot. Although felling damage might still occur, there is no log extraction damage in this way. Farmers can also arrange that logging does not take place during the cropping season. This makes it a more attractive mode of logging to farmers, whereas it usually also gives them a better position to negotiate compensation or some other kind of payment. The 1998 "*Timber Resources Management Regulations*" have banned chain-sawing, both to control logging as well as to improve the timber to lumber conversion efficiency. It is, therefore, an illegal activity. There was, however, apparently little recognition of the useful role that this activity played in meeting the needs of local people and the demands in the domestic market for cheap, if somewhat roughly sawn, lumber, so this kind of logging still goes on unabated.

1.4.5. Farmers/communities

Farmers are active tree users/managers and conserve and manage trees in their farming/land-use system for a range of products and services that these trees provide. Farmers mostly practice shrub/tree fallowing, a system which relies on the regeneration of woody vegetation to restore levels of nutrients after a number of years of cultivation. Farmers' main focus is thereby on pioneer tree species, which are often species with a lesser economic (=timber) value.

Farmers moreover collect non-timber forest products, especially for domestic purposes. Most of those would come from farmers' own crop and fallow lands (Falconer, 1992). Certain products (often marketable/commercial ones such as bush-meat, canes, chewing sticks, food wrapping leaves and medicines) require more of a forest environment. With old-growth forest or old(er) secondary forest becoming scarce off-reserve, people increasingly need to enter forest reserves to collect these.

Farmers, on whose land the majority of unreserved tree resources are found, have no rights to timber trees (although some domestic use is permitted) and when timber trees are felled, farmers receive little or no compensation for damage to cacao and other crops. They may or may not receive small direct payments from loggers and/or negligible benefits from royalties (through traditional authorities and/or district assemblies).

1.4.6. Ministry of Lands, Forestry and Mines

The Ministry of Lands, Forestry and Mines exist to ensure the *sustainable management and judicious utilization of the country's land, forest, wildlife and mineral resources*. The Ministry in this respect operates at the strategic rather than at the executive level (the latter is basically the responsibility of FC, RMSC and DFO).

The Ministry is thus the body primarily responsible for policy-making and legislation. The Ministry is also charged to ensure the equitable access to and benefit sharing from land, forest, wildlife and mineral resources and is thus meant to promote and facilitate local community and private sector participation in resource management and utilization. The Ministry is also charged to ensure good governance (accountability, transparency) in issues pertaining to land administration/ownership.

1.4.7. Office of Administrator of Stool Lands

The Office of the Administrator of Stool Lands is another government body taking a share of the royalties paid in association with the exploitation of off-reserve timber trees. The Office of the Administrator of Stool Lands falls under the Lands Commission of the Ministry of Lands, Forestry and Mines and takes 6 % to cover expenses associated with its task of being "trustee" for the stools.

1.4.8. District Assemblies

District Assemblies consist of elected representatives of all towns and villages in a district and government appointed representatives and represent local government. They are – in general – responsible for a district's overall management and development. They take 29.7 % of royalties associated with the exploitation of the off-reserve timber. There appears to be no clear specification as to how this money is supposed to be spent but the basic assumption is that it should go to community development activities. District Assemblies, however, are more often than not seriously constrained financially and the royalties are therefore often used to meet administrative expenses instead.

1.4.9. Traditional authorities

Mentioned here should be paramount chiefs, stool chiefs and traditional councils (=bodies composed around a paramount chief and consisting of a number of stool chiefs). Chiefs and councils, through a combination of statutory and customary law, are essentially the land- and forest/tree-holding authorities in the off-reserve areas. Government, however, has by legislation given itself the right to exercise control of especially timber tree management (or rather exploitation) in the off-reserve areas. Despite their legal position as owners of both timber as well as non-timber trees traditional authorities have thus only been left with decision-making powers regarding management/exploitation of non-timber trees in the off-reserve areas.

Despite the above, traditional authorities still derive some benefits from the exploitation of the off-reserve areas, because they receive part of the royalties to be paid by loggers. 13.5 % of these royalties is allocated to stool chiefs and 10.8 % to traditional councils. There is no clear specification as to how this money should be used by those concerned, but it is commonly acknowledged that it is usually used towards private ends rather than towards the common good.

1.5. Project's beneficiaries

The project's potential beneficiaries will especially be those stakeholders that are actively and directly (see paragraph 1.4.) involved in off-reserve tree use/management: FC, RMSC, DFO, loggers/chain-sawers and farmers/communities.

One could say that of the five stakeholders mentioned above, there are three whose formal/designated job it is to manage the off-reserve tree resources: FC, RMSC and DFO. These stakeholders are arguably and undoubtedly the ones that are most in need of information on the off-reserve tree resources and therefore the ones that will benefit directly from the project.

Because of improved information, management of tree resources is likely to improve, which will eventually result in an improved condition of the off-reserve tree resources. This will then benefit those stakeholders that depend on the off-reserve tree resources for their livelihoods and well-being, namely the loggers/chain-sawers and the farmers/communities. The project's benefits for these stakeholder groups will be more indirect and will take longer time to accrue. See Figure 1.4.

1.6. Information users/needs

The FC is responsible for forestry issues concerning the national – economic – interest, such as the development and control of the timber industry and the marketing of timber. The FC is currently developing a digital database on timber trees in forest reserves. Hereby information on species, diameters and growth rates is stored in tabular form whereas also a spatial component in the form of digital stock maps is being developed. This database is in essence the starting point for a computerized "log tracking system" which will enable tracking of timber from source to destination including during transport and processing.

Above-mentioned log tracking system is being developed within the framework of FLEGT, the abbreviation standing for Forest Law Enforcement, Governance and Trade. FLEGT is a European Union programme targeting illegal logging and timber trade. Ghana was one of the first countries in Africa to endorse FLEGT and in January 2005 its government launched its "validation of legal timber programme" (VLTP) through the FC and the development of the log tracking system takes place within VLTP.

The digital database including the digital stock maps will simplify and quicken activities such as establishing/predicting current/future logging quota, planning/management of logging operations, keeping track of species that are being over- or under-exploited, identifying areas in need of reforestation, afforestation or forest improvement, etcetera. The FC would eventually like to extend the database to include timber originating from the off-reserve areas as well.

RMSC and DFO are involved in the day-to-day planning/management of resources. RMSC thereby has (as is in its name) a supporting role and DFO an executing role. RMSC and DFO currently confine themselves to the planning/management of reserves (forest and wildlife) and to those parts of the off-reserve areas where timber is found. RMSC and DFO are usually involved in pre-felling surveys/stock enumeration, the allocation of tree felling quota and eventually the monitoring of logging activities. Contractors plan/manage the actual logging operations.

RMSC seems to be the organisation that would be most suitable to take the task of collecting more information on the off-reserve tree resources upon itself or at least to facilitate it. The future need for information thereby clearly goes beyond the current one on just timber (as a tree product) and timber tree species (as the ones providing this product). The focus should also be on non-timber tree products/species given the important role these play in rural household economies through providing food, medicine, income, etcetera. The focus should also be on the functions of trees in terms of soil/water conservation (because it is related to sustained food/tree crop production) and to biodiversity conservation and carbon sequestration, because the latter two are not necessarily issues of national/global concern only, but might warrant local concern too.

In terms of needs for information there are – in general – three types of information that could be focused on: information on resource status, resource dynamics and actual and potential resource use/management. Within these broader categories of information one could subsequently focus on parameters such as:

Tree resource status:

» Occurrence/location/densities;
» distribution;

- » species;
- » diameter, height, crown size, volume, biomass.

Tree resource dynamics:

- » Regeneration;
- » growth rates;
- » spatial dynamics (information on change is particularly important in situations of dwindling resources).

Actual and potential tree resource use/management:

- » Data on use (current/future) of timber (=wood) and non-timber (=non-wood) products;
- » future demand for the same;
- » current management practices;
- » future incentive mechanisms for improved management practices.

The most appropriate scale on which information needs to be collected seems to be forest district level as this corresponds with the operational forest management unit level in Ghana.

The most appropriate frequency on which information needs to be collected is difficult to determine in advance as much of it depends on the dynamics (changes) in the resource status and use/management.

There are two units within RMSC that are particularly well placed in respect of the above: RIS (resource information systems) and CFM (collaborative forest management). The 1st unit is mandated *"to facilitate the organization, management and dissemination of resources information critical to forest and wildlife management policy formulation and decision-making"* (thereby using surveying, digital mapping, remote sensing, GIS). The 2nd unit is mandated *"to explore the development of collaborative forest management systems that bring communities and other stakeholders into mainstream management and development of resources".*

Strength of RIS seems to be related to especially the "quantitative" aspects of information (off-reserve tree resource condition, distribution and its changes/dynamics over time). Strength of CFM seems to be related to especially the "qualitative" aspect of information (off-reserve tree resource use/functions, but also incentive mechanisms to stimulate improved use and co-management by loggers/chain-sawers and farmers/communities).

1.7. Project's research problem

From the preceding, it can be deduced that the GORTMAN project's research problem was "information" or rather lack thereof.

Information is important because it is a prerequisite for (more) sustainable management. The bottom-line hereby really is that "*if one doesn't know what there is, where it is and how it is changing, how does one know how to manage it*".

The off-reserve tree resources of Ghana might also be called "trees outside forests" (TOF), the internationally commonly used term for these kinds of resources (FAO, 1998). Worldwide trees outside forests are becoming increasingly more important because they help to off-set the various negative effects of the continuing loss/degradation of forests. Initially there was much emphasis on the role they played at local level, helping to sustain rural household economies, to maintain/restore the physical environment needed to sustain crop production and to secure/maintain land ownership or land use rights. Recently, however, it is also increasingly being recognised that they play an important role at national/global level as well by, for example, meeting needs for both products/commodities such as timber and non-timber forest products as well as environmental services such as biodiversity conservation and carbon sequestration (Arnold & Dewees, 1997; Bellefontaine *et al*., 2002).

TOF, whether remnants of forest or planted, are also seen as an important element in the broader "forest landscape restoration" approach as is currently being developed by leading international forestry organisations/institutions such as ITTO, IUCN, FAO, CIFOR and WWF (McCracken *et al*., 2007).

A characteristic of TOF is that they are often highly scattered and highly dynamic ("present today, gone tomorrow"). Ghana's off-reserve tree resources form no exception. This brings with it certain methodological problems in their quantitative assessment. Their highly scattered nature makes traditional forest inventory methods less useful and their highly dynamic nature makes repeated inventorying more or less a necessity. Inventories, however, are time-consuming, labour-intensive and therefore costly. Conducting them at frequent intervals is therefore not really an attractive prospect (especially in developing countries).

Both the above-mentioned quantitative assessment problems (scattered occurrence and dynamics) could possibly be overcome through the use of remote sensing technology. People were skeptical about this first, but especially recent technological developments (new sensors, new software, etcetera) now offer opportunities that did not exist before. Problems that hamper conventional inventorying (time, labour, money) do not necessarily apply here, but what could – at least for the time being – obstruct progress could be limited capacity as regards knowledge/skills of/in remote sensing for (TOF) mapping and monitoring.

A specific aspect of quantitative assessment of TOF would be inventory of NTFPs. Whereas timber (=wood) inventory is relatively straightforward, inventory of NTFPs brings a considerable number of very specific problems with it that – among others – are associated with the range of products and the range of sources involved (Wong, 2000). Within Ghana, assessment of NTFPs has only taken place inside forest reserves (Falconer, 1992).

The qualitative assessment of TOF (uses/functions, importance, management, etcetera) basically doesn't bring any special or insurmountable methodological problems with it. Available would be the meanwhile well-known extensive toolbox of participatory appraisal/learning techniques that over time have proven their suitability for this work. What, however, is not commonly done in this respect is to look explicitly at the aspect of spatial/geographical variability of the issues studied and to spatially integrate qualitative assessment data with quantitative assessment data to see if there are any relationships between them. Doing so evidently has potential to add value to the work. GIS technology could be used in this respect.

A specific aspect of the qualitative assessment of the off-reserve tree resources in Ghana is to explore possible incentive mechanisms for their improved use/management. Continuation of current practices of gradually clearing away all tree resources outside reserves is clearly not an attractive prospect for any of the stakeholders concerned (government, loggers/chain-sawers and farmers/communities). Not only because further destruction and degradation of the off-reserve tree resource is undesirable in it self, but also because it will increase pressure on the forest reserves, which is equally undesirable.

1.8. Project's research approach

The GORTMAN project's research approach is schematically represented in Figure 1.5 below.

1.9. Project's organisation

The GORTMAN project was organised in such a way that the different partners all had their own work-packages which, to a large extent, could be implemented independently and were their own responsibility (see the "preface" of this document). Consequently all partners also chose to carry out their share of the project in different ways:

- UG had staff involvement in design of field-data collection methodology, testing of field-data protocols and analysis of collected field-data, but the actual field-data collection was done by RMSC's CFMU and "Rural Development Youth Association" (RUDIYA). Results were eventually presented in a small book.
- ITC had staff involvement in design of field-data collection methodology, testing of field-data protocols and analysis of collected field-data, but the actual field-data collection was done by various MSc students within the framework of their individual thesis work. Results were eventually presented in MSc theses.
- UF contributed through the work of a PhD student and the results of his work were eventually presented in his dissertation.

For a list of the various documents produced by the project and used for this report, see Appendix 1.

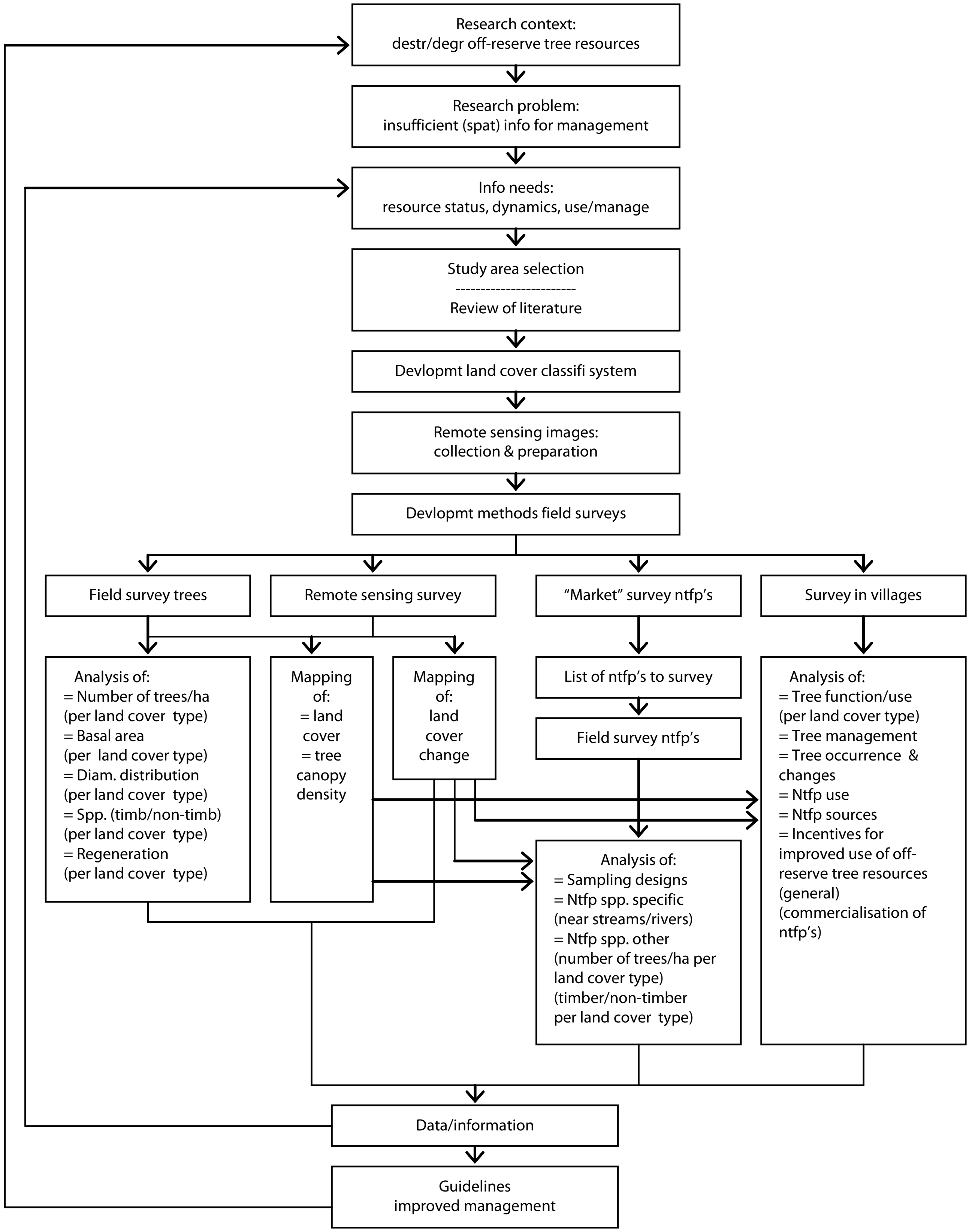


Fig. 1.5. Research approach.

2 Concepts & definitions

2.1. Remote sensing

The following are two of the many definitions of remote sensing one can find in literature:

» Remote sensing is the science of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation (Lillesand *et al*., 2004).
» Remote sensing is the science of acquiring, processing and interpreting images that record the interaction between electromagnetic energy and matter (Sabins, 1996).

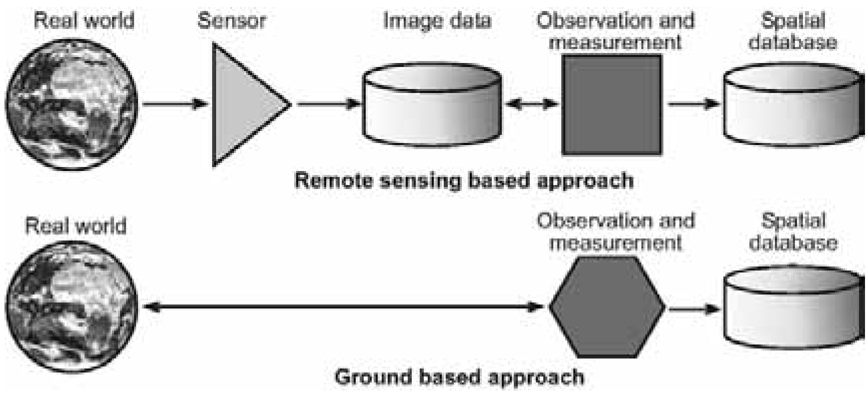


Fig. 2.1. Principle of a remote sensing based approach compared with a ground based approach in terms of spatial data acquisition. (Source: ITC, 2004.)

These two definitions reflect what most definitions of remote sensing have in common, namely:

» That data on characteristics of the earth's surface are acquired by a device that is not in contact with the objects being measured (as opposed to ground-based approaches) (see Figure 2.1).
» That data on characteristics being measured are related to the electromagnetic energy reflected and emitted by the earth's surface.

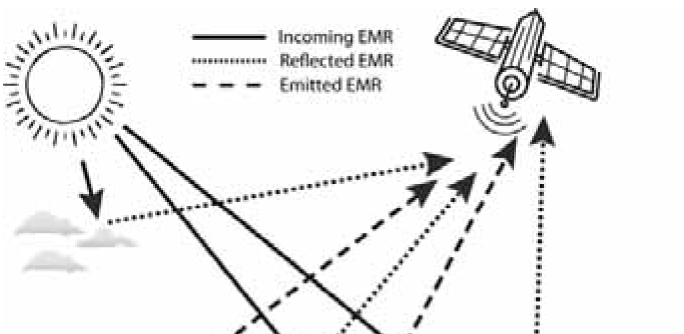


Fig. 2.2. Principle of remote sensing in terms of its measurement of reflected and emitted electromagnetic energy. (Source: ITC, 2004.)

The sun radiates electromagnetic (EM) energy, part of which is transmitted to the surface of the earth (whereas the other part is absorbed/scattered by particles in the atmosphere). The radiation reaching the surface of the earth is partly absorbed, partly transmitted and partly reflected. The earth itself is also a source of energy and is therefore also an emitter of EM energy. See Figure 2.2.

EM energy radiates in accordance with basic wave theory and comprises a wide spectrum of wavelengths (see Figure 2.3). Conventional remote sensing thereby typically operates in the visible (red, green, blue) and infrared (near, middle, thermal) part of the spectrum.

The devices used for measuring the EM energy can be mounted on a range of carriers: satellites, high and low altitude aircraft, but also on ground-borne vehicles such as cranes. In satellite (or so-called space-borne) remote sensing (which was the focus of the project) the devices used for measuring the EM energy are usually referred to as sensors, whereas the satellite itself is referred to as a platform.

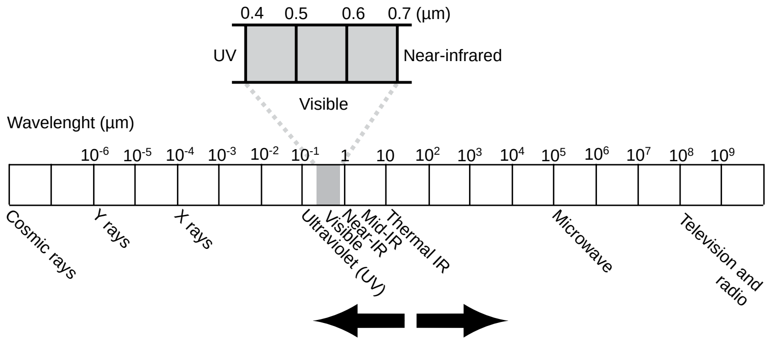


Fig. 2.3. Electromagnetic spectrum with typical remote sensing window in visible and infrared wavelength ranges (green arrow). (Source: ITC, 2004.)

2.2. Spectral signatures

All features on the surface of the earth have their own characteristics in terms of absorption, transmittance, reflection and emission of electromagnetic energy.

Some absorb more and reflect less than others and for different parts of the spectrum. Black objects, as the most extreme example, absorb all energy and thus reflect none. Green vegetation on the other hand (and especially the chlorophyll that it contains) strongly absorbs energy in the visible red and blue wavelengths, but highly reflects in the visible green: hence our perception of vegetation being green.

Each object on the surface of the earth in this way has its own spectral reflection characteristics, its so-called spectral signature, based on the materials it is made of. Knowledge hereof ultimately enables the translation of the raw digital image data as measured/recorded by the sensor (see further) into more meaningful thematic information such as land cover types (water, built-up, bare soil, crops, forests/trees, etcetera).

2.3. Pixel

Sensors typically measure/record and store reflection values in a regular arrangement of rows and columns of grid-cells. See Figure 2.4. Grid-cells are thereby called pixels. Together these pixels form an image and a pixel is thus the smallest element of an image. Each pixel corresponds with a particular area on the ground for which reflected energy was measured and recorded.

The size of the area covered by the pixel, the pixel-size, is basically defined by the sensor that is used in image acquisition and can range from less than 1 m^2 to more than 1 km^2. Currently much used sensors are Landsat ETM+ (pixel size 30 m) and Terra ASTER (pixel size 15 m). Imagery with these pixel sizes is usually referred to as medium resolution imagery.

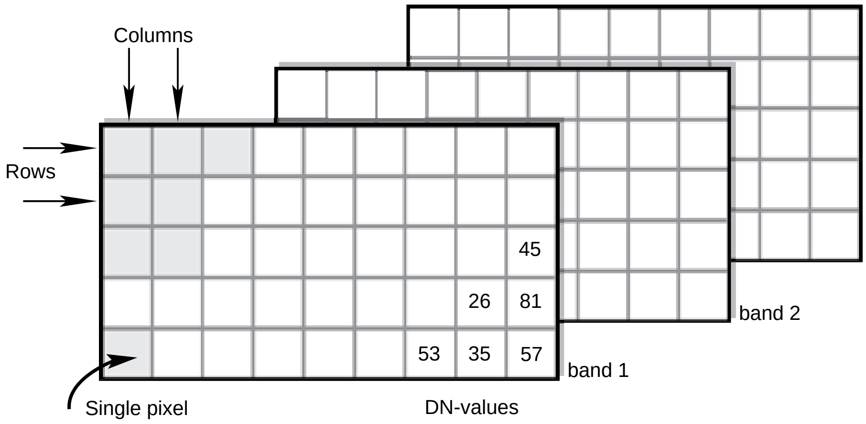


Fig. 2.4. The structure of an image with pixels with digital numbers in rows and columns and multiple bands. (Source: ITC, 2004.)

Sensors typically measure/record reflection values for a range of different wavelengths or parts of the electromagnetic spectrum and then store these in different so-called bands. See Figure 2.4.

2.4. Digital numbers

The magnitude of the measured/recorded reflected EM energy for each pixel in an image is converted to so-called digital numbers (DN) and rescaled in a range between 0 and 255 (corresponding with no reflectance (=0) to very high reflectance (=255)). See Figure 2.4. The digital numbers in an image can be (and usually are) visualized using colours.

2.5. Image classification process

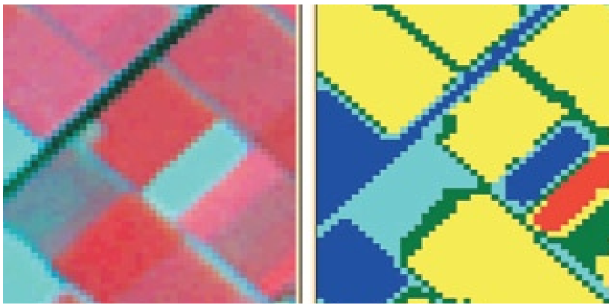


Fig. 2.5. The process of classification of an image (a) in which each pixel is assigned to some thematic class (b). (Source: ITC, 2004.)

The process of assigning themes or classes (in case of the project land cover classes) to raw digital image data (digital numbers) is commonly referred to as image classification. For an illustration of this process, see Figure 2.5.

Many different image classification methods exist. All these different methods, however, can basically be grouped into the following three approaches:
- Automated;
- manual;
- hybrid.

In automated or digital image classification an algorithm is used to systematically assign individual pixels or groups of contiguous pixels to one of a number of predefined classes. The process, however, still requires human input/information in the sense that it is an analyst/operator who defines which conditions pixels need to meet before they can be assigned to certain classes.

In manual or visual image classification analysts/operators employ cues in an image that can be perceived by the human eye (such as colour, texture, pattern, shape, size and (locational) relationship to other objects) to identify the various classes within an image. Analysts/operators view an image on either a computer screen or a hardcopy printout and then draw polygons around areas that are identified as belonging to certain classes.

In hybrid image classification a combination of automated and manual methods is used. One could, for example, use an automated method to do the initial classification and then use a manual method to refine the classification and correct obvious errors.

2.6. Automated/digital image classification methods

The following two automated/digital image classification methods are commonly used:
- Pixel-based;
- object-based.

2.6.1. Pixel-based classification

As described in the previous paragraph, in automated or digital image classification computers/algorithms basically do the work of assigning individual pixels to classes. Human input/information, however, is still required in the sense that it is an analyst/operator who defines which conditions pixels need to meet before they can be assigned to classes.

This human input/information can – in principle – be provided before and after the algorithm is run. When provided before, the procedure is referred to as supervised classification, but when provided after, the procedure is referred to as unsupervised classification.

In supervised classification, an analyst/operator first identifies clusters of more or less homogeneous pixels in an image that can be considered as representative examples for various predefined classes. These clusters of pixels are referred to as training samples. They are subsequently used by the algorithm to classify the remainder of the image based on similarities between the sample/training pixels and the other pixels.

In unsupervised classification, the procedure starts with the algorithm clustering pixels with more or less similar reflectance values into more or less homogeneous classes. These classes, however, are as yet un-labelled and it is only afterwards that the analyst/operator comes in to give the clusters of pixels as identified by the algorithm meaningful names.

Supervised/unsupervised classification as described above is referred to as pixel-based because it basically looks at spectral signatures/information on a pixel-by-pixel basis without incorporating any contextual information. Both in supervised as well as unsupervised classification one can choose between different algorithms. Supervised classification, however, has a greater variety in the available algorithms.

2.6.2. *Object-based classification*

Another (relatively new) approach to image classification is object-based classification. Object-based classification refers to objects, groups of more or less homogeneous pixels, which together form an object with distinct boundaries and separated from neighbouring objects.

In object-based classification the objects are thus defined before the actual classification, whereas in pixel-based classification the classification procedure itself creates the objects.

In object-based classification, the procedure starts with the grouping of contiguous pixels into relatively homogeneous areas through a process that is referred to as segmentation. Starting from a single seed pixel its neighbouring pixels are evaluated and when they are within a range defined by the algorithm they are assigned to the object of the seed pixel. This process is called region-growing: from a centre-point (the seed pixel) the algorithm seeks for boundaries, for example pixels with a distinct difference from the seed pixel and its neighbours. The entire image is thus divided into segments. For an illustration of this process, see Figure 2.6.

Fig. 2.6. Illustration of process of segmentation of an image as step in object-based classification. (Source: Definiens Imaging, 2003.)

Once an image has been segmented in this way, the classification will take place at the segment level instead of the pixel level.

2.7. Accuracy assessment

Image classification is preceded by fieldwork and followed by accuracy assessment. Fieldwork prior to image classification is essentially standard procedure and is meant to guide analysts/operators with linking spectral signatures/values to land cover classes. After classification one should check its results with another set of field observations. Distinctly different land cover classes do not always have distinctly different spectral signatures or the other way round and as a consequence errors in the classification are likely to occur: these need to be analysed in order to be able to judge whether the resulting land cover map is of acceptable quality or not.

The accuracy of a land cover map can be assessed using statistical sampling procedures outlined in many remote sensing textbooks. The basic idea is to select a number of points in each of the land cover types in the final classified map and then to go into the field to see what type of land cover is actually there.

This information is then compiled in a contingency table (or confusion/error matrix) such as shown in Table 2.1, so that accuracy (overall, but also accuracy of each class) can be determined.

Table 2.1. Illustration of process of accuracy assessment of a classified image using a so-called contingency table. (Source: AMNH, 2008.)

Contingency table: a pixel by pixel comparison of ground reference class to satellite-based map class.

		Satellite Map Class (pixel counts)					Producers Accuracy	
	Cover Type	Conifer	Hardwood	Grass	Barren	Total	Percent Correct	
ground reference	Conifer	911	20	1	0	932	97.7	(1-omission error)
	Hardwood	40	343	72	2	457	75.1	
	Grass	0	62	176	14	252	69.8	
	Barren	0	0	19	27	46	58.7	
	Total	951	425	288	43	1687		
	Users Accuracy, Percent Correct	95.8	80.7	65.7	62.8		86.4	
		(1-comission error)						

The table above shows that of 1687 ground reference points, 1457 (911+343+176+27) were correctly classified, which gives the classification an overall accuracy of 86.4 %.

The column at the right (producers accuracy) shows how well (or not) pixels of a given land cover were classified by the analyst/operator. For grass, for example, this was 69.8 %. This basically means that out of the 252 points on the ground that were grass, only 176 were actually classified as such by the analyst/operator in the map.

The row at the bottom (user's accuracy) shows the probability that a pixel, that is classified into a certain given land cover, actually represents that category on the ground. For hardwood, for example, this was 80.7 %. This basically means that out of the 425 points on the map that were thought/expected to be hardwood, 343 actually turned out to be so on the ground.

3 Methods & materials

3.1. General

The project's activities as regards data collection/analysis are schematically presented in Figure 3.1.

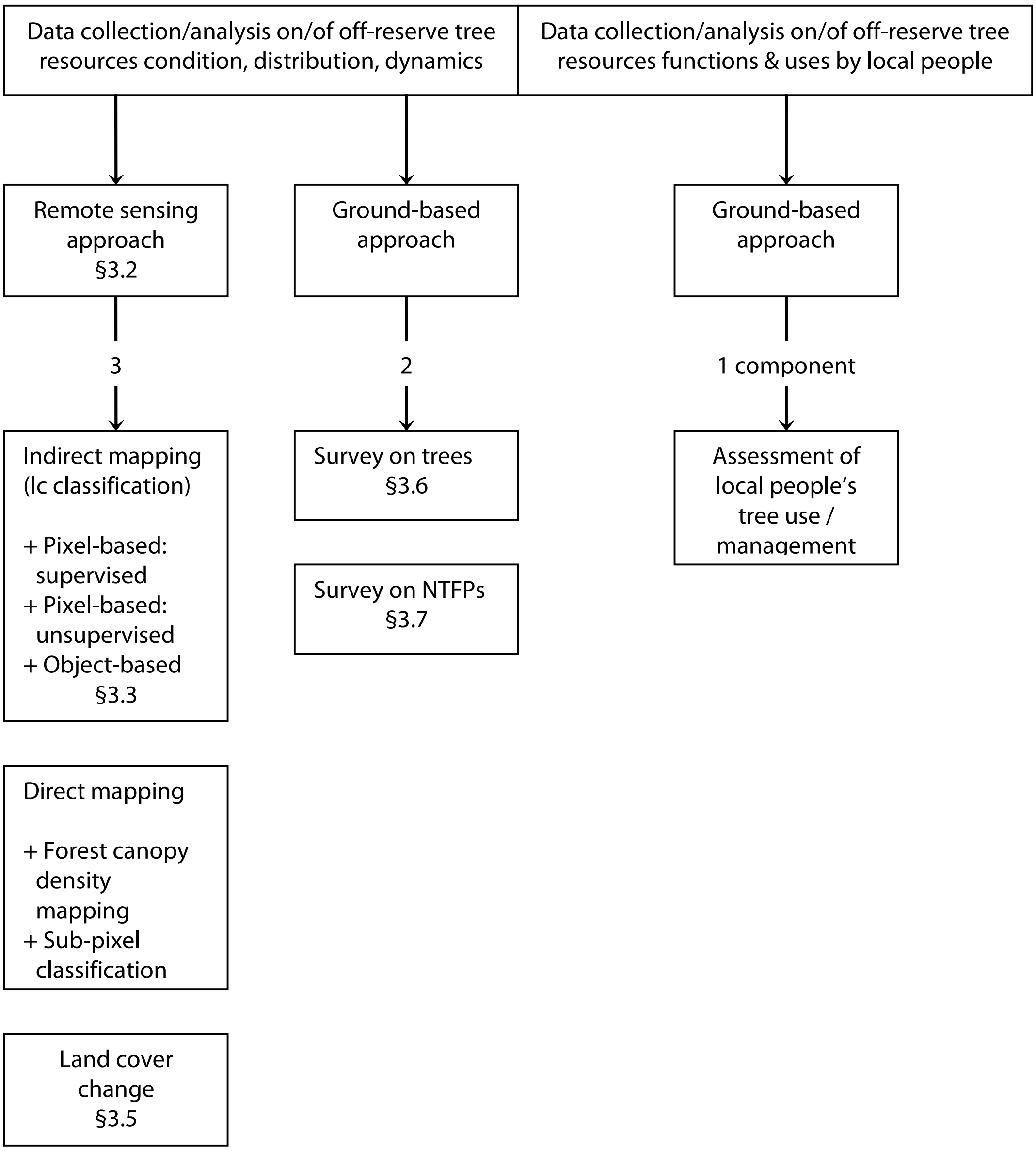


Fig. 3.1. Schematic representation of data collection/analysis approaches/components of project.

In the following paragraphs the various data collection/analysis approaches/components as presented in Figure 3.1 (see paragraph numbers) will be elaborated upon in more detail. Paragraph 3.9 gives an overview of the most important materials used in/by the project.

3.2. Project's remote sensing approach in general

In principle high resolution imagery would have allowed direct mapping and assessment of the off-reserve tree resources, but such imagery is expensive, covers small(er) areas and is not always readily available, so (in addition to high costs) getting a full coverage of a single season for the entire study area would have been problematic.

Given that the project wanted to develop an operational method for the mapping and assessment of the off-reserve tree resources, especially affordability as a criterion in its choice of imagery played an important role and made it decide on ETM+ and ASTER. Problem, however, with using medium resolution imagery such as ETM+ and ASTER for mapping and assessment of single trees occurring in predominantly agricultural areas (such as in the off-reserve areas) is that the size of such trees is often such that they cover only part of the pixel and that also other features such as crops or grass are likely to occur in the same pixel. This means the pixel will not necessarily reflect the tree. A sensor measures the average of the reflectance of all features occurring in the pixel. The pixel might therefore also reflect the crop and/or grass surrounding the tree or the combination of the trees, crops and grass. See Figure 3.2.

This problem, which is referred to as the so-called "mixed pixel" problem, implies that direct mapping and assessment of the off-reserve tree resources from medium resolution imagery becomes difficult.

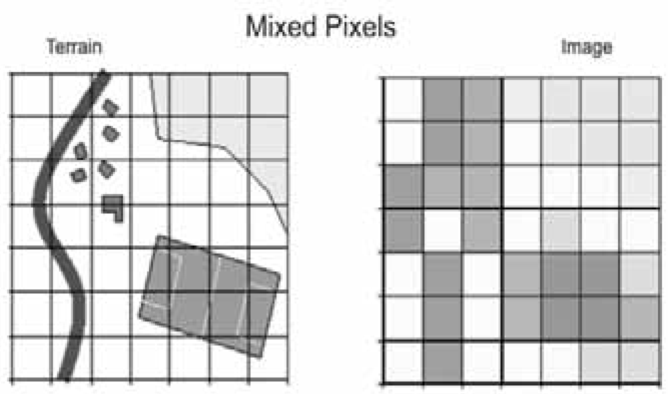


Fig. 3.2. Illustration of origin of mixed pixels: different land cover types occur within one pixel (note the relative abundance of mixed pixels). (Source: ITC, 2004.)

An approach that can be used to overcome this mixed pixel problem is to map and assess the off-reserve tree resources in an indirect manner. That is: through another entity. Common in this respect is to focus on land cover type as the to be mapped and assessed entity and then to assume that there is a land cover type – tree density relationship.

Pilot-work in an area south of Kumasi in 2002 (whilst the project was being formulated), followed by a reconnaissance visit to the off-reserve areas of the foreseen study area, indicated that in the off-reserve areas of Ghana this approach might well work because there undoubtedly seemed to exist a relationship between the most commonly occurring land cover types and the numbers of trees growing in them.

Hence, when average tree densities for the various land cover types are known from a field survey, a sufficiently detailed land cover map could give a first impression of expected tree densities.

Based on the above, the indirect mapping and assessment approach became the main focus of the project. In essence this was thus an approach based on both remote sensing (described in paragraph 3.3) as well as ground-based survey (described in paragraph 3.6).

There was nevertheless still also some limited experimental work undertaken with the direct mapping and assessment of the off-reserve tree resources in parts of the study area. This will be described separately in paragraph 3.4.

3.3. Indirect mapping and assessment: land cover classification

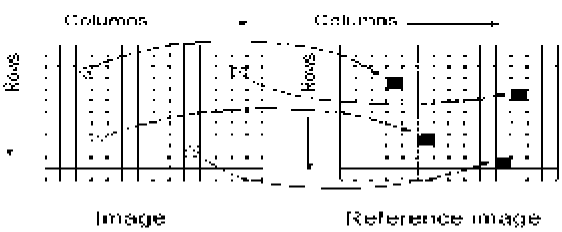


Fig. 3.3. The process of geo-referencing using reference points from a digital topographic map. (Source: ITC, 2001).

3.3.1. Image (pre-)processing

The project first acquired relevant imagery and digital topographic data of the study area. After their acquisition all imagery was geo-referenced using the digital topographic maps. In this process a relationship is created between an image and real world co-ordinates, because an image as such basically just consists of rows and columns of pixels without any reference to their geographical location (see Figure 3.3).

Parameters of the co-ordinate system that was now attached to the imagery (and maps) are given in Figure 3.4.

The fact that both imagery as well as the available digital topographic data now had the same co-ordinate system facilitated over-laying of imagery with, for example, data on roads, rivers, settlements, etcetera, which was essential for some of the spatial analysis work done in the project.

The software used for pixel-based land cover classification was ERDAS Imagine. Algorithms used were "Maximum Likehood" for supervised and "Isodata" for unsupervised classification.

The software used for object-oriented land cover classification was eCognition. Algorithm used was "Standard Nearest Neighbour".

Pilot-work in an area south of Kumasi in 2002 (whilst the project was being formulated) indicated that "fields" of the various land cover types are typically about 0.3 ha in size. The segmentation in the object-oriented land cover classification therefore aimed at creating segments/objects of approximately this same dimension. Figure 3.5 shows how different software parameters were set in order to achieve this.

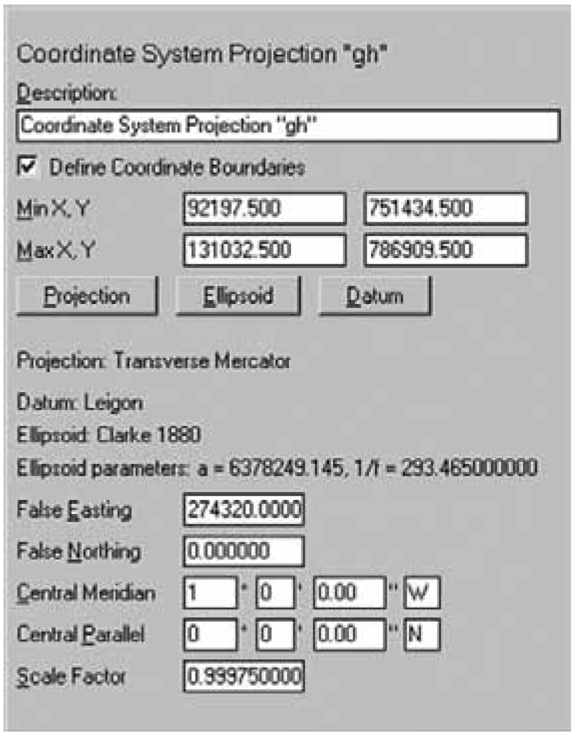


Fig. 3.4. Parameters of the co-ordinate system attached to imagery and maps used by the project.

Image classification was preceded by fieldwork, whereby different areas representative for the previously agreed upon land cover types were located, looked at and marked. Such fieldwork was meant to assist/guide the process of selection of training samples (clusters of pixels representative for the various land cover types) in the image, subsequently to be used by the algorithm while classifying.

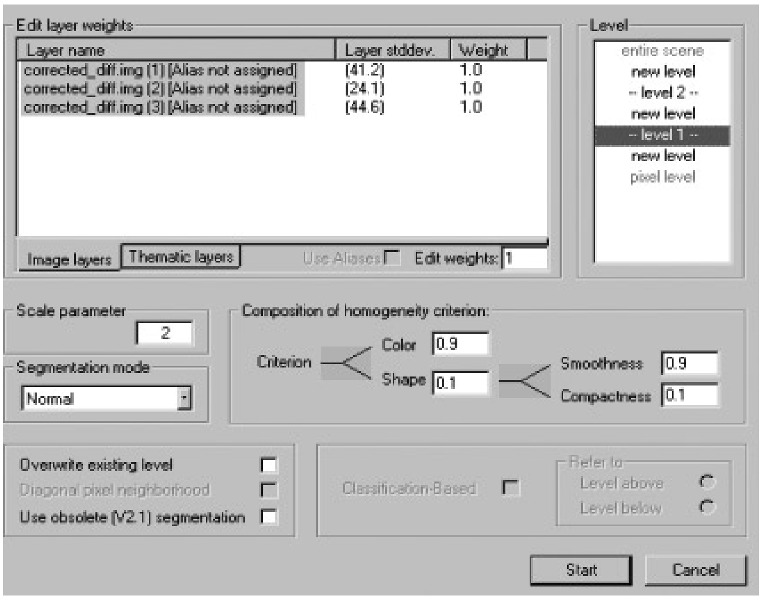


Fig. 3.5. eCognition software parameters as set/used during the process of image segmentation.

3.3.2. Land cover classification system

Because the mapping and assessment of land cover was the basis for all activities in the project it was important to have a commonly accepted land cover classification system. This land cover classification system was therefore jointly developed during a reconnaissance visit to the study area and a subsequent workshop in which all the partners in the project participated.

For the land cover classification it was decided to use the land cover classification system given below. Classes were chosen because:

- They were expected to be associated with different tree densities;
- they were expected to be mapable as their reflectance characteristics were thought likely to be different;
- they were easily recognizable in the field and could be described clearly/concisely;
- they were suitable for all project partners undertaking field data collection and acceptable to the end-user of the project's results RMSC.

Grass
Often dominated by *Pennisetum purpureum* and *Imperata cylindrica*. Often former agricultural land where the mentioned grasses invaded after over-cultivation and soil impoverishment. Trees are few or are absent.

Crops (annual + perennial)
Often a mixture of annuals such as maize (*Zea mays*) and cocoyam (*Xanthosoma sagittifolium*) and perennials such as cassava (*Manihot esculenta*) and plantain (*Musa paradisiaca*) cultivated for food. Often inter-planted with young seedlings of crops such as cacao, oil palm and cashew. Trees occur, mostly scattered. The element of tree-crop competition is considered to be important here.

Tree crop – cacao
Combination of cacao as tree/cash crop in an under-storey and left-over forest trees as an over-storey, retained to nurture the cacao through the provision of shade and nutrients. Often big, tall trees, in varying densities. Fruit trees such as Citrus sinensis, *Persia americana* and *Magnifera indica* also occur.

Tree crop – other
Tree/cash crops such as oil palm and cashew, but increasingly also new, hybrid variety cacao. These crops require light and the big, tall trees as found over the old variety cacao are removed.

Shrub fallow
This might also be called "young" fallow. This is agricultural land that has not been cultivated for 1 to 5 years. There is dense vegetation, mostly shrubby and often regenerated from old stumps/rootstock. Present is also often vigorous and dense growth of *Chromolaena odorata*.

Tree fallow
This might also be called "older" fallow. This is agricultural land that has not been cultivated for 6 to 10 years. There is dense vegetation, no longer shrubby but more tree-like. Also present is young secondary forest with trees of pioneer species.

Forest
This could be left-over patches of original primary forest or older secondary forest that has over time developed from tree fallow.

Built-up
These are settlements with bare areas around them and roads.

3.3.3. Accuracy assessment

Image classification was followed by accuracy assessment of the land cover maps produced. Thereby standard sampling procedures (recommended in the case of land cover classification are simple random sampling or stratified random sampling) and contingency tables (or confusion/error matrices) were employed.

3.4. Direct mapping and assessment

The project's work on direct assessment of the off-reserve tree resources focussed on the following two methods:

- Forest canopy density mapping.
- Sub-pixel classification.

Forest canopy density (FCD) mapping was originally developed for forest managers. It is a useful parameter in the characterisation of forest condition as it indicates degrees of forest degradation (dense canopies indicating intact/ healthy forest and sparse or no canopies indicating the opposite) and as such gives information on the type of rehabilitation treatment that might be required.

FCD mapping expresses canopy density in percentages, going from 0-10 % to 90-100 % for each pixel. It uses specialist software and can only be used with imagery acquired by sensors that can measure/record thermal energy (in addition to electromagnetic energy). Landsat's TM and ETM+ sensors have that capability. Terra's ASTER, however, doesn't. FCD mapping basically integrates the values of the following indices when determining canopy density:

» AVI: Advanced Vegetation Index;
» SI: Shadow Index;
» BI: Bare Soil Index;
» TI: Thermal Index.

Figure 3.6 below illustrates the relationships between forest condition and the above mentioned four indices:

The graph basically shows that AVI increases with increasing tree vegetation (although AVI responds to all vegetation, it is – in addition – also sensitive to vegetation quantity). High AVI values correspond with high SI values, because where there is more tree vegetation (especially multi-storeyed with tall, big trees) there is also more shadow. Conditions like this, however, tend to mitigate temperatures and produce low TI values. Where there is much tree vegetation, there is usually not much bare soil exposure and therefore BI will be low. For additional background reading on forest canopy density mapping, see Rikimaru (2002).

In sub-pixel classification one basically tries to reverse the process of spectral mixing and to break down the spectral signatures of a mixed pixel into its constituent components and to determine the approximate proportion of each pixel that is occupied by these. A mixed spectral signal at pixel level is thus in fact un-mixed to pure spectral signals at sub-pixel level.

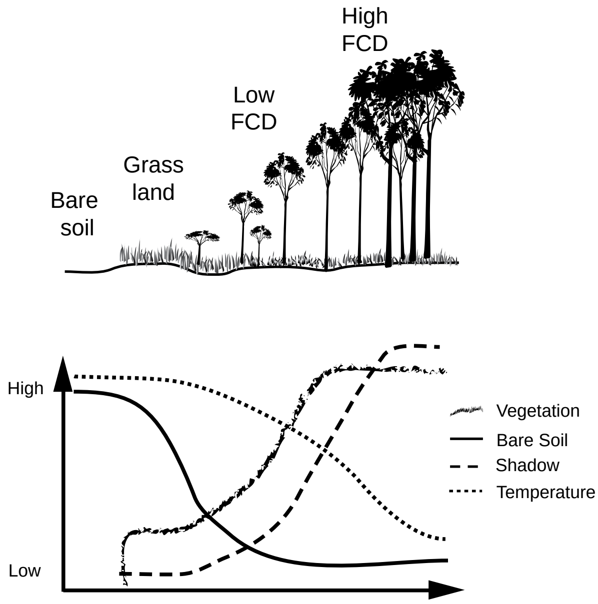


Fig. 3.6. The characteristics of the four indices being used in forest canopy density mapping. (Source: Rikimaru, 2002).

The sub-pixel classification procedure requires the identification of a so-called material of interest (MOI) (trees in off-reserve areas in case of the project) in a pixel first. Thereafter the classifier removes/subtracts different fractions of different background (BG) materials from the pixel, until it arrives at a residual which closely matches the MOIs spectrum. See Figure 3.7 below for a schematical representation of this process.

The resulting classified image stores information on the proportion of each pixel that is occupied by the MOI (in percentages).

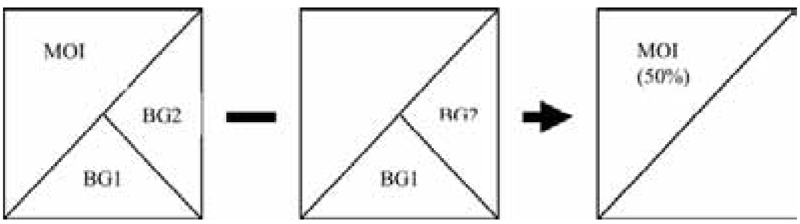


Fig. 3.7. Schematical representation of concept of ERDAS Imagine sub-pixel classification procedure.

Used was the sub-pixel classifier within ERDAS Imagine software which can be used with both TM/ETM+ as well as ASTER imagery.

For additional background reading on sub-pixel classification, see Huguenin *et al.* (1997).

3.5. Land cover change

Studying land cover change in an area is mostly done to obtain information on the "dynamics" of that area. Of particular interest for the project was to analyse whether the off-reserve tree resources' occurrence and distribution had changed over time and to try and find explanations for the observed changes.

Studying land cover change using satellite imagery requires that besides recent imagery also old(er) imagery is available. Especially important in this respect is that all imagery is from the same period of the year in order to avoid that the effects of seasonality influence the result of the change analysis (one wants observed changes to be real changes and not changes that occur because one is looking at two different seasons).

Change detection method used was the so-called post-classification comparison method. In this method images that are chosen for a change analysis are first classified independently and then the resulting two maps are overlayed/compared with each other to determine where change has taken place.

In practice the above-mentioned step of determining where change has taken place often takes the form of a "crossing" of the two to be compared maps. In this operation pixels at the same position in both maps are compared with each other and track is being kept of all the combinations that occur between the classes in both maps.

Output is a so-called cross-map with fairly meaningless classes such as forest*crops (pixel is forest in the one map and same pixel is crops in the other) or forest*forest (pixel is forest in the one map and same pixel is also forest in the other).

Such maps can then be re-coded leading to a new map showing change classes such as, for example, deforestation (=forest*crops), forest-unchanged (=forest*forest), afforestation (=crops*forest) and crops-unchanged (=crops*crops) which are more meaningful and describe change processes.

One of the problems with this kind of change detection is that errors from each of the individual land cover maps are (cumulatively) incorporated into the final change product. A typical problem related to this is that, whereas one may be able to assess the accuracy of the classification of a recent image, it may be quite impossible to check the accuracy of the classification of an old(er) image because ground-thruthing in the field is no longer possible.

3.6. Survey on trees

3.6.1. General

The collection of field data on the different characteristics of trees in the study area (numbers per ha, dimensions, species, etc.) was spread out over two years: 2003 and 2004. In the 1st year the northern part of the study area was surveyed and in the 2nd the southern part.

Before the actual survey started, first a preliminary land cover classification was made. The land cover types then served as the strata in the survey's stratified random sampling design (with the number of plots in each stratum/land cover type proportional to the area covered by that particular stratum/land cover type).

3.6.2. Stratified random sampling

General

Stratified (random) sampling is based on the principle that if a highly variable resource (such as the one under consideration) is first sub-divided into a number of sub-areas in which variance is relatively low, a given degree of intensity of sampling (for example determined by limited time/resources) should give a greater precision or lower error in the final result than could be expected if the area was not stratified (Husch *et al*., 2003). Randomness basically eliminates bias in the choice of sample points.

Procedure

For land cover types grass, crops (annual and perennial) and tree crops (mainly cacao), plot size was 3000 m^2, whereas for land cover types shrub fallow, tree fallow and forest, plot size was 500 m^2. Plots were circular.

A guiding principle in choice of plot size should be to have a plot sufficiently large to include a representative number of trees, but small enough so that measurement time per plot is not excessive (Husch *et al*., 2003).

During reconnaissance visits to the study area it was observed that the land cover types grass, crops (annual and perennial) and tree crops (mainly cacao) usually do not have very large numbers of trees in them, so a larger plot size was needed to catch as many trees as possible and avoid having too many zero plots.

During these same visits to the study area it was also observed that the land cover types shrub fallow, tree fallow and forest usually have much large(r) numbers of trees in them. It is, moreover, often difficult to move around in these land cover types because of the presence of *Chromolaena* and climbers/creepers, so a smaller plot size was needed to cut down on the amount of work to be done in these plots.

Circular plots have the advantage that they have a larger ratio of area to perimeter than most other types of plots, which minimizes the problem of so-called borderline trees (trees on the border of plots that need checking to decide whether they are in or out). Circular plots, moreover, are easy to establish because they are only defined by their plot centre and radius. (Loetsch et al., 1973).

Measurements
In the sample plots all trees with a dbh ≥ 10 cm were measured for diameter and height. Also their species names were recorded. Thereby use was made of Hawthorne (1990).

In 2003 an inventory of regeneration of timber tree species and non-timber tree species (for timber species list: see Appendix 2) was carried out, basically to see if there was any difference in this respect between these two main groups of species, both of which are assumed to be removed by farmers as unwanted "weeds" from certain land cover types. This entailed that in all plots (both the 3000 m^2 as well as the 500 m^2 ones) all saplings (dbh 2 – 4.9 cm) and all poles (dbh 5 – 9.9 cm) were measured (for dbh) and named. Seedlings (dbh < 2 cm and with height ≥ 15 cm) were only counted and named in smaller sub-plots of 300 m^2.

3.6.3. Data analysis

In the analysis of the data on trees collected during the surveys use was made of descriptive statistics (such as average/mean, median, variance, standard deviation, standardized skewness and standardized kurtosis) and the following basic statistical tests:

- Shapiro-Wilks (test for normality);
- Kolmogorov (test for normality);
- Cochran's C (test for homogeneity of variances);
- ANOVA-table (test for significant differences between means);
- Fisher's LSD (test for significant differences between means);
- Simple – linear – regression.

3.7. Survey on NTFPs

3.7.1. General

The NTFP field inventory was preceded by a limited market/household survey in which the NTFPs that people collect for subsistence use and income generation were identified. UF visited the markets of Goaso and Mim and conducted random household interviews in a number (6) of villages. The plant species associated with the identified products were targetted in the field survey.

UF's survey was also aimed at gathering local knowledge on the ecology, distribution and current/past availability of non-timber forest product plant species that could subsequently be of guidance in the design of appropriate methods for their quantitative assessment.

Amongst the products mentioned by people there were three that were harvested from plant species that predominantly occur in vegetation that is found along streams/rivers: *rattan* (*Calamus deeratus*), *bamboo* (*Bambusa vulgaris*) and *raphia* (*Raphia hookeri*). The various other products that people collected were more commonly harvested from trees/shrubs found in forest, cropland and fallow land.

For the inventory of *rattan*, *bamboo* and *raphia* it was decided to use the so-called adaptive cluster sampling method, whereas for the inventory of the other products systematic cluster sampling was chosen.

3.7.2. Adaptive cluster sampling

General
Adaptive cluster sampling was chosen because it was considered the most appropriate and efficient method of sampling for rattan, bamboo and raphia, which are all species that tend to occur at fairly low densities and in an aggregated manner (Thompson, 1990).

Procedure
First a random 2% sub-sample of all streams/rivers in the study area was created using ArcView software (from attribute table which holds id's of segments of streams/rivers). At randomly selected starting points in each segment two 50 x 50 m plots were laid out (one at each side of the stream/river). This procedure was repeated at 500 m intervals in both directions from the starting point. See Figure 3.8.

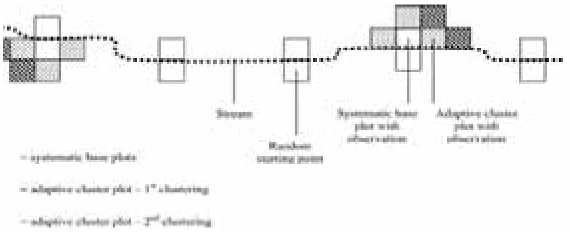


Fig. 3.8. Illustration of the sampling design for the adaptive cluster sampling with systematic base for *bamboo, raphia* and *rattan* occurring near streams/rivers.

Also here a fairly large plot size was chosen in order to be sure that a representative number of trees/plants were sampled.

Square plots have a larger problem with borderline trees and are more prone to errors in establishment because of errors in measuring distance and setting up of right angles. They, however, have the advantage that their boundaries are straight and easy to mark The curved boundaries of circular plots are more difficult to mark and to estimate, especially when plots are somewhat larger and there is undergrowth inhibiting visibility (Loetsch et al., 1973).

The plots (on both sides of the river/stream) were then surveyed for the species of interest. Rule thereby was that if no specimens of these species were found in five consecutive plots, surveying (at that side of the river/stream) would be abandoned.

If, however, an observation of a species of interest was made in such a systematic base plot, an adjoining adaptive cluster of plots would be laid out and sampled in addition. This procedure would repeat itself if specimens of the sought after species were also found in the adaptive cluster plots (more adaptive cluster plots added to the initial ones) If not, sampling would stop at that particular location.

The sampling design in this manner became one for adaptive cluster sampling with a systematic base. This would subsequently enable a comparison of the effectiveness of systematic sampling versus adaptive cluster sampling.

Measurements
When *bamboo* was found in plots, the diameter of the clump would be measured in two perpendicular directions and the average of these two measurements would subsequently be used to calculate the base area of the clump. For a clump also the number of culms and the average diameter of the culms would be recorded.

When *rattan* or *raphia* were found, it was recorded whether the plants were mature or immature. *Rattan* was considered immature when the canes were < 3 m in length and mature when they were ≥ 3 m in length. *Raphia* was considered immature when the palms were < 3 m in height and mature when they were ≥ 3 m in height.

3.7.3. Systematic cluster sampling

General
Stratified sampling (with land cover types as strata) was actually considered the most efficient way of sampling under the given circumstances, but unfortunately there was no land cover map available yet at the time of survey design to help to facilitate this. Systematic cluster sampling was then chosen instead.

Systematic sampling will ordinarily and especially when surveying large, heterogeneous, landscapes, yield more accurate estimates than random sampling for the same number of samples because the samples are better distributed over the area, (Husch *et al*., 2003). Clustered sampling will ordinarily help to reduce time/cost associated with travel in the terrain.

Procedure

For the inventory in cropland and fallow land, first a 7 x 7 km grid was put over the entire study area. The grid-points (points where the 7 x 7 km grid-lines intersect) were subsequently used as starting points for sampling.

At a grid-point first a 50 x 50 m plot was laid out and sampled. After sampling of the first plot at the grid point, three more plots were laid out as satellites to the first one (the four plots lying in a cluster at the corners of a 100 x 100 m square). See Figure 3.9.

There would basically be four directions into which the cluster of plots could be put: north-east, north-west, south-east and south-west. The alternative chosen would be the one in which as many different land-covers as possible would be included in the cluster.

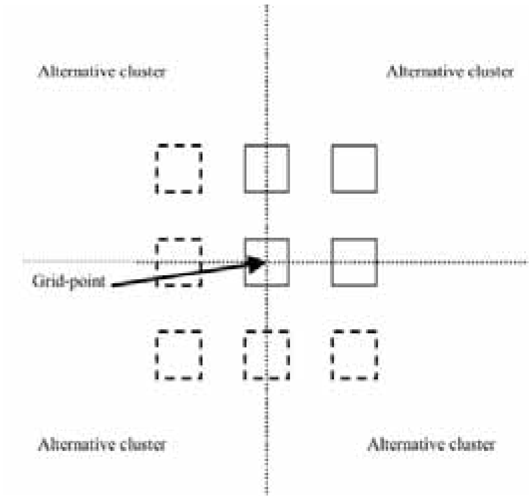


Fig 3.9. Illustration of the sampling design for the systematic cluster sampling in land covers crop (annual + perennial), cacao, tree fallow and shrub fallow.

Measurements
In the plots all trees with a dbh ≥ 10 cm were measured (for dbh) and named. The land cover of the plot was also recorded, according to the agreed classification system.

3.8. Assessment of local people's tree use and management

UGs survey focusing on tree functions/uses, management and management incentives comprised three phases: reconnaissance, design and implementation.

The reconnaissance phase was used to familiarize the researchers with the study area and to become acquainted with the various aspects of tree use/management pertaining to it. Focus group discussions and individual interviews were conducted in eight villages. Focus group discussions involved traditional leaders, representatives of local government at village level and members of community forest committees and mainly focused on people's knowledge/perception of current policies on off-reserve tree use/management. Individual interviews concentrated more on peoples' actual use and management of the off-reserve tree resources.

The information gathered during the reconnaissance was subsequently used to design a household questionnaire and guidelines for group discussions and individual interviews. The household questionnaire was extensive and covered a considerable range of issues, including household demographic characteristics, economics, agricultural activities and use/management of trees. It was tested and adapted where necessary before being used during the subsequent main survey.

The main survey was implemented in the following 28 villages:

- Asuadai,
- Nyamebekyere,
- Atimponya,
- Bediako,
- Gyaankuntabuo,
- Ayomso,
- Kwakuduakrom,
- Kwahu,
- Duadakrom,
- Ahantamo,
- Ahenkro,
- Mensakrom,
- Duruwakrom,
- Adwumakese,
- Duase,
- Agravi,
- Krakyekrom,
- Anwona,
- Dominase,
- Kyirikasa,
- Fianko,
- Mfama,
- Gyasikrom,
- Asumura,
- Tipokrom,
- Antwi-Agyeikrom,
- Mfante,
- Nekete.

Villages were in essence purposively selected. For their distribution see Figure 3.10.

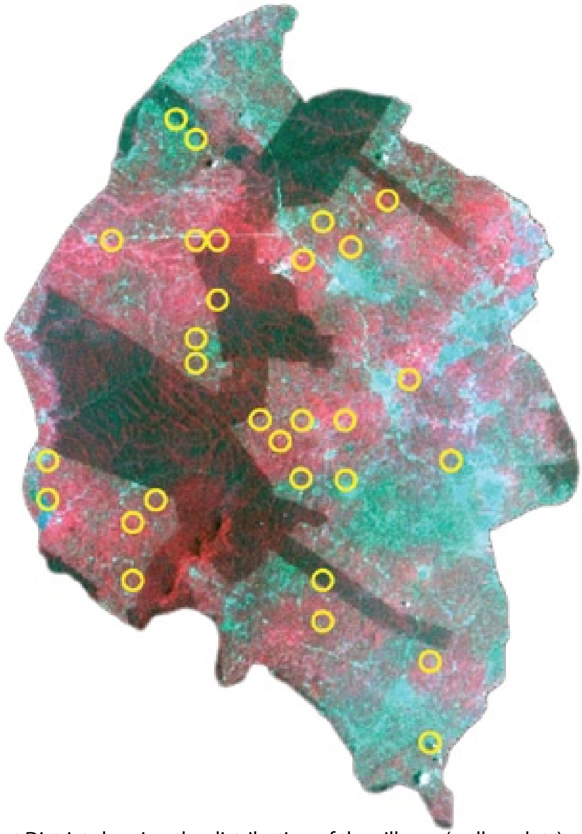


Fig. 3.10. Map of Goaso Forest District showing the distribution of the villages (yellow dots) selected for discussions/interviews.

Care was taken that the villages were fairly evenly distributed over the entire study area. This was essentially done by dividing the study area into five "geographical sectors" (north-east, central-east, south-south-east, north-north-west and south-west) and by selecting four to eight villages from each of them.

Because it was thought that farmers' tree use/management might be related to them being near(er) or (further) away from forest reserves, care was also taken that the selected villages were fairly evenly distributed in terms of their distance to forest reserve edges. Three "zones" were hereby distinguished: < 1 km, 1-5 km and > 5 km away from the edges of forest reserves.

Within a village the interviewees were randomly selected with the number of interviewees being proportional to the population of the village. Eventually a total of 466 household questionnaires were completed.

Within each of the geographical sectors one village was elected for group discussions. Three group discussions took place within each of these villages: one with women, one with men and one with people dealing with forest/trees in a more formal capacity such as community forest committee members and unit committee members (representatives of local government at village level).

Discussions/interviews were held with the DFO, representatives of six logging companies and representatives of RUDEYA[2] (Rural Development Youth Association).

The UG team also visited the markets of Goaso, Mim, Kasapim and Sankore to get an idea/impression of the NTFPs that were being traded in the study area and of the magnitude of this trade.

2 RUDEYA is a local non-governmental organisation (NGO) that has been operating in Goaso Forest District since 2002 and is involved in:

- assisting the DFO with establishing community forest committees;
- developing income generating activities such as snail rearing, mushroom cultivation and production of honey;
- supporting establishment of small scale tree plantation through the provision of seedlings and equipment;
- environmental education on forestry laws and bushfire prevention.

Although ITC's main focus was on the collection of field data on trees, its surveyors talked to farmers/villagers about tree functions/uses whenever an opportunity presented itself. They thus managed to collect valuable information in addition to that collected by the UG team.

3.9. Materials

For the classification of land cover in the study area, the following satellite images were used:

- ETM+ of 14/03/2003,
- ASTER of 26/02/2003,
- ASTER of 28/01/2004,
- ASTER of 09/03/2004.

In addition to the above, the project also had access to a number of old(er) images that were used for the land cover change analysis. These were:

- TM of 18/01/1986,
- TM of 02/01/1989,
- TM of 25/12/1990,
- ETM+ of 02/02/2000,
- ETM+ of 24/12/2002.

All imagery used was acquired during the long dry season months, because atmospheric conditions for image acquisition in these months are better than in the wet season months (when there is too much cloud cover).

In the dry season months, moreover, the land used for cropping is more or less bare (maybe with stubble or left-over, dried-out, stalks of, for example, maize left on the field) which minimizes confusion between crops on the one hand and shrubs/trees on the other.

	Band	Wavelenght(µm)	Resolution(m)
Blue	1	0.45 - 0.52	30
Green	2	0.52 - 0.60	30
Red	3	0.63 - 0.69	30
Near IR	4	0.76 - 0.90	30
SWIR	5	1.55 - 1.75	30
Thermal IR	6	10.40 - 12.50	120 (TM) 60(ETM+)
SWIR	7	2.08 - 2.35	30
Panchromatic		0.5 - 0.9	15

Fig. 3.11. Technical characteristics of the TM/ETM+ sensor. (Source: Lillesand *et al*., 2004).

For the land cover classification of the study area as a whole, the ETM+ image was used because this image covered the whole study in one scene thus reducing problems related to overlapping scenes and differences in atmospheric conditions between scenes.

Another advantage of using this image and not the slightly more recent and slightly higher resolution ASTER images was that the ETM+ image was almost free of clouds and quite clear whereas the ASTER images had much cloud and haze over certain areas.

The ASTER images were used for experimental work on land cover classification pertaining to only parts of the study area whereby lack of full coverage did not really matter.

For the technical characteristics of the TM/ETM+ respectively ASTER sensors, see Figures 3.11 respectively 3.12.

Characteristic	VNIR	SWIR	TIR
Spectral Range	Band 1 0.52-0.60 µm Nadir looking	Band 4: 1.600-1.700 µm	Band 10: 8.125-8.475 µm
	Band 2 0.63-0.69 µm Nadir looking	Band 5: 2.145-2.185 µm	Band 11: 8.475-8.825 µm
	Band 3 0.76-0.86 µm Nadir looking	Band 6: 2.185-2.225 µm	Band 12: 8.925-9.275 µm
	Band 3 0.76-0.86 µm Backward looking	Band 7: 2.235-2.285 µm	Band 13: 10.25-10.95 µm
		Band 8: 2.295-2.365 µm	Band 14: 10.95-11.65 µm
		Band 9: 2.360-2.430 µm	
Ground Resolution	15 m	30 m	90 m

Fig. 3.12. Technical characteristics of the ASTER sensor. (Source: Lillesand *et al*., 2004).

In addition to the satellite imagery mentioned above the following materials were used:

- Topographic maps;
- field guide to forest trees of Ghana;
- questionnaires;
- GPS;
- compass;
- measuring tape, diameter tape, hypsometer and densimeter (all of these pieces of equipment for measurement of trees);
- different sources of secondary data.

For photographs of the various data collection/analysis activities undertaken by the project, see Appendix 3.

4 Results

4.1. General

The set-up of this chapter follows the different data collection/analysis components of the project as described in chapter 3. See corresponding paragraph numbers in Figure 4.1

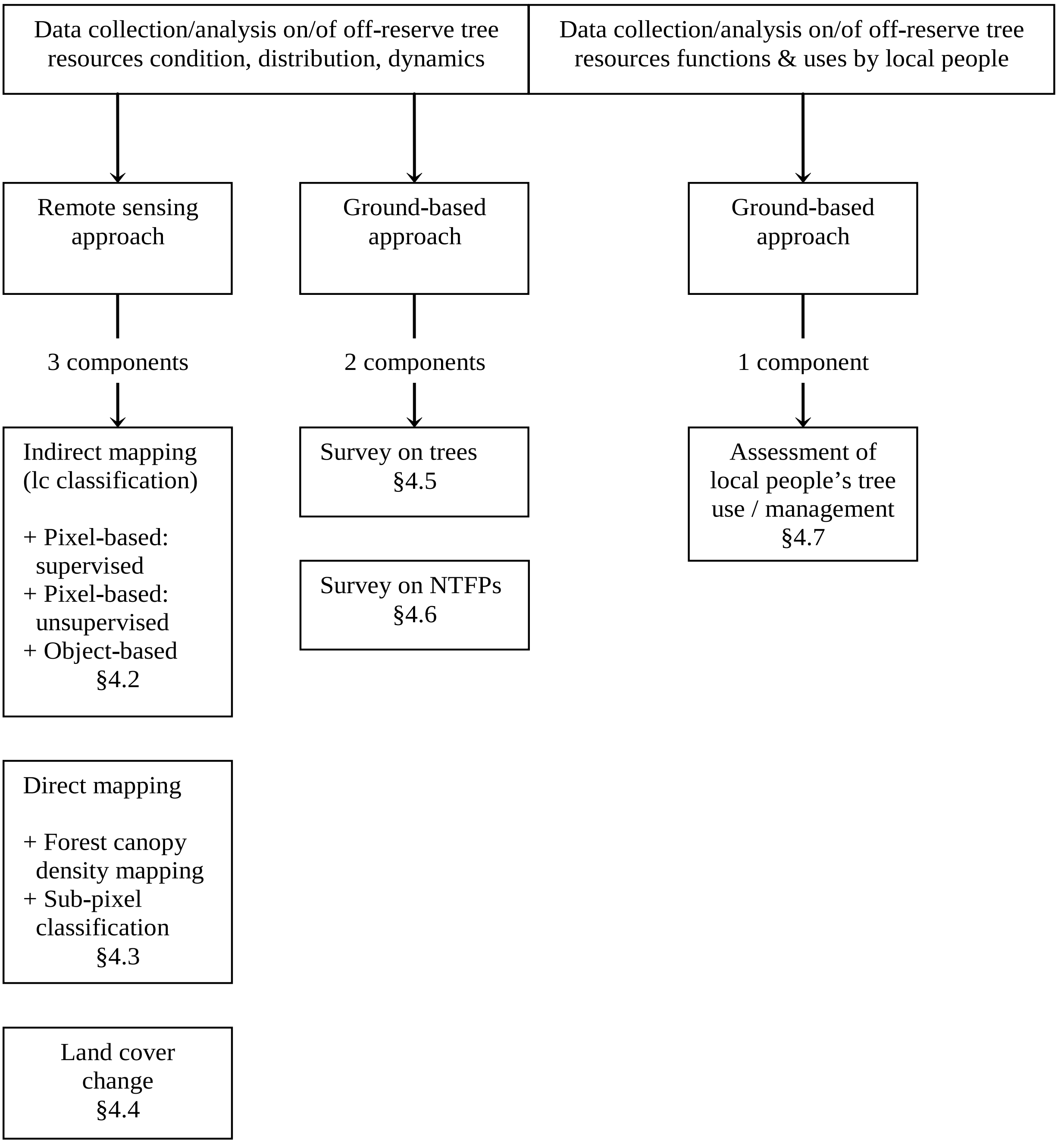


Fig. 4.1. Schematic representation of results/outcomes of data collection/analysis activities undertaken by the project.

4.2. Indirect mapping/assessment: land cover classification

4.2.1. Pixel-based: supervised

Initially land cover classification of the entire study area using the Landsat ETM+ image of the 14th of March 2003 was undertaken using the supervised classification method. Thereby initially 14 spectral signatures were identified/ selected as training samples. These were linked to the following 14 land cover classes:

» Grass 1 (dry grass);
» grass 2 (wet grass);
» built-up (settlements & roads);
» crop 1 (annuals);
» crop 2 (perennials such as plantain and cassava, often interplanted with young cacao and oil palm plants);
» shrub fallow (with dominance of *Chromolaena*);
» riverine shrub;
» water;
» cloud;
» cloud shadow;
» cacao 1 (tree density low);
» cacao 2 (tree density medium);
» cacao 3 (tree density high);
» forest & tree fallow.

Forest (un-reserved) and tree fallow were impossible to separate spectrally and thus grouped together. Most pixels allocated to this class are likely to represent tree fallow because the occurrence of forest (un-reserved) in the study area is no longer significant.

The presence of tree crop – other (mature oil palm, cashew, new variety cacao) in the study area seemed insignificant and if it did occur, it was spectrally indistinguishable from crop 2, so it was not mapped separately.

Cloud and cloud shadow are obviously not land covers in the strict sense of the word. Their presence on an image, however, makes it impossible to discern which land cover lies underneath, in fact making these areas unidentifiable.

Maps with so many classes, however, easily take on a salt-and-pepper appearance, making it difficult to get a general picture of land cover in an area and to see patterns. The relationship between land cover and tree density moreover exist for land cover at a higher level of aggregation. For this reason the initial 14 classes were merged into the following 6 aggregated ones:

» Grass (= grass 1 + 2);
» crop (= crop 1 + 2);
» cacao (= cacao 1 + 2 + 3);
» shrub fallow;
» forest & tree fallow;
» other (= built-up + riverine shrub + water + cloud + cloud shadow).

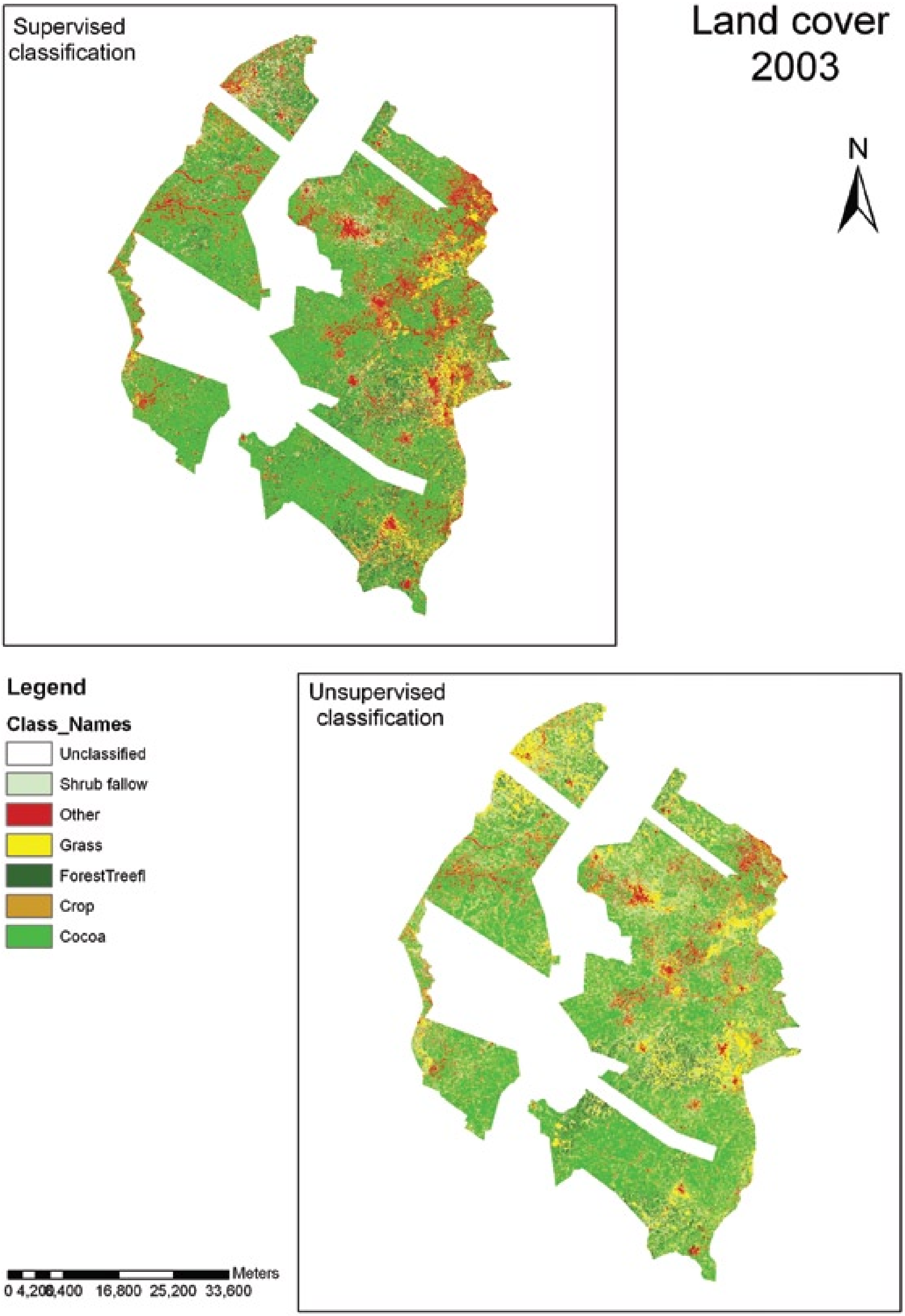


Fig. 4.2. Land cover maps of the entire study area (off-reserve part) created using pixel-based supervised & unsupervised classification. Based on ETM+ image of 14th of March 2003.

Visually comparing the resulting land cover map (see Figure 4.2. upper part) with the satellite image suggested that the land cover classes cacao, forest & tree fallow and other were over-represented and grass, crop and shrub fallow under-represented.

4.2.2. *Pixel-based: unsupervised*

With the outcome of the supervised classification method not being satisfactory (see above), unsupervised classification was done, whereby pixels with more or less similar reflectance values were initially clustered into 25 more or less homogeneous classes. These were subsequently labelled as follows:

- 2 x predominantly cloud shadow & water;
- 2 x predominantly forest & tree fallow;
- 1 x predominantly riverine shrub;
- 4 x predominantly shrub fallow;
- 1 x predominantly crop;
- 2 x predominantly grass;
- 1 x predominantly built-up & cloud;
- 12 x predominantly cacao.

Already pre-empting the subsequent recoding into final land cover classes, no distinction was made between crop 1 and 2, grass 1 and 2 and cacao 1, 2 and 3.

The 25 spectral classes were then aggregated into the same 6 final classes as in the supervised classification, namely:

- Grass;
- crop;
- cacao;
- shrub fallow;
- forest & tree fallow;
- other.

Visual comparison of the resulting land cover map (see Figure 4.2. lower part) with the satellite image now showed a much greater similarity between the two as compared with the result of the supervised classification.

An accuracy assessment was carried out on the result of the unsupervised classification because that was seemingly the better of the two maps.

60 randomly selected points (which were more or less equally divided over the various different land cover classes) were visited in the field. 57 of these turned out to have been classified correctly, which gave the classification an overall accuracy of 95 %.

4.2.3. *Object-based*

Work with object-based classification concentrated on an area in the north-eastern part of the study area. Use was made of the Terra ASTER image of the 26th of February 2003 which was almost free of clouds and quite clear for this part of the study area.

The image was first segmented at a high level of detail resulting in very small segments. These were subsequently aggregated into larger segments until these segments coincided with the fields/units of the various land cover types visible in the image.

After segmentation, representative segments for the various land cover classes were selected as training segments and then used to classify the remainder of the segments according to mean spectral values of the pixels in them.

The resulting map is shown in Figure 4.3. Tree fallow and shrub fallow were combined because they could not be separated spectrally.

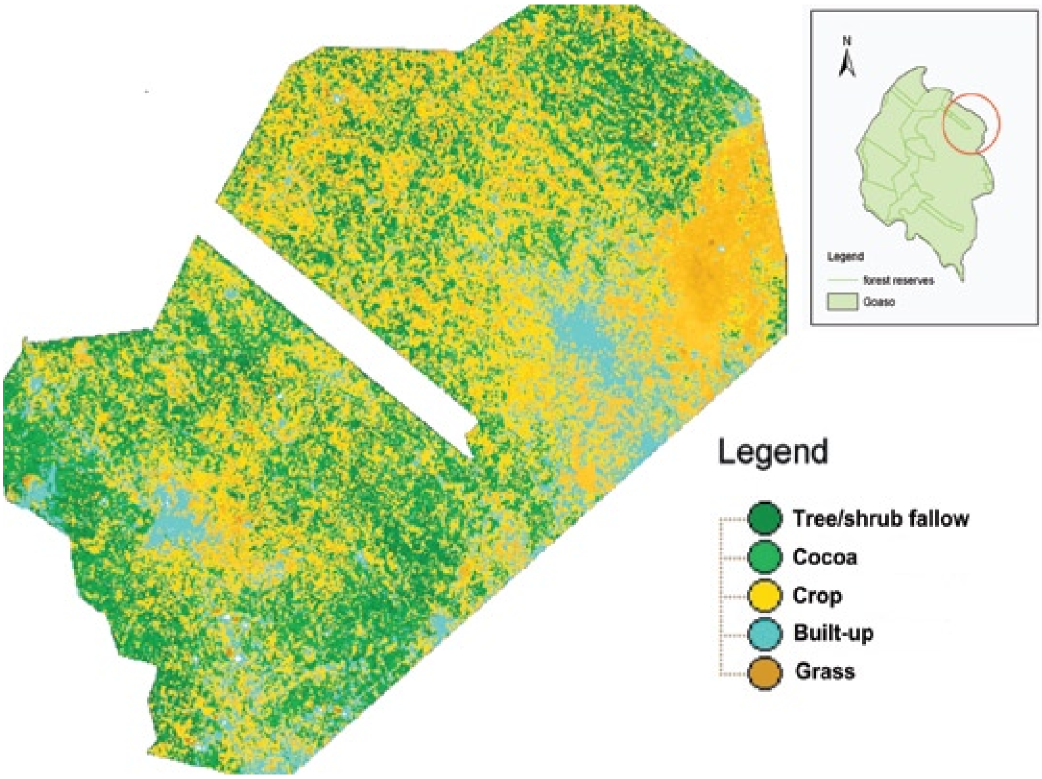


Fig. 4.3. Land cover map of part of the study area created using object-oriented classification. Based on ASTER image of 26th of February 2003.

Overall accuracy of the map (based on 30 randomly selected points more or less equally divided over the various different land cover classes) was 92 %.

4.3. Direct mapping and assessment

4.3.1. Forest canopy density mapping

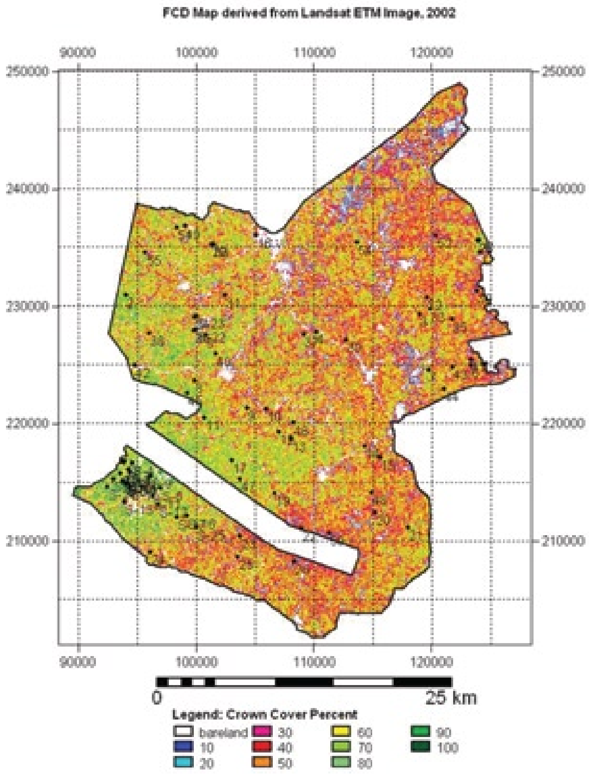


Fig. 4.4. Forest canopy density map derived from ETM+ image of 24/12/2002 making use of forest canopy density mapping software.

Work with forest canopy density mapping concentrated on the eastern/south-eastern part of the study area. Use was made of an ETM+ image of the 24th of December 2002. See Figure 4.4 for the result.

The numbers in the legend refer to the upper limit of the crown cover classes shown. Class 10 thus actually refers to crown cover densities ranging from 1 % to 10 %, class 20 to crown covers densities ranging from 11 % to 20 %, etc.

The map roughly shows an area with a somewhat stronger dominance of green (higher crown cover) to the west and an area with a somewhat stronger dominance of red (lower crown cover) to the east.

Comparison of canopy density derived from the map with canopy density in the field (which was collected for 80 points) showed that the map had an accuracy of 22 %.

4.3.2. *Sub-pixel classification*

Work with sub-pixel classification concentrated on the same eastern/south-eastern part of the study area. Use was now made of an ASTER image of the 9th of March 2004. See Figure 4.5 for the result.

The Erdas Imagine sub-pixel classifier can only detect a predefined material of interest (the off-reserve trees in the case of the project) when it covers at least 20 % of a pixel. White areas in the map therefore not only represent truly bare areas such as settlements, roads and bare soil, but also areas where the off-reserve tree cover is below 20 %.

The map shows a mixture of green (higher crown cover) and red (lower crown cover) more or less spread evenly over the area, with roughly a somewhat stronger dominance of red around settlements (white areas).

Comparison of canopy density derived from the map with canopy density in the field (which was collected for 80 points) showed that the map had an accuracy of 71 %.

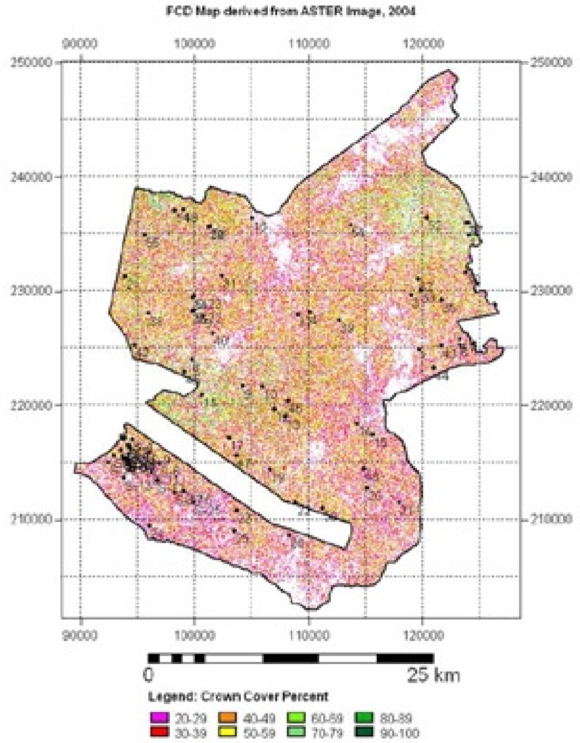


Fig. 4.5. Forest canopy density map derived from ASTER image of 09/03/2004 making use of sub-pixel classifier of Erdas Imagine.

4.4. Land cover change

Work on land cover change was carried out in 2004 and concentrated on an area in the eastern/south-eastern part of the study area. Used were a Landsat TM image of 18/01/1986 and a Terra ASTER image of 09/03/2004.

Both images were classified using the unsupervised classification method whereby initially pixels with more or less similar reflection values were clustered into 100 more or less homogeneous classes. These were gradually aggregated into 7 classes which were given the following labels:

- Built-up;
- grass;
- crops (annual/perennial);
- cacao < 20;
- cacao > 20;
- fallow (tree/shrub);
- cacao hybrid.

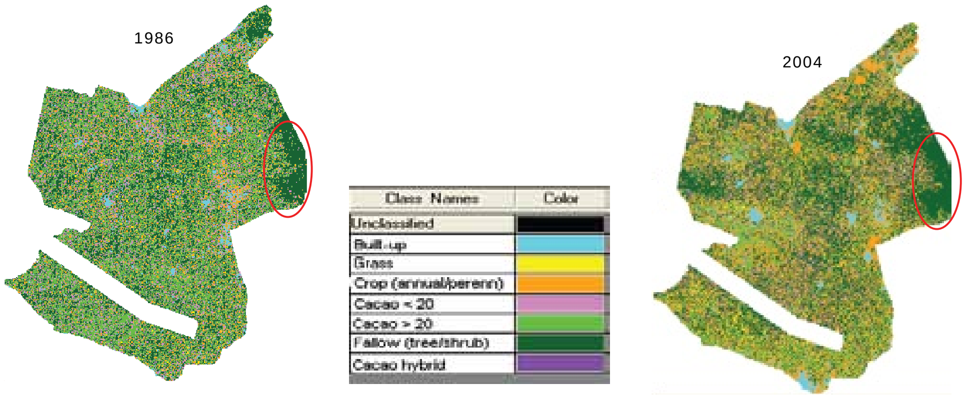
Also here tree fallow and shrub fallow were combined because they could not be separated spectrally with sufficient reliability.

Cacao < 20 represents cacao with low tree densities (=less than 20 shade trees/ha), whereas cacao > 20 represents cacao with medium to high tree densities.

Although the project's land cover classification system advocates the use of just "cacao" as a class, two sub-classes were used here because it was expected that in this manner the process of gradual removal of trees (through logging or other kinds of removal of trees) could be made visible.

Cacao hybrid refers to cacao farms where the new, hybrid, cacao variety is used. Although not confirmed by research, farmers think that this variety does not like shade. They therefore remove the old shade trees when establishing such hybrid cacao plantations and the number of trees in them is thus zero or very close to zero.

For the two land cover maps of 1986 and 2004 and the areas covered by the different land cover classes in the different years, see Figure 4.6.



LC class	Area (ha) 1986	Area (ha) 2004
Built-up	2249	2971
Grass	1303	3762
Crop	9273	25486
Cacao < 20	9593	3687
Cacao > 20	31605	20957
Fallow	41217	36200
Cacao hybrid	0	2353

Fig. 4.6. Land cover maps for part of the study area for two different years: 1986 and 2004. Created using a TM image of 18/01/1986 and an ASTER image of 09/03/2004 and unsupervised classification.

The two maps show an increase in the land cover classes built-up, grass and crop between the two years and a decrease in the land cover classes cacao < 20, cacao > 20 and fallow. Cacao hybrid is not present in 1986, but is in 2004 (the variety was introduced in 1990s). One can also see a dark green patch to the right side of the area that is classified as fallow (indicated with red ellipse) that has remained more or less unchanged over the years, whereas in the same period a considerable part of the other dark green has disappeared. The unchanged dark green patch is actually part of a forest reserve.

Although the maps seem to suggest that cacao farming is in decline, this is not confirmed by field observations. Young cacao seedlings inter-planted with annual/perennial crops can be commonly observed in the field: there are thus new cacao farms in the making.

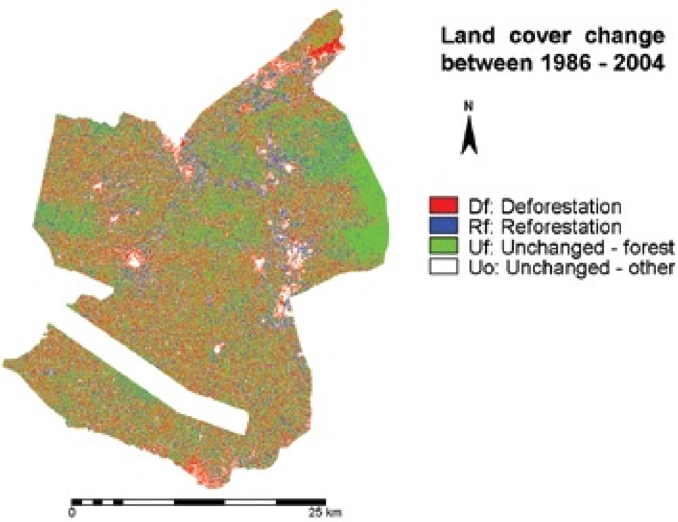


Fig 4.7. Land cover change between 1986 and 2004 expressed in terms of loss and/or gain of trees.

Figure 4.7 shows a land cover change map focusing especially on loss/gain of tree cover. Strictly speaking one cannot use the terms “deforestation” and “reforestation” in this map because one is in essence mostly dealing with trees that constitute part of other land covers and only occasionally with “forest” (the occasional left-over patch of primary forest or old(er) secondary forest in the area). Use of this terminology in the current context should rather be interpreted as follows:

“Deforestation” refers to change from land covers with medium to high tree densities to land covers with low tree densities or no trees (cacao > 20 + fallow to all other classes). “Reforestation” refers to the reverse process (all other classes to cacao > 20 + fallow). “Unchanged – forest” refers to cacao > 20 + fallow remaining the same, whereas “unchanged – others” refers to all other classes remaining the same.

The deforestation in the area is clearly going hand-in-hand with agricultural expansion. This – in its turn – could well be related with population increase in the study area. Census data indicate that in 1970, 1984 and 2000 the number of people in the study area was 82,275, 122,585 respectively 174,026, which means that for example in the period 1984 – 2000 (which comes closest to the period of the land cover change analysis) population increase in the study area was almost 42 %.

Worth noting here is also that cacao production in the study area has steadily been increasing in the period 1986 – 2004 (see Figure 4.8). Cacao producer prices have increased (see Figure 4.9) since especially the mid 1990s. First rather gradually, later quite explosively.

Fig 4.8. Cacao production in the study area between 1986 – 2004. (Source: Ghana Cocobod.)

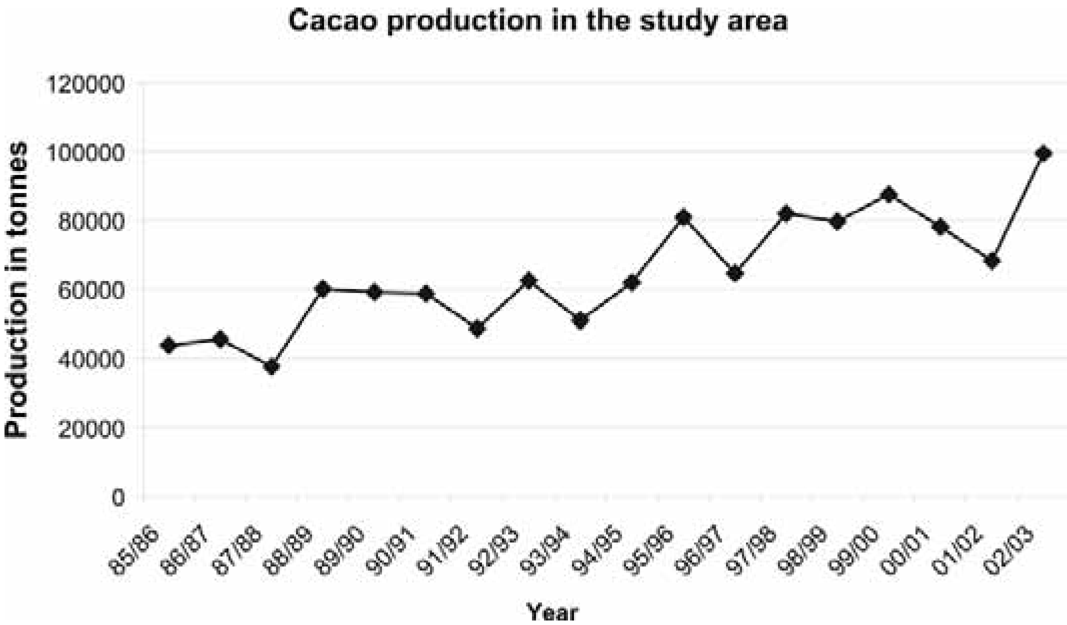
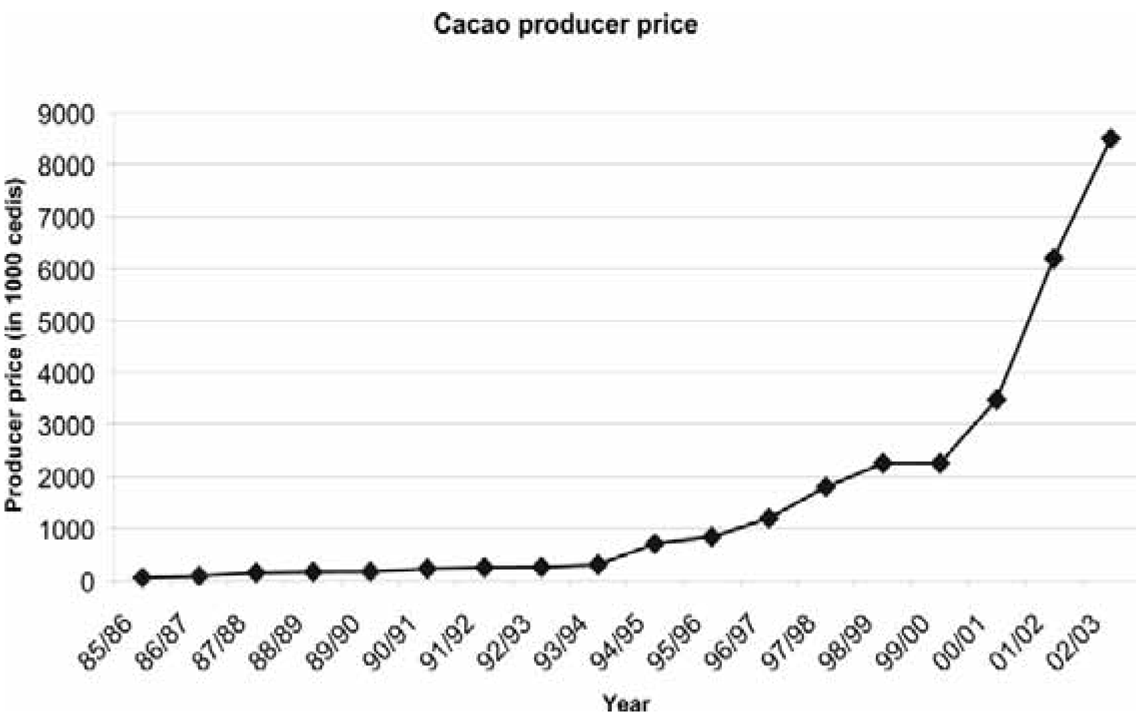


Fig. 4.9. Cacao producer price development between 1986 – 2004. (Source: Ghana Cocobod.)



When looking more closely at where the agricultural expansion/deforestation takes place, it seems that this is predominantly near settlements, near roads and near rivers/streams. This is illustrated by both the three scatter-plots in Figure 4.10 as well as by Figure 4.11 (which is showing a part of the map in Figure 4.7 in more detail).

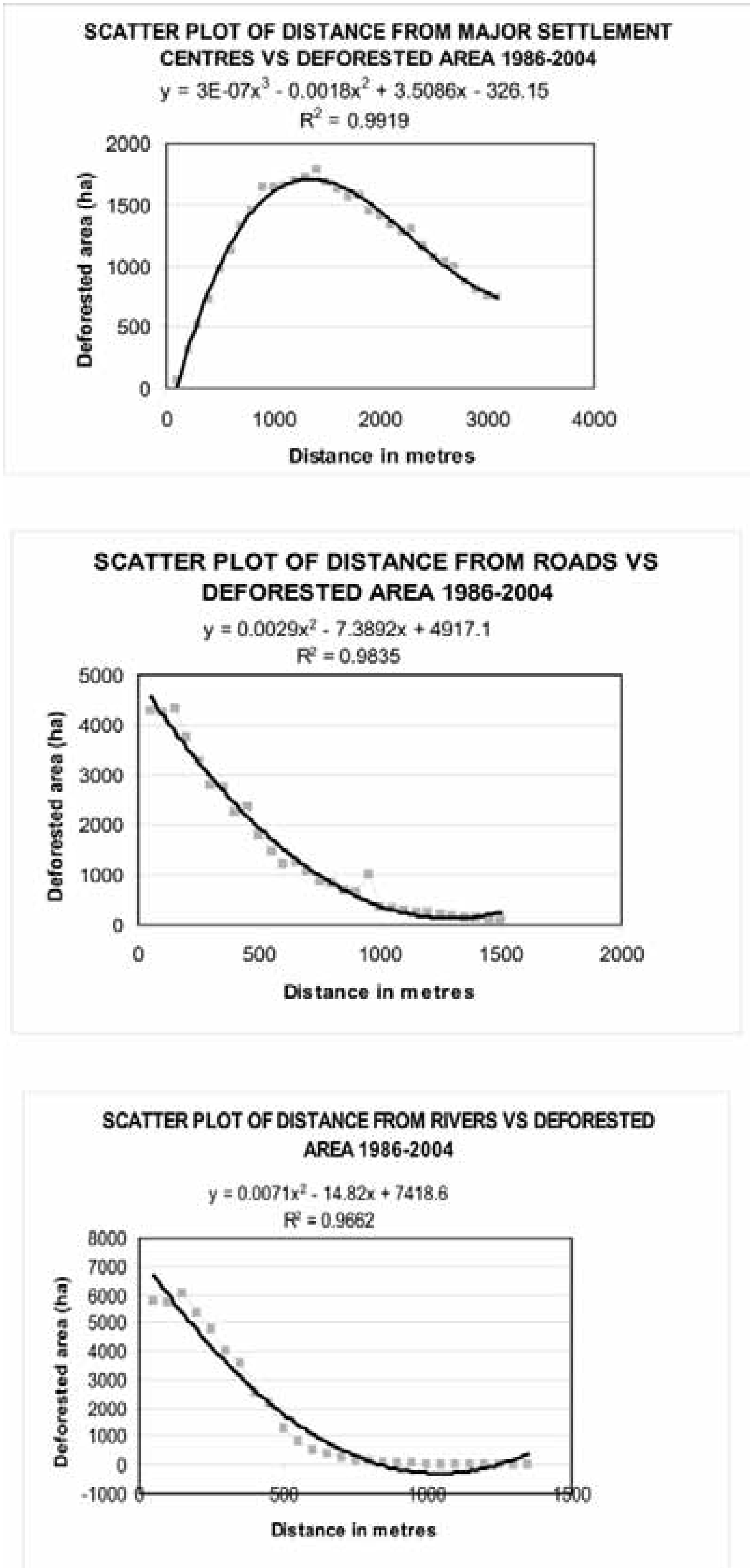


Fig. 4.10. Scatter-plots showing the relationship between deforestation and various distance parameters.

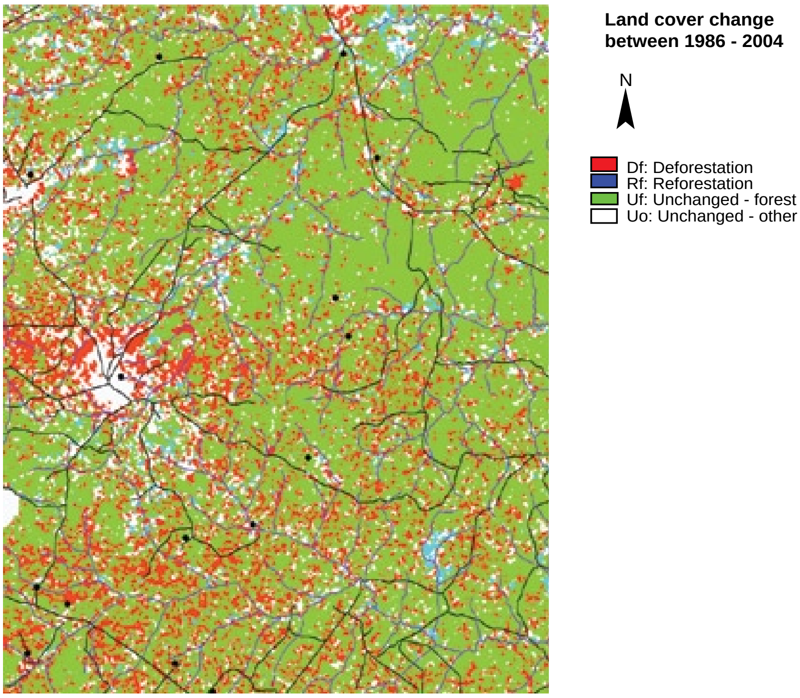


Fig. 4.11. Close-up of land cover change map 1986 – 2004 showing the occurrence of deforestation (red colour) near settlements (white colour) and roads and rivers/streams (blue lines)

4.5. Field survey trees

4.5.1. Tree density

The field data on trees (as distinguished from those on NTFPs, see paragraph 4.6) collected in 2003 and 2004 were analysed together.

Spread over two years a total of 117 plots were surveyed, mainly in the eastern part of the study area. Of these plots, 37 were located in cropland (annual + perennial), 40 in cacao, 25 in tree fallow, 10 in shrub fallow and 5 in grassland.

The focus in the analysis was firstly on tree density (being the parameter to be linked to land cover classes as mapped from satellite imagery). More in particular focus was on the following two commonly used measures of tree density:

» Number of trees per ha.
» Basal area.

Given in Table 4.1 below are the descriptive statistics for the variable number of trees per ha for the five land cover classes.

Table 4.1. Descriptive statistics for variable number of trees per ha for the different land covers.

	Crop (ann/perenn)	Cacao	Tree fallow	Shrub fallow	Grass
No. of plots	37	40	25	10	5
Average	37	61	243	112	9
Median	33	55	240	90	11
Variance	651.93	2389.84	16877.20	7840.00	50.20
Standard deviation	25.53	48.89	129.91	88.55	7.09
Minimum	0	0	44	0	0
Maximum	99	223	520	260	17
Stnd. skewness	1.9307	3.3554	1.1506	0.5669	-0.2572
Stnd. kurtosis	0.1944	3.0179	-0.1032	-0.7226	-0.9382

Although at first sight the average (or mean) numbers of trees per ha for the land covers look different from each other, further analysis was undertaken to determine whether they were significantly different from each other from the statistical point of view as well. There were, however, three things complicating matters in this respect:

» The fact that for two of the land covers (shrub fallow and grass) the number of plots sampled was too low for a meaningful statistical analysis.
» The fact that at least some of the other three land covers (crop, cacao and tree fallow) showed signs of departure from being normally distributed, something which would tend to invalidate statistical tests that assume that data come from a normal distribution (see Appendix 4 for the results of different tests checking on normality).
» The fact that at least some of the other three land covers (crop, cacao and tree fallow) showed considerable differences in standard deviation, something which would tend to invalidate statistical tests that assume that standard deviations are more or less similar (see Appendix 4 for the results of different tests checking on variance).

Due to the 1st problem the data for shrub fallow and grass was not included in the further analysis (at least not in respect of numbers of trees per ha). The 2nd and 3rd problems were overcome by transforming the data using a logarithmic function.

A F-test/ANOVA table (see Table 4.2) subsequently showed that there was indeed a statistically significant difference between the means of the three variables at the 95 % confidence level (p-value less than 0.05).

Fisher's least significant differences multiple range test was subsequently used to show that all combinations of the three means were significantly different from each other at the 95 % confidence level (see Table 4.3).

Table 4.2.Results of analysis of variance on logarithmically transformed variable numbers of trees per ha for the land covers crop (annual + perennial), cacao and tree fallow.

ANOVA Table

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-ratio	p-Value
Between groups	9.8262	2	4.9131	57.14	0.0000
Within groups	7.91075	92	0.085864		
Total (cor.)	17.737	94			

Table 4.3. Results of Fisher's multiple range test on logarithmically transformed variable numbers of trees per ha for the land covers crop (annual + perennial), cacao and tree fallow.

Multiple Range Tests

Method: 95.0 percent LSD

	Count	Mean	Homogenous Groups
LogCropNo	35	1.49656	X
LogCocoaNo	35	1.7552	X
LogTrf1No	25	2.31136	X

Contrast	Difference	+/- Limits
LogCropNo - LogCocoaNo	*-0.258637	0.139218
LogCrop - LogTrf1No	*-0.814792	0.152505
LogCocoaNo - LogTrf1NO	*-0.556155	0.152505

* denotes a satistically significance difference.

Given in Table 4.4 below are the descriptive statistics of the variable basal area (expressed in m^2 per ha) for the five land cover classes.

Table 4.4. Descriptive statistics for variable basal area for the different land covers.

	Crop (ann/perenn)	Cacao	Tree fallow	Shrub fallow	Grass
No. of plots	37	40	25	10	5
Average	8.11	18.63	27.68	11.68	4.97
Median	5.94	9.35	20.71	5.61	2.75
Variance	83.18	622.41	766.41	193.43	31.17
Standard deviation	9.12	24.95	27.68	13.91	5.58
Minimum	0	0	0.77	0	0
Maximum	41.96	109.39	108.87	43.33	11.37
Stnd. skewness	5.1998	5.7411	3.6714	1.9523	0.4205
Stnd. kurtosis	6.3276	6.2618	3.0543	1.2768	-1.4157

With basal area the same problem occurred as described above for number of trees per ha, namely that of non-normality of data and large differences in standard deviations. Unfortunately, a logarithmic transformation solved only the problem of large differences in standard deviations, but not that of the data not being distributed normally. Consequently further testing of the statistical significance of differences between means was abandoned.

The correlation between the variables number of trees per ha and basal area varies between relatively weak and moderately strong for the different land cover types. Coefficients in this respect are 0.29 for crop, 0.84 for cacao and 0.29 for tree fallow. Corresponding r-squares are 8.70% for crop, 70.37% for cacao and 8.49% for tree fallow. Also see Appendix 5.

4.5.2. Diameter distribution

Figure 4.12 shows the diameter distribution of the trees in the various land cover types. Tree fallow and to a lesser extent shrub fallow are the only land cover types that exhibit the inverted J-curve that is considered typical for uneven-aged natural forest vegetation. Crop has a somewhat U-shaped distribution and cacao a more or less even/flat one, clearly showing the effects of human activities/intervention.

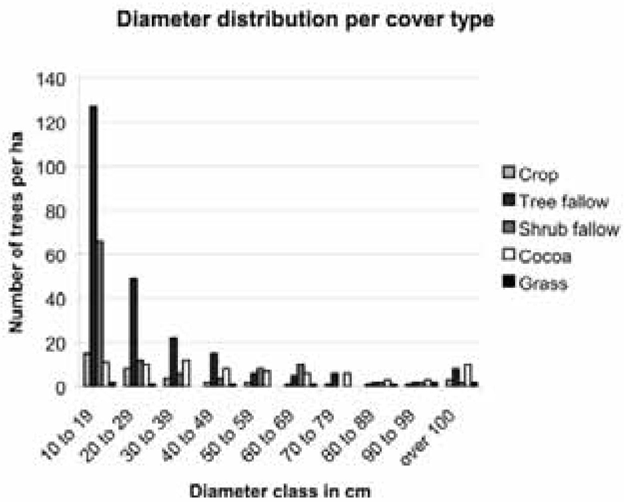


Fig. 4.12 Diameter distribution of the trees as found/sampled in the different land cover types.

4.5.3. Species

The focus in the analysis of the tree species found during the field surveys 2003/2004 was on timber and non-timber.

In Ghana timber (=economic) tree species fall within a classification system whereby they are assigned a so-called "star-rating". Of particular interest within the context of the project are species that have star-ratings scarlet, red, pink and green.

Scarlet/red/pink star species are those currently in commercial trade, whereas green star species are those that are not (yet) in commercial trade, but may well be once the scarlet/red/pink star species become logged out.

Star-ratings scarlet/red/pink are related to a species' rarity/imminent threat of extinction. Scarlet species are those that are currently under imminent threat of economic extinction, red species are those for which current rates of exploitation present a significant danger of economic extinction and pink species are significantly exploited, but not yet so as to cause concern for their economic future.

Out of all trees sampled during the field surveys 2003/2004, 42 % were specimens of timber species. There was not much variation in this respect in terms of land cover types. Crop (annual/perennial), cacao and tree fallow showed percentages of 42, 44 and 42 (shrub fallow and grass showed percentages of 30 and 82, but these should not really be seen as representative numbers because of the low number of plots sampled).

The ten most commonly occurring timber species were the following (in decreasing order of commonness):

- *Alstonia boonei* (local name: *sinuro*) (star-rating: green),
- *Terminalia superba* (local name: *ofram*) (star-rating: pink),
- *Ceiba pentandra* (local name: *onyina*) (star-rating: green),
- *Albizia adianthifolia* (local name: *pampena*) (star-rating: green),
- *Bombax buonopozense* (local name: *akata*) (star-rating: green),
- *Triplochiton scleroxylon* (local name: *wawa*) (star-rating: scarlet),
- *Amphimas pterocarpoides* (local name: *yaya*) (star-rating: green),
- *Milicia excelsa* (local name: *odum*) (star-rating: scarlet),
- *Pycnanthus angolensis* (local name: *otie*) (star-rating: pink),
- *Sterculia rhinopetala* (local name: *wawabima*) (star-rating: pink).

Each of these species comprised about five percent or more of the timber trees sampled. Together the species comprise about two thirds of all the timber trees sampled. Although a mixture of scarlet/red/pink and green species, the green species were more dominant (as was to be expected because they are less exploited).

When setting a felling limit of 70 cm dbh (minimum for Ghana) (Kotey *et al*., 1998), out of all the timber tree species sampled, 32 % were of harvestable size. About two thirds of these were found in cacao. Of all these harvestable timber trees, 42 % had a scarlet/red/pink and 58 % a green star-rating.

The eight most commonly occurring non-timber species were the following (in decreasing order of commonness):

- *Trilepisium madagascariense* (local name: *okure*),
- *Ficus sur* (local name: *nwadua*),
- *Glyphaea brevis* (local name: *foto*),
- *Ficus exasperata* (local name: *nyankyerene*),
- *Morinda lucida* (local name: *konkroma*),
- *Funtumia elastica* (local name: *fruntum*),
- *Blighia sapida* (local name: *akye*),
- *Ricinodendron heudelotii* (local name: *wama*).

Each of these species comprised about five percent or more of the non-timber trees sampled. Together they comprise about two thirds of all the non-timber trees sampled.

4.5.4. Regeneration

The data collected on regeneration in 2003, like those collected on trees in 2003/2004, have distributions departing from normality and large differences in variation between the land cover types, which renders, for example, comparison of means very difficult. There was also the problem of low numbers of plots per land cover: it was even more pronounced here because data came from one survey-year only instead of from two. Results of the regeneration survey are therefore presented here as general tables/graphs rather than as detailed statistics. To get the general picture in this case seems sufficient.

In Table 4.5 one finds the average/mean numbers of seedlings, saplings and poles for the different land cover types without a distinction being made between timber and non-timber species.

Table 4.5. Average/mean numbers of different stages of regeneration for the different land covers without distinguishing between timber and non-timber species.

Land cover	No. of plots	No. of seedlings/ha	No. of saplings/ha	No. of poles/ha
Crop (an/peren)	21	2981	37	26
Cacao	13	3095	21	10
Tree fallow	16	2583	555	295
Shrub fallow	7	1305	331	80
Grass	3	667	0	0

Crop (annual/perennial), cacao and tree fallow all have high numbers of seedlings per ha. The data on seedlings were the only ones that did not show the statistical deficiencies mentioned above and could therefore be analysed statistically, which showed that there were no statistically significant differences here (p-value > 0.05 at 95% confidence level). Shrub fallow and grass show considerably lower numbers of seedlings per ha.

Figure 4.13 illustrates that subsequently in crop (annual/perennial) and in cacao saplings and poles decline to dramatically lower numbers. In tree and shrub fallow they decline also, but more gradually along the inverted j-curve typical for uneven-aged natural forest vegetation. Grass has no saplings/poles whatsoever.

In Table 4.6 one finds the average/mean numbers of seedlings, saplings and poles for the different land cover types broken down into timber and non-timber species for the two land cover types that showed such a dramatic decrease in numbers going from seedlings to saplings/poles (crop (annual/perennial) and cacao).

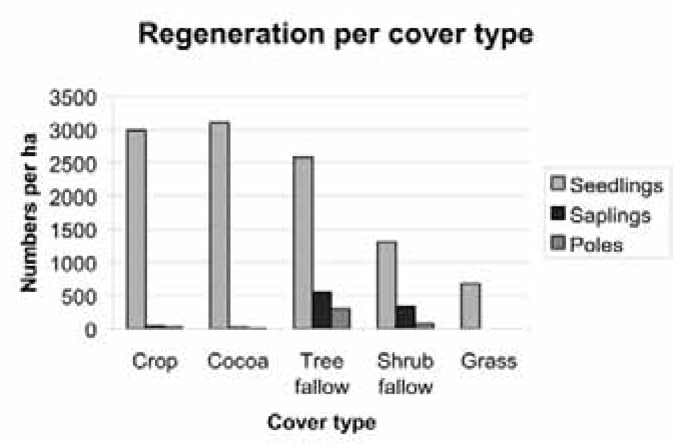


Figure 4.13. Average/mean numbers of different stages of regeneration for the different land covers without distinguishing between timber and non-timber species.

Table 4.6. Average/mean numbers of different stages of regeneration for land cover types crop (annual/perennial) and cacao distinguishing between timber and non-timber species.

Land cover	No. of seedling/ha timber spp.	No. of saplings/ha timber spp.	No. of poles/ha timber spp.
Crop (annual/perennial)	1062	22	19
Cacao	2164	11	9
	No. of seedling/ha non-timber spp.	**No. of saplings/ha non-timber spp.**	**No. of poles/ha non-timber spp.**
Crop (annual/perennial)	1919	19	7
Cacao	931	10	3

Worth noting here is that in cover type crop (annual/perennial) the number of seedlings of non-timber species is about twice the number of seedlings of timber species, but that it is the other way round in cover type cacao.

The above-mentioned differences between timber and non-timber species were statistically significant at seedling-level (p-value < 0.05 at 95 % confidence level). Differences subsequently level out at sapling/pole level, whereby for both land covers and for both timber as well as non-timber species, the number of saplings/poles per ha has been brought back to virtually 0 % of the original seedling numbers.

4.6. Field survey NTFPs

4.6.1. Main NTFPs collected

Table 4.7 below shows the main NTFPs people said they collected for either home/subsistence use or sale/generation of income.

The plant species and the locations where they occurred as presented in Table 4.7 were subsequently targeted in the NTFP survey.

Of the species used for NTFP collection by people, five are designated timber species: *Daniellia ogea* (star-rating pink), *Nauclea diderrichii* (scarlet), *Alstonia boonei* (green), *Strombosia glaucescens* (pink) and *Chrysophyllum albidum* (pink).

Table 4.7. NTFPs that people indicated they collected for subsistence use and income generation.

Species name	Local name	Occurrence/habitat	Uses
Calamus deeratus	*demere*	Near streams/rivers	Baskets Furniture
Raphia hookeri	*adobe*	Near streams/rivers	Baskets Mats
Bambusa vulgaris	*mpampro*	Near streams/rivers	Construction Handicraft
Terapleura tetraptera	*prekese*	Forest, cropland, fallow land	Spice Medicinal
Ricinodendron heudelottii	*wawa*	Forest, cropland, fallow land	Carving Medicinal Oil
Daniellia Ogea	*ehyedua*	Forest, cropland, fallow land	Incense
Christiana Africana	*sesedua*	Forest, cropland, fallow land	Carving
Nauclea diderrichii	*kusia*	Forest, cropland, fallow land	Carving
Spiropetalum heterophyllum	*ahomakyem*	Forest, cropland, fallow land	Medicinal
Rauwolfia vomitoria	*kakapenpen*	Forest, cropland, fallow land	Medicinal
Alstonia Boonei	*sinuro*	Forest, cropland, fallow land	Medicinal Carving
Cola Nitida	*bese*	Forest, cropland, fallow land	Food
Strombosia glaucescens	*afena*	Forest, cropland, fallow land	Construction
Margaritaria Discoidea	*pepea*	Forest, cropland, fallow land	Construction
Ficus exasperata	*nyankyerene*	Forest, cropland, fallow land	Medicinal
Spathodea campanulata	*akuakuoninsuo*	Forest, cropland, fallow land	Medicinal
Chrysophyllum Albidum	*akasaa*	Forest, cropland, fallow land	Fruit

4.6.2. Sampling designs

Because the adaptive cluster sampling used for surveying *rattan*, *bamboo* and *raphia* was applied with a systematic base, it was possible to compare adaptive cluster sampling with systematic sampling.

This comparison was done both in terms of statistical as well as economic efficiency. It is common to use sampling error of a method as a measure of statistical efficiency, whereas time required by a method can be used as a measure of economic efficiency. Ideal would be inventory methods with both high statistical as well as high economic efficiencies (that is: producing a low sampling error and requiring relatively little time). Such methods, however, are not very common and when choosing an inventory method usually a balance needs to be struck between these two kinds of efficiencies.

Table 4.8 shows the results of both systematic as well as adaptive cluster sampling in terms of the average/mean number of canes/clumps/palms found per ha, the 95 % confidence intervals for these averages/means and the sampling errors E %.

Table 4.8. Comparison of statistical efficiency of systematic sampling and adaptive cluster sampling.

Species	Systematic sampling			Adaptive cluster sampling			Relative efficiency
	Mean no per ha	Conf. interval of 95%	E $\%_S$ (sampl. error)	Mean no per ha	Conf. interval	E$\%_A$ (sampl. error)	$\frac{E \%_S}{E \%_A}$
Calamus deeratus	10.5	0 – 22.6	114.6	11	10 - 13	12.86	8.91
Bambusa vulgaris	2	0.4 – 3.3	76.8	2.8	2.5 – 3.0	8.75	8.77
Raphia hookeri	30.8	15 - 47	51.5	29	28 - 30	6.35	8.12

It can be seen from Table 4.8 that the sampling error of systematic sampling is about 8 times higher than the sampling error of adaptive cluster sampling for the three species. One can therefore conclude that for the three species adaptive cluster sampling is about 8 times more efficient relative to systematic sampling.

Table 4.9 shows the results of an analysis of time needed for systematic and adaptive cluster sampling. The 2nd column of the table shows the average/mean time needed to sample a systematic plot. A total of 63 systematic plots were sampled. Time per plot includes time for travel from one plot to another, plot demarcation and plot enumeration.
The 3rd column of the table shows the extra time that was needed to sample the cluster plots. Time for travel from one plot to another was assumed to be zero here the cluster plots were adjacent to the systematic plots and each other.
The 4th column of the table shows how many extra systematic plots could have been sampled in the time that was spent on sampling the cluster plots (so column 3/column 2). The 5th column shows that theoretical number of extra systematic plots as a percentage of the actual number of systematic plots sampled (63).
Columns 6, 7 and 8 finally show three sampling errors: that of the systematic sampling, the theoretical systematic sampling (if the time spent on the cluster sampling could have been spent on extra systematic plots) and the adaptive cluster sampling.

Table 4.9. Comparison of economic efficiency of systematic sampling and adaptive cluster sampling.

Species	Mean time per syst plot (in min)	$t_E = t_A - t_S$ (in min)	No. of syst plot in t_E	No. of syst plot in t_E as % of 63	E $\%_S$	E $\%_{S+E}$	E $\%_A$
Calamus deeratus	52	205	4	6.2	114.6	113.8	12.9
Bambusa vulgaris	55	564	10	16.2	76.8	74.6	8.8
Raphia hookeri	55	2450	45	71.2	51.5	41	6.4

From the above it can be concluded that adaptive cluster sampling takes extra time as compared to systematic sampling (6 % for *rattan* to 71 % for *raphia*) but that this seems time well spent because it reduces the sampling error for the three species considerably. If this extra time would have been spent on extra systematic sampling only a comparatively marginal improvement of sampling error would have been achieved. The conclusion can therefore be that adaptive cluster sampling is also more efficient than systematic sampling from the economic point of view.

4.6.3. Species

For the inventory in cropland and fallow land (using systematic cluster sampling method) a total of 128 plots were surveyed. Of these plots, 15 were located in cropland (annual + perennial), 67 in cocoa, 36 in tree fallow and 10 in shrub fallow.

The focus in the analysis was essentially on the presence/ absence of the species given in Table 4.7 (being the species used for subsistence/commercial NTFP collection by people). Figure 4.14 in this respect shows that several of these species were either absent or almost absent from the surveyed plots.

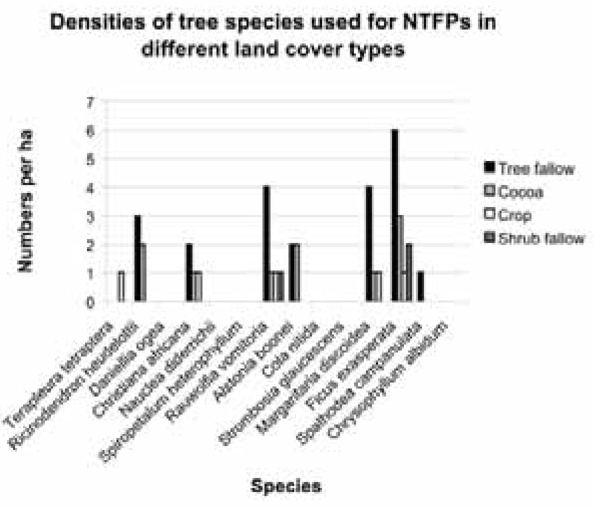


Fig. 4.14 Densities of the various tree species used by people for NTFP collection in different land cover types.

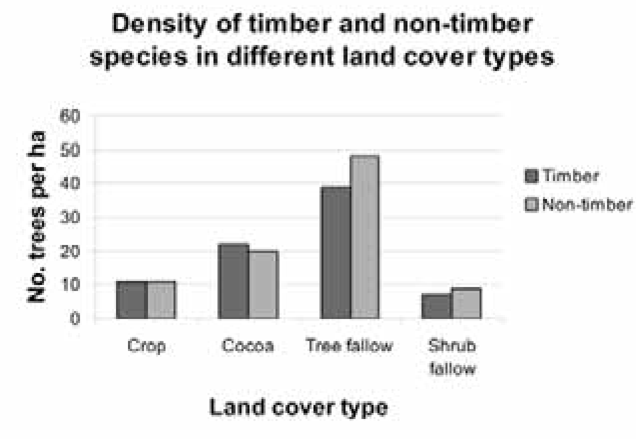


Fig. 4.15.Densities of timber and non-timber species in different land cover types.

Species that were completely absent from the surveyed plots were the four scarlet/red/pink timber species occurring in the list in Table 4.7 *Daniellia ogea*, *Nauclea diderrichii*, *Strombosia glaucescens* and *Chrysophyllum albidum* but also certain non-timber species like *Spiropetalum heterophyllum* and *Cola nitida*.

The species that did occur in the surveyed plots show a somewhat higher density in especially tree fallow and to a lesser extent cacao.

General comparison of the occurrence of timber species versus non-timber species (without specific focus on NTFP-species) shows that out of all trees sampled, 48 % were specimens of timber species. Crop, cacao, tree fallow and shrub fallow showed timber tree percentages of 50, 52, 45 and 44. See also Figure 4.15.

4.7. Assessment of local people's tree use/management

4.7.1. General points of interest on local people's farming

It appeared to be most common for farmers in the study area to have two types of farms (or rather places where they farm): one where they grow food crops and one where they grow cash crops. These two farms are not necessarily found in the same location: people's food crop farms in this respect tend to be nearer to the place where they live than their cash crop farms. The predominant size for both these kinds of farms is 1 to 5 ha and the majority of them (90 %) is located within 5 km of settlements.

Off all farmers that have two types of farms, 90 % considers their cash crop farm as being the economically most important one. Cacao is considered the most important cash crop. Oil palm cultivation also takes place but not on the same scale as cacao cultivation. Locally, however, it is considered important (even more than cacao).

Apart from cash/food crop farms, about $^1/_3$ of farmers also have one or more fallow farms. These lie interspersed with the farms that are currently under cultivation. Of the farmers that have (a) fallow farm(s), more than half would prefer a fallow period of 6 to 10 years. The actual fallow period, however, is 4 to 6 years on average. Fallow periods as short as 2 years were nevertheless also mentioned.

Farmers indicate that length of fallow period is decreasing because there is an increasing shortage of arable land. Population in the area is increasing and demand for land is high. There are also good markets for cash/food crops that encourage people to extend their farms to increase their income.

4.7.2. General points of interest on local people's tree use and management

Farmers indicated that the most common cause of depletion of on-farm tree resources is timber logging, but slash-and-burn practice, bush-fires and wind-storms play a role also. More than 50 % of respondents mentioned that timber was logged from their farms in the last five years. It is common that between 1 to 10 trees are taken from farms by loggers. Occasionally more trees are taken, but the number seldom exceeds 20.

According to farmers timber logging in Goaso Forest District started 11 to 15 years ago. In that time it was essentially concentrated in the southern part of the forest district. Meanwhile it has moved further up north. Currently most intensive logging is taking place in the north-east.

Currently most commonly logged species are the following:

- *Tieghemella heckelii** *(baku)*
- *Chrysophyllum albidum* *(akasa)*
- *Aningeria altissima* *(asamfena)*
- *Antiaris toxicaria* *(kyenkyen)*
- *Terminalia superba* *(ofram)*
- *Terminalia ivorensis** *(emire)*
- *Khaya ivorensis** *(dubini)*
- *Milicia excelsa** *(odum)*
- *Pycnanthus angolensis* *(otie)*
- *Triplochiton scleroxylon** *(wawa)*

*Species marked with * are species with a scarlet star-rating, whereas the other species have a pink star-rating.*

Farmers do not like logging on their farms as it damages crops, damages trees (that have a function/use to them) and causes soil compaction (because of use of heavy machinery). 71 % of farmers indicate that they have received no or insufficient compensation for damages to their crops incurred during logging.

About $^1/_3$ of farmers indicate that they have entered into individual arrangements with loggers to get at least some benefit out of the timber exploitation on their farms. Deliberate killing of timber trees by farmers in order to avoid problems with logging later is common ($^2/_3$ of respondents).

Timber logging and competition between trees and crops are seen as the two undesirable aspects of having trees on their farm, but at the same time farmers also see the positive aspects of having trees on their farms.

As the positive aspects of trees on farms specifically mentioned were provision of shade, improvement of soils, regulation of water-flow, improvement of microclimatic conditions (lower temperature, higher humidity, less wind) and a range of tree products.

People in particular value the tree functions provision of shade and improvement of soils given the importance of these two functions in both cacao as well as food crop farming. People, in this respect, attach an even bigger value/importance to provision of shade than to improvement of soils, which does not seem surprising given the economic importance people attach to especially their cacao farms.

With the appreciation of the various functions trees provide in people's livelihoods and farming systems, clearly also come efforts to retain and conserve trees on farms. Farmers' retention/conservation of trees on their farms as far as it concerns shade/soil conservation is thus not related to distance to forest, but rather to the specific function the trees have in a farmer's land use system.

People also value trees for a specific product they collect from it (rather than a service), but seemingly not to the extent that they will retain/conserve such trees on their farms when they would, for example, have (serious) negative effects on their crops.

When people were asked what they do when certain products become scarce on the farm, they merely replied they go to the forest reserve, the left-over unreserved forest or simply purchase them.

4.7.3. Tree species and their functions/uses

More in-depth questioning showed that people possessed a considerable knowledge of tree species and their functions/uses.

People were asked for what function they valued the different tree species that were found in the different land cover types most. Replies were subsequently grouped into the following three primary function categories:

- » F-value: primary function is related to tree products such as food, spices, medicine;
- » P-value: primary function is related to tree products such as fuel wood, timber, poles;
- » S-value: primary function is related to tree services such as provision of shade, improvement of soils, regulation of water, protection from wind.

Result of this exercise is shown in Figure 4.16.

Figure 4.16 shows that tree species with a primary value related to food/spice/medicine are more commonly found in cropland than in the other two land cover types considered. Tree species with production (fuel, timber, pole) as their most highly valued function seemingly occur more frequently in the two land cover types cacao and tree fallow. Tree species with services (shade, soil, water) as their most highly valued function are more or less equally common in all three land cover types.

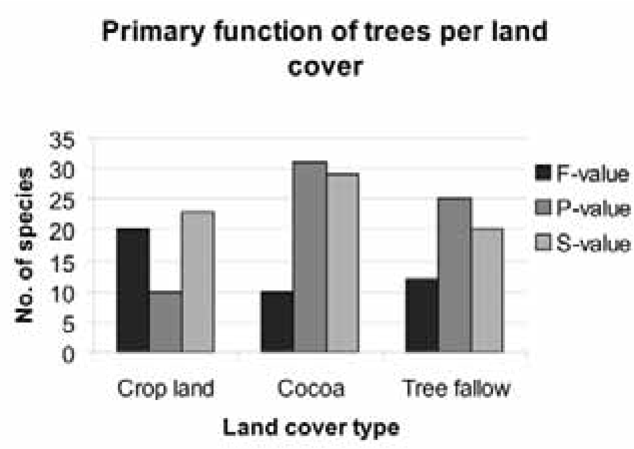


Fig. 4.16. Primary functions of the various tree species found in the different land cover types.

Although farmers consider timber trees a nuisance (at least when commercially logged), they also value them because they provide them with a range of services and products. Table 4.10 below shows a number of the timber and non-timber species most commonly mentioned by people when asked about trees species used for a number of particular purposes. The list is by no means exhaustive (more species, more functions/uses) but reflects some of the knowledge people have.

Table 4.10. Timber/non-timber species used/valued by people for a range of products and services.

Species name	Timber/Non-timber	medicinal	fuel wood	charcoal	fertility
Ceiba pentandra (onyina)	Timber	x			x
Terminalia superba (ofram)	Timber				x
Terminalia ivorensis (emire)	Timber				x
Triplochiton scleroxylon (wawa)	Timber				x
Bombax buonopozense (akonkodie)	Timber	x			
Khaya ivorensis (dubini)	Timber	x			
Pycnanthus angolensis (otie)	Timber	x			
Alstonia boonei (sinuro)	Timber	x			x
Celtis milbraedii (esa)	Timber		x	x	
Chrysophyllum albidum (akasaa)	Timber		x		
Cylicodiscus gabunensis (denya)	Timber			x	
Piptadeniastrum africanum (dahoma)	Timber			x	
Milicia excelsa (odum)	Timber			x	x
Ricinodendron heudelotii (wama)	Non-timber				x
Morinda lucida (konkroma)	Non-timber				x
Ficus sur (nwadua)	Non-timber				x
Musanga cecropioides (odwuma)	Non-timber				x
Rauwolfia vomitaria (kakapenpen)	Non-timber	x			
Spathodia campanulata (akuakuoninsuo)	Non-timber	x			
Trilepisium madagascariense (okure)	Non-timber		x	x	
Ficus exasperata (nyankyerene)	Non-timber		x		
Margaritaria discoidea (pepea)	Non-timber		x	x	
Macaranga barteri (opam)	Non-timber		x		

4.7.4. Non-timber forest products

The survey also looked more specifically at non-timber forest products people collect. Focus hereby was not so much on the tree/plant species the NTFPs were collected from, but rather on the places (the land cover types) they were collected from.

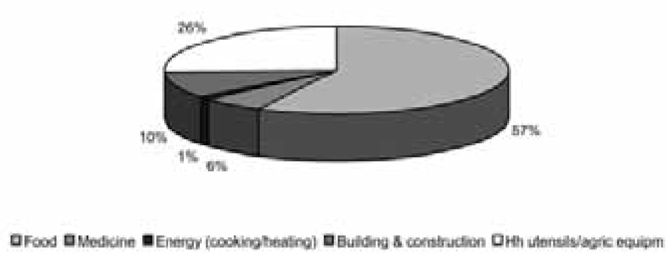


Fig. 4.17. NTFPs collected by people according to five broad categories of use.

Figure 4.17 shows the NTFPs collected by people according to five broad categories of use: food, energy, household utensils/agricultural equipment, medicine and building/construction.

About 50 % of NTFPs collected belong to the category food and comprise products of both plant as well as animal origin such as wild fruits, leaves for making soups, seeds for making cooking oil, spices for flavouring food, mushrooms, snails and bush meat. About 25 % of NTFPs collected are linked to the manufacture of utensils and equipment for household and agricultural use such as pestles, mortars, grinders, stirrers, baskets, mats, brooms, ladles, spoons, chewing sticks and handles for tools such as hoes and axes. For building and construction people collect NTFPs such as *bamboo*, *raphia*, *rattan*, rope made from climbers and saplings/poles used for making the frame for mud-houses. Ingredients for traditional medicine are collected in the shape of herbs or parts of trees. Collection of fuel wood needs no further elaboration.

The category of NTFPs that people value most is food. The various plants and animals that people collect help to enrich/supplement their diets, but do not seem to be collected in large quantities (nor for subsistence use or for trading).

Figure 4.18 shows the importance of the different land cover types as sources of NTFPs (respondents could give multiple answers).

Although forests, be it reserved or un-reserved (=left-over patches of original primary forest or older secondary forest in off-reserve areas), are an important source of NTFPs, cacao, fallow and crop farms were still mentioned by about one third of the respondents.

Several of the NTFPs collected, such as mushrooms and snails (highly valued by people) but also the more common kinds of bush meat such as *grasscutter* and *duiker*) come from both forested as well as non-forested areas.

Especially wild fruits and fuel wood are collected mainly from the off-reserve areas. Other NTFPs, especially some used for building and construction such as *bamboo*, *raphia* and *rattan*, have nowadays become scarce in the off-reserve areas and are mostly collected from the forest reserves.

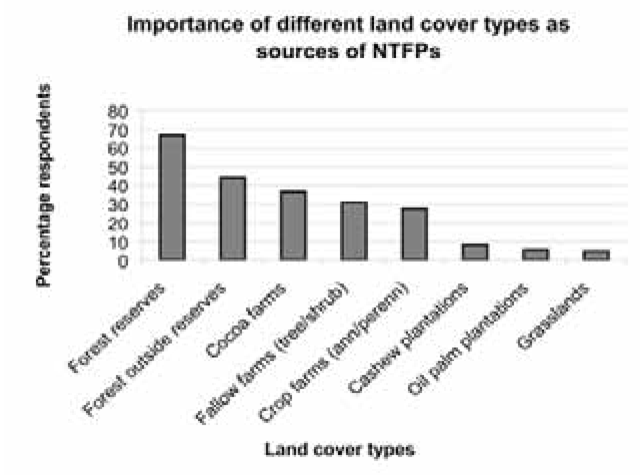


Fig. 4.18. The importance of different land cover types as sources of NTFPs.

Respondents said that supply of NTFPs from the off-reserve areas has been decreasing in the last five years. As main causes of the disappearance of trees/habitat logging and agricultural expansion and intensification (triggered by population increase) are mentioned.

Although a considerable number of NTFPs is used by people at the household level, commercial sale on local markets (Goaso, Kasapim and Sankore) is relatively low. Products sold were fruits, seeds, leaves, bark and bush meat. See Figure 4.19. Most of these, however, were reported to come from outside Goaso Forest District, particularly Kumasi.

Fig. 4.19. NTFPs sold on local market.

4.7.5. Incentives

The issue of incentives for improved use/management of the off-reserve tree resources (especially as regards timber tree species) was not exhaustively discussed with farmers. What nevertheless emerged (as was to be expected) is that farmers consider the issue of logging (with its largely non-functioning system of rules/regulations that in theory should give them the right to veto logging and to compensation for crop damage, but in practice doesn't) as by far the biggest non-incentive for them in terms of retention/conservation of timber trees on their farms.

About 20 % of respondents cultivate land under share-cropping/leasehold arrangements. This in principle might affect more active management of trees – such as planting – on farms, even when it concerns non-timber trees, because under customary law even such trees belong to the land owner and not the farmer.

5 Discussion

5.1. General

This chapter no longer follows the different data collection/analysis components of the project (as was done in chapters 3 and 4) but focuses on (groups of) research questions instead. The set-up is as follows:

- » §5.2: focuses on research questions 1 and 2. (Linked to methods for mapping/assessment of off-reserve tree resources.);
- » §5.3: focuses on research questions 3, 4 & 5. (Linked to the condition and functions/uses of off-reserve tree resources.);
- » §5.4: focuses on research question 6. (Linked to land cover change and its consequences for off-reserve tree resources);
- » §5.5: focuses on research questions 7 and 8. (Linked to incentives for better management of off-reserve tree resources).

5.2. Methods for mapping/assessment of the off-reserve tree resources

5.2.1. Indirect mapping/assessment: land cover classification

The landscape in Goaso Forest District is a mosaic of small fields/units of various different land cover types, having irregular shapes and unclear boundaries between them. A pixel-based approach to land cover classification with 30 m resolution imagery in this kind of landscape proved difficult as it is much affected by the mixed pixel problem.

In supervised classification the mixed pixel problem seriously affected the selection of suitable training samples. These showed a very strong tendency to overlap spectrally. This confused the algorithm and made it difficult to correctly allocate pixels to the various predefined land cover classes, which resulted in considerable misclassification.

In unsupervised classification the mixed pixel problem is less pronounced (as opposed to in supervised classification) because one starts the classification process with the identification of spectral classes and only thereafter selects related land cover classes, which leads to a better control over spectral separability between land cover classes. The nature of mixed pixels in terms of their spectral characteristics, however, still causes confusion and land covers that are in essence different may be classified as being similar. The error, however, is likely to be less. Hence, misclassification is likely to be less.

In object-oriented classification the mixed pixel problem is also less pronounced because one does not focus on the spectral characteristics of individual pixels but rather on the spectral homogeneity between neighbouring pixels.

Only limited time/effort went into the pixel-based land cover classification approach and in this respect both the supervised as well as the unsupervised classification approaches seem to hold potential for improvement.

Also the object-oriented classification approach seems to hold potential for improvement. What would definitely be worthwhile trying is to use it with 30 m resolution imagery (given some of the problems with area coverage experienced with Terra ASTER). The Disadvantage of the object-oriented classification approach is that, it in essence, it requires more of an operator/analyst in terms of skills/knowledge than the pixel-based methods. Even at a basic level.

The achieved high accuracies for the unsupervised and object oriented classifications are not uncommon for classification at the level of aggregation of land cover classes as applied in the project. In general one could hereby

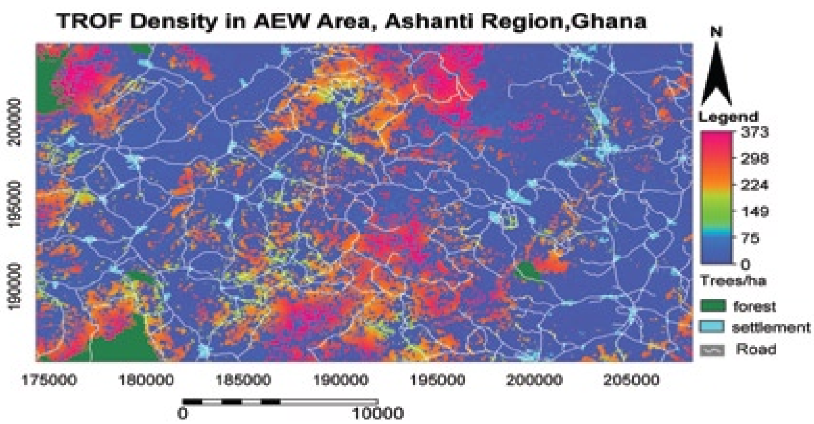


Fig. 5.1. Example of a tree density map created during pilot work done by the project in 2002.

say that the more detailed one wants a thematic classification system to be, the less accurate ones results for the individual classes are likely to be.

For the purpose of the project the level of detail of the applied land cover classification system was determined by the assumed relation between land cover and tree densities. Results from the field surveys suggest that there is no need to review the classification system (e.g. one with a higher level of detail).

With land cover maps produced and corresponding tree densities established through field surveys, a next step could be to create tree density maps such as the one shown in Figure 5.1[2]., which was made by ITC during pilot work in an area south of Kumasi in 2002.

With GIS also other factors that affect tree densities can be incorporated in such maps. This can lead to improvement/ refinement of current tree density maps merely based on average tree densities per land cover to more detailed and sophisticated maps such as the one shown above.

5.2.2. Direct mapping/assessment

When looking at the results of the direct assessment of the off-reserve tree resources using forest canopy density mapping and sub-pixel classification, general observation is that the 1st method has given quite a poor outcome and that the 2nd is showing potential. It is in this respect not only the accuracy assessment that underlies this observation but also the visual comparison between Figures 4.4 respectively 4.5 and Figure 4.6 (bottom) (the latter showing the result of pixel-based land cover classification for the same area). Figures 4.4 and 4.6 have only limited resemblance whereas Figures 4.5 and 4.6 have reasonable resemblance.

When comparing the outcome of the forest canopy density mapping with the image used with it, it seems it has been over-estimating canopy density especially in areas with somewhat lower tree densities such as cropland and cacao with low(er) numbers of trees. Shrubs (regenerating from stumps and root-stock), crops (especially the perennial ones such as plantain and cassava) and the cacao trees/bushes themselves occurring in such environments seemingly confuse the Forest Canopy Density Mapper and entice it into recording higher canopy densities than there actually are.

What might also have affected the outcome of both methods to a certain extent is the fact that both images used were acquired during the dry season months when at least part of the trees could have exhibited reduced foliage or even complete leaflessness or could have had dry brownish leathery leaves which also have different reflection values (there was, however, no other choice than to use these images given that imagery from the wet season has too much cloud cover to be usable).

The forest found in the study area is of the moist, semi-deciduous, north-east sub-type. These forests (personal communication *Kyereh Boateng*) have upper canopy trees whose composition is such that about 50 percent are evergreen and the other 50% are deciduous. The deciduous trees exhibit degrees of leaflessness that vary from one species to another. In extreme cases one can have species in which shed leaves are replaced with new ones almost simultaneously, whilst in others there is an extended period of over one month when the crown is completely leafless. In between these there are intermediate categories. The situation is further complicated by the fact that some species shed their leaves and pick up new ones just before the dry season, so that in the dry season itself they don't appear deciduous.

2 A tree density map as shown in Figure 5.1 was also produced during the main phase of the project for that part of the study area for which object-based classification was done. The result, however, was not very satisfactorily as the map had a strong salt-and-pepper appearance due to the very fragmented nature of the landscape in the study area (compared to the area shown in the figure above) and was thus not included in chapter 4.

Apart from the not altogether satisfactorily results, especially sub-pixel classification also has the disadvantage (in similar fashion with object-oriented classification) that, it in essence, it requires more of an operator/analyst in terms of skills/knowledge than the standard pixel-based methods.

An issue furthermore seems to be how exactly to interpret the output of these methods. High canopy densities do not necessarily imply there are also large numbers of trees. High canopy density in a pixel could, for example, come from the presence of one big tree with a wide crown, but also from a number of trees with somewhat smaller crowns.

5.2.3. Field surveys

The two partners in the project that were involved in the field surveying of trees used stratified random sampling (ITC) and systematic cluster sampling (UF) approaches. Although analysis/comparison of these two approaches as such was not the intention of the project, some – general – comments on both will still be made here.

Both approaches – in essence – experienced similar problems, namely:

» That the data collected on trees showed large variation in the tree density parameters surveyed. Although this seemed to reflect the heterogeneity of the resource, it caused problems with statistical testing;
» that the procedures followed (plot-allocation proportional to size of strata (ITC) respectively post-stratification of plots (UF)) were such that some of the land covers (shrub fallow and grass) were sampled with too low an intensity, which caused problems with statistical testing as well.

Sampling intensity was in both cases fixed before the field work started and was essentially based on two arguments:

» Limitations of time;
» the fact that (given that not many off-reserve tree resource inventories had taken place before) it was unknown what variation could be expected in the field and thus what an acceptable sampling error would be.

This was undoubtedly the most appropriate approach under the circumstances. The experiences from the surveys, however, now clearly present opportunities for improvement. Thereby sampling error and sampling intensity are definitely issues that need attention.

The large plot sizes employed in both procedures worked reasonably well although zero plots could not be avoided altogether. This, however, seems inherent to the heterogeneity of the resource and not to the procedure applied.

Whether plots are circular or square does not really seem to matter other than that they both have a number of practical advantages and disadvantages.

The adaptive cluster sampling method that was applied in the survey of *rattan*, *bamboo* and *raphia*, performed satisfactory under the special circumstances for which it was intentionally selected and therefore – one could probably say – lived up to expectations.

5.3. Off-reserve tree resources' condition and functions/uses

Arguably one of the most significant outcomes of the surveys on trees is that they confirmed the assumption that to a large extent guided many of the project's activities, namely that tree densities in the off-reserve areas are related to the land cover types in which they occur.

The ITC's survey thereby gave consistently higher average numbers of trees per ha for all the different land cover types than the UF survey, especially so for tree and shrub fallow. Reason(s) for these observed differences is/are difficult to ascertain at this point in time. The fact that different sampling approaches were employed has possibly played a role here.
The only reference that could be found with which to compare results was Nkyi (1989) who found average numbers of trees per ha for cacao and crops of 107 respectively 33. This author, however, included trees with a dbh > 5 cm in his survey and applied a completely different sampling approach as compared with the ones used in the project. The study, however, took place under similar ecological/vegetation conditions as were found in the project's study area (moist semi-deciduous forest zone).

The diameter distribution of the trees in the various land cover types clearly shows the differences between natural (tree/shrub fallow) and man-made (crops and cacao) systems. Cropland shows very low numbers of trees in especially the middle diameter classes. Many trees (although not all, because some may serve other, useful, purposes as well) are likely to be removed here because they compete too much with the crops underneath. Occasionally a very big tree is still found, often because it is too much effort to remove it (personal communication farmers).

Cacao farms (as opposed to cropland) have higher numbers of trees in the middle diameter classes, because in this land cover type these trees have an important function, namely the provision of shade (which is something that is valued less in cropland) Different stages of cacao development, moreover, require different degrees of shade (gathered from personal communication with farmers), which could explain the high variation in numbers of trees per ha found in especially cacao.

In respect of the ratio timber/non-timber trees currently found in the off-reserve areas, both field surveys (ITC, UF) found more or less the same, namely that timber trees (still) comprise 40 to 50 % of all the trees found (overall and in the different land cover types). In discussions and interviews, the people explicitly mentioned that in particular *Terminalia superba* (*ofram*), *Triplochiton scleroxylon (wawa)*, *Milicia excelsa (odum)*, *Ceiba pentandra (onyina)* and *Terminalia ivorensis (emire)* are now getting scarce(r). This, however, was not confirmed by the ITC survey which showed that at least four of these species still occurred in the top-ten of most frequently occurring timber species (each of them comprising at least 5 % or more of total numbers of timber trees present). Also trees of harvestable size still for about $^1/_3$ consist of timber trees of which scarlet/red/pink species comprise 40 %. The area is thus not yet completely logged-over. That there is nevertheless reason for concern becomes clear from the UF study on the species used for NTFPs which suggests that several of these species have now completely or almost completely disappeared (something that was confirmed by ITC's survey in which these species (4 timber and 2 non-timber) were also not or only rarely encountered. What is of particular interest in this respect is that there are 2 non-timber species amongst those disappearing/no longer found, which means that it is not only timber logging that is doing the "damage", but also (presumably agricultural) activities of farmers.

Also the situation as regards the occurrence/disappearance of *rattan*, *bamboo* and *raphia* gives rise for concern. In this particular case it is clearly not timber logging, but agricultural expansion/intensification that is involved (see paragraph 5.4).

As far as regeneration is concerned, it is clear that in cropland and cacao farms, intervention by farmers quite considerably reduces the initially high number of seedlings, most of which seem to have been weeded out by the time they reach sapling/pole size. There is no difference in this respect between seedlings of timber and non-timber species. Presumably farmers initially want to bring down numbers of regeneration for more general reasons such as competition with crops and it is only at some later point in time (when the trees are beyond pole dimensions) that specimens of timber trees are killed by farmers with a view to future logging/damage.

Regeneration in shrub fallow is reportedly suffering from encroachment by *acheampong* which tends to grow so vigorously and abundantly that it smothers the tree regeneration. Although the *Chromolaena odorata* itself seems to promote rapid soil-nutrient recycling, its occurrence disrupts the processes of fallow regeneration and with that causes a undesirable decline in agro-biodiversity (Amanor, 1996).

In grassland, regeneration has a problem establishing itself due to competition with the aggressive grasses (many of which spread through root-stock) and even if they manage to do so, they subsequently fall victim to bushfires raging through especially these grasslands.

Rather than distance to forest, it turned out that it was the specific function(s) that trees have in a farmers land- use system, that govern/affect tree retention/conservation on farms.

Illustrative in this respect is the exercise that was done on the primary function of the different tree species that were found in the different land cover types which shows that there is a reasoning, based on knowledge (partly documented), behind what people do with trees on their farms.
Timber trees are maintained on farms because they serve useful purposes to farmers (until they have outlived their useful purpose and/or their logging becomes imminent). Other trees (non-timber) might be removed even if they have certain useful characteristics (such as non-timber forest products) because they might also have characteristics that are less/not so much valued by farmers under particular circumstances.

Farmers usually balance the advantages and disadvantages of having trees on their farms and consequently retain/conserve them in the numbers and the places that suit them best. Farmers in Goaso Forest District are no exception.

That the resource base is nevertheless in decline is needless to say and again shown in the results of the study on the currently most important sources of non-timber forest products. Forests are nowadays the most important source of NTFPs whereas about 15 years ago most of them came from the people's own crop lands, cacao farms and fallow lands Falconer (1992).

Of particular importance in this respect seems to be the disappearance of tree fallow land. This land cover (especially in the further stages of development) most closely resembles forest (primary/old(er) secondary) and one could expect that several of the products people nowadays collect from the forest proper would have come from there previously.

5.4. Land cover change

The land cover change in the study area, as observed on the satellite images, fits in well with observations made during field surveys by ITC and UF and information gathered from people during focus group discussion and individual interviews by UG.

Population is steadily increasing (natural increment, lower mortality and in-migration) which lead to expansion of built-up areas and an increased need for cropping land because people need a place to live and food to eat.

The agricultural expansion, however, is not only related to farming at subsistence level. In the discussions/interviews, people explicitly mentioned that it is also driven by good markets for both cash as well as food crops, which encourage people to extend their farms to increase their income.

As was already mentioned in chapter 4, the fact that land cover class cacao has decreased between the reference years does not mean that cacao farming in the area is in decline. The observed change rather suggests that cacao farms that were degraded/abandoned after the droughts, bushfires, diseases and low producer prices of the 1970s and 1980s, have meanwhile (partly) been cleared and replaced with new farms with, for example, new, hybrid, cacao varieties or farms-in-the making (=still hidden under food crops).

Since the beginning of the 21st century Ghana is experiencing a kind of cacao boom with increasing and high production figures and producer prices (see Figures 4.7 and 4.8). Such producer prices are clearly an incentive for people to continue/restart growing cacao (provided soil nutrient and soil moisture conditions of people's land will allow for it). Partly the increasing and high production comes from the intensification of the production on land already under cacao, through increased fertiliser and pesticide use. Partly, however, it also comes from an increase in area under cultivation (Vigneri, 2007). In discussions/interviews farmers very clearly expressed that they value especially their cacao farm(s) very highly.

Much of the agricultural expansion takes place near settlements, roads and streams/rivers. People prefer to cultivate land that is near the place where they live for obvious reasons (distance, security), with food crops preferably nearest to the settlements and cash crops a little further away, but nevertheless still located within a distance of 5 km of settlements. If land near settlements is no longer available people prefer to cultivate land that is at least fairly easily accessible (e.g. near roads).

The fact that much agricultural expansion/deforestation takes place near rivers/streams seems (yet another) expression of the fact that agricultural land is getting scarce. Regulations stipulate that no one is allowed to cut trees and cultivate crops near rivers/streams as a soil/water conservation measure. When land is still plentiful, such regulations are followed, but with increasing scarcity they are more and more ignored.

Observations made by UF during their survey on *rattan*, *bamboo* and *raphia*, which took place near streams/rivers, strongly confirm what is seen in the land cover change analysis. Land clearing/crop farming takes place right up to the bank of streams/rivers and farmers even grow crops (such as rice, which can thrive under water-logged conditions) in areas that are regularly flooded.

It is precisely because of these kinds of practices that the occurrence and density of valuable NTFP species such as *rattan*, *bamboo* and *raphia* is at its present low levels because farmers completely destroy or fragment their habitat.

The observed decrease in fallow and increase in grass are two more indicators of the more intensive use of land at present as compared with the past (be it in different ways). Although farmers indicate that they would prefer a fallow period of 6 to 10 years, the average fallow period is now 4 – 6 years, which means that in any case tree fallow is becoming scarcer because land is no longer fallowed long enough to reach that stage. Grass is showing an increase because the shortening of fallow periods leads to increasing over-cultivation and soil impoverishment and with that encroachment by grasses such as *Pennisetum purpureum* and *Imperata cylindrica* becomes more common.

The change analysis was not really able to shed much light on the issue of timber logging or the removal of (timber) trees by farmers (through ring-barking or setting fire to them).

An aspect in respect of logging/removal of timber trees is of course also the fact that a considerable amount of it is done illegally, which means that there is no official documentation available with which findings can be compared to and/or substantiated.

In discussions/interviews, however, it was said that the area under consideration was mostly logged over 10 to 15 years ago and that at present logging activities are low key. Two thirds of farmers moreover indicate that they themselves deliberately kill timber trees on their farms in order to avoid problems with logging at some later stage. Worthwhile mentioning in this respect is that evidence of the removal of (timber) trees by farmers (through ring-barking or setting fire to them) was clearly observed during the collection of ground-truth for the accuracy assessment of forest canopy density mapping and sub-pixel classification. Out of 80 plots visited for this purpose, 22 had evidence of deliberate killing of trees by farmers.

5.5. Incentives

It seems obvious that for improved use/management by farmers of especially timber trees (which would mean refraining from illegal removal and/or deliberately killing these trees) the current benefit sharing scheme and rules/regulations for logging need to be reviewed. It seems obvious (again) that in this respect farmers, as the key stakeholders, need to become considerably more actively involved in policy-making and decision-making than has been the case until now.

The above, however, is nothing new and much has already been said and written about it (Mayers *et al*. (1996), Mayers & Kotey (1996)) but a workable solution has as yet not emerged.

The project's findings in respect of current collection/marketing of NTFPs in Goaso suggest that the commercialization of such products as an incentive mechanism for the improved off-reserve tree resources' use/management in the study area does not seem to have much potential because:

» The resource base is already in decline and would therefore first need to recover (presumably through active intervention).
» There is currently no market (although people collect for subsistence purposes) which would therefore first need to be developed.

Whether both resource as well as market can be successfully developed seems unpredictable at present.

6 Conclusions

Drawing conclusions is seemingly best done by referring back to the research questions that the project formulated as presented in the introduction to this document and to assess to what extent they can be answered.

Q.1. To what extent can remote sensing technology be used for the assessment of off-reserve tree resources condition and distribution?

RS technology is an essential tool in the assessment of off-reserve tree resources density distribution, especially over larger areas. However, direct assessment is problematic. A viable option is indirect assessment/land cover classification and linking that to field survey data on trees from the various land covers.

Current levels of technology in terms of imagery and software are capable of mapping land cover in sufficient detail.

Q.2. What is/are the most appropriate operational method(s) for the assessment of off-reserve tree resources condition and distribution?

It is deemed impossible to give an answer to this question here at present given that many factors, which can be considered relevant in this respect, have not yet been fully explored. The combination of a remote sensing based survey with a ground-based survey of trees is less time consuming and therefore cheaper than a full-scale conventional survey/inventory but is still demanding in terms of human/financial resources required.

Something that in this respect also needs to be explored further is the statistical soundness of the field survey methods whereby especially sampling error and sampling intensity need further attention. If it would be necessary to increase sampling intensity then undoubtedly also human/financial resources required for surveying will increase.

Q.3. What is the off-reserve tree resources condition and distribution and what factors influence these?

The off-reserve tree resources condition – in general – is rather worrying with logging, but especially also the expansion and intensification of agriculture, causing damage. There seems to be no particular patterns in tree resources distribution other than that tree densities are strongly related to different land cover types.

Much of the study area is dominated by a mixture of cash (cacao) and food crop farming. There are, however, some areas that seemingly have a stronger dominance of food crop farming. What determines the location of these areas vis-à-vis the location of the mixed cash/food crop farming is unclear as it was not subjected to investigation.

Q.4. What are the main functions/uses of off-reserve tree resources for/by local stakeholders?

Arguably the main functions of tree resources for local people seem to be their service functions provision of shade and improvement of soil, given the important role these play in productivity of people's farming/land-use system and with that their livelihoods. Supply of tree products is not an unimportant function, but seems of less importance.

Q.5. What are the main sources (=land cover types) of tree products for local stakeholders?

The main sources of tree products are the land covers cropland, cacao and tree fallow. Forest, however, is strongly on the increase as a source because certain products are getting scarcer in above-mentioned land cover types.

The land covers shrub fallow and grass have, due to problems with the occurrence of various invading/aggressive kinds of plants and their effects on trees, clearly only a small role to play nowadays.

Q.6. How has off-reserve tree resources' distribution changed over the last 10 to 15 years and are there certain patterns of change?

Due to agricultural expansion/intensification especially fallow vegetation is declining. Agricultural expansion mostly starts near villages and then spreads outwards from there. Agricultural expansion also takes place near roads (presumably because of accessibility) and near rivers/streams where hitherto protected riparian vegetation falls victim to it. The latter is especially detrimental to important NTFPs such as *rattan*, *bamboo* and *raphia* that specifically occur in such habitats.
The disappearance of fallow vegetation is worrying because it disrupts the process of maintenance and restoration of soil fertility, but also because it leads to a decline in agro-biodiversity, effects of which are as yet difficult to predict.

Q.7. What are potential incentive mechanisms for improved use/management of off-reserve tree resources by local stakeholders?

The possibly most important incentive for local people to retain/conserve the off-reserve tree resources seemingly lies in the role they play in shade provision/soil improvement.

Q.8. What – in particular – is the role and importance of non-timber forest products from off-reserve lands for local stakeholders and could this possibly serve as an incentive mechanism?

Non-timber forest products are used for local subsistence, but there is no market for them. Commercialization of such products as an incentive mechanism therefore doesn't seem to have much potential.

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Appendix 1

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Main project collaborators (other than authors of project documents).

UG

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RMSC

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Appendix 2

Timber species and their star rating (from Forestry Commission).

Genus	Species	Local Name	Star Rating
Afzelia	*africana*	PAPAO	Red
Albizia	*ferruginea*	AWIEMFOSAMINA	Scarlet
Albizia	*zygia*	OKORO	Green
Alstonia	*boonei*	SINURO	Green
Amphimas	*pterocarpoides*	YAYA	Green
Aningeria	*altissima*	ASAMFENA	Pink
Aningeria	*robusta*	SAMFENANINI	Pink
Anopyxis	*klaineana*	KOKOTE	Red
Antiaris	*toxicaria*	KYENKYEN	Pink
Antrocaryon	*micraster*	APROKUMA	Red
Berlinia	*confusa*	KWATAFOMPABOA	Green
Berlinia	*spp.*	KWATAFOMPABOANINI	Green
Rhodognaphalon	*brevicuspe*	ONYINAKoBEN	Red
Bombax	*buonopozense*	AKATA	Green
Canarium	*schweinfurthii*	BEDIWONUA	Pink
Ceiba	*pentandra*	ONYINA	Green
Celtis	*mildbraedii*	ESA	Green
Celtis	*zenkeri*	ESAKOKO	Green
Chrysophyllum	*albidum*	AKASAA	Pink
Chrysophyllum	*subnudum*	ADASEMA	Red
Copaifera	*salikounda*	ENTEDUA	Red
Cordia	*platythyrsa*	TWENEBOABERE	Green
Cordia	*millenii*	TWENEBOA	Green
Cylicodiscus	*gabunensis*	DENYAo	Pink
Cynometra	*ananta*	ANANTA	Pink
Daniellia	*ogea*	EHYEDUA	Pink
Daniellia	*spp*	HYEDUA	Pink
Daniellia	*thurifera*	SOPI	Pink
Dialium	*aubrevillei*	DUABANKYE	Green
Diospyros	*sanza-minika*	SANZA-MULIKA	Blue
Distemonanthus	*benthamianus*	BONSAMDUA	Pink
Entandrophragma	*angolense*	EDINAM	Red
Entandrophragma	*candollei*	PENKWA-AKOA	Scarlet
Entandrophragma	*cylindricum*	PENKWA	Scarlet
Entandrophragma	*utile*	EFOoBRODEDWO	Scarlet
Erythrupleum	*guineense*	POTRODOM	Pink
Erythrophleum	*suaveolens*	ODOM	Pink
Guarea	*cedrata*	KWABOHORO	Pink
Guarea	*thompsonii*	KWADWUMA	Pink
Guibortia	*ehie*	ANOKYE-HYEDUA	Red

Heretiera	*utilis*	NYANKOM	Red
Khaya	*anthoeca*	*KRUMBEN*	*Scarlet*
Khaya	*grandifoliolia*	*KRUBA*	*Scarlet*
Khaya	*ivorensis*	*DUBINI*	*Scarlet*
Klainedoxa	*gabonensis*	*KROMA*	*Green*
Lophira	*alata*	*KAKU*	*Red*
Lovoa	*trichilioides*	*DUBINIBIRI*	*Red*
Mammea	*africana*	*BOMPAGYA*	*Pink*
Mansonia	*altissima*	*OPRONO*	*Pink*
Milicia	*excelsa*	*ODUM*	*Scarlet*
Mitragyna	*spp*	*SUBAHA*	*Red*
Nauclea	*diderrichii*	*KUSIA*	*Scarlet*
Nesogordonia	*papaverifera*	*DANTA*	*Pink*
Parkia	*bicolor(+)*	*ASOMA*	*Green*
Pericopsis	*elata*	*KOKRODUA*	*Scarlet*
Petersianthus	*macrocarpus*	*ESIA*	*Green*
Piptadeniastrum	*africanum*	*DAHOMA*	*Pink*
Pterygota	*macrocarpa+*	*KYEREYe*	*Red*
Pycnanthus	*angolensis*	*OTIE*	*Pink*
Sterculia	*rhinopetala*	*WAWABIMA*	*Pink*
Strombosia	*glaucescens*	*AFENA*	*Pink*
Terminalia	*ivorensis*	*EMIRE*	*Scarlet*
Terminalia	*superba*	*OFRAM*	*Pink*
Tieghemella	*heckelii*	*BAKU*	*Scarlet*
Triplochiton	*scleroxylon*	*WAWA*	*Scarlet*
Turraeanthus	*africanus*	*APAPAYE*	*Pink*
Morus	*mesozygia*	*WONTON*	
Sterculia	*Oblongata*	*OHAA*	*Pink*
Zanthoxylum	*gilletii*	*OKUO*	
Cola	*gigantea*	*WATAPUO*	*Green*
Erythroxylum	*mannii*	*BENKYI*	
Hannoa	*klaineana*	*HOTROHOTRO*	
Parinari	*excelsa*	*AFAM*	
Blighia	*sapida*	*AKYE*	
Albizia	*adianthifolia*	*PAMPENA*	*Green*
Breviea	*leptosperma*	*KANKABIM*	
Gilbertiodendro	*limba*	*TETEKON*	
Lannea	*welwitschii*	*KUMNINI*	*Green*
Okoubaka	*aubrevillei*	*ODII*	
Celtis	*aldolfi-frider*	*ESAKOSUA*	

Appendix 3

Photographs illustrating the project's data collection/analysis activities.

Appendix 4

Tests for normality and variance of variable number of trees per ha

Test for normality for Crop Number

Shapiro-Wilks W statistic = 0.93419
p-value = 0.038894
Estimated overall Kolmogorov-Smirnov statistic DN = 0.128145
p-value = 0.577871

Test for normality for Cocoa Number

Shapiro-Wilks W statistic = 0.91198
p-value = 0.001923
Estimated overall Kolmogorov-Smirnov statistic DN = 0.132845
p-value = 0.490925

Test for normality for Treefl Number

Shapiro-Wilks W statistic = 0.94985
p-value = 0.260403
Estimated overall Kolmogorov-Smirnov statistic DN = 0.146597
p-value = 0.655853

Test for normality for LogCrop Number

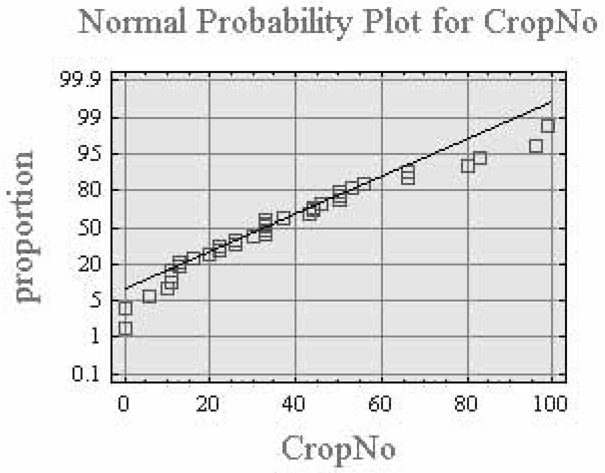
Shapiro-Wilks W statistic = 0.957375
p-value = 0.243245
Estimated overall Kolmogorov-Smirnov statistic DN = 0.128370
p-value = 0.611284

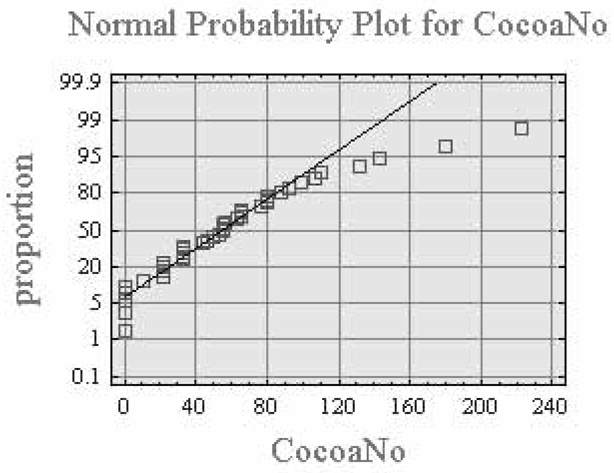
Test for normality for LogCocoa Number

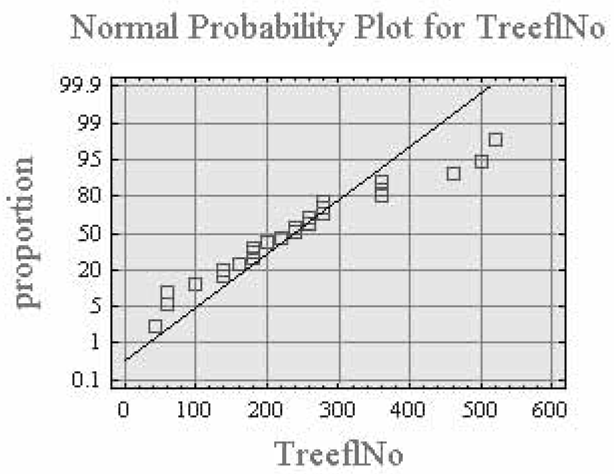
Shapiro-Wilks W statistic = 0.982218
p-value = 0.871723
Estimated overall Kolmogorov-Smirnov statistic DN = 0.085540
p-value = 0.959934

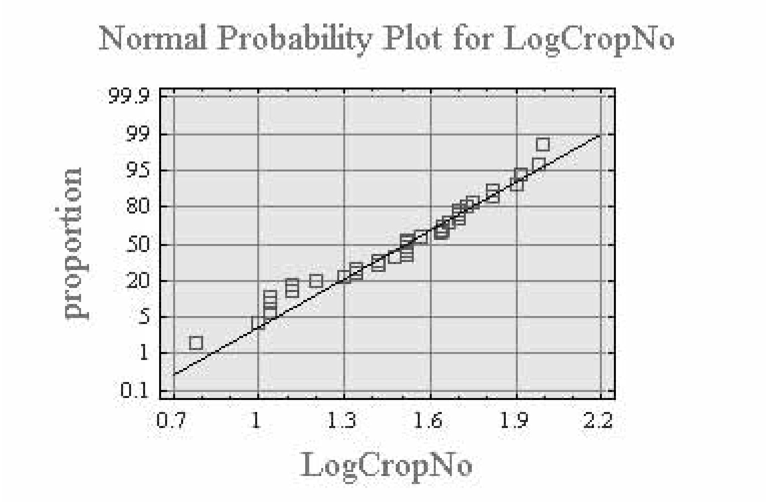
Test for normality for LogTreefl Number

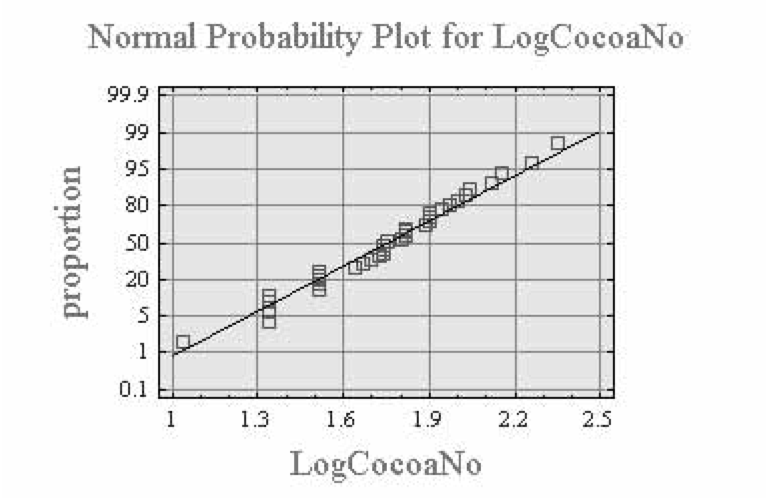
Shapiro-Wilks W statistic = 0.927333
p-value = 0.0785579
Estimated overall Kolmogorov-Smirnov statistic DN = 0.140838
p-value = 0.704249

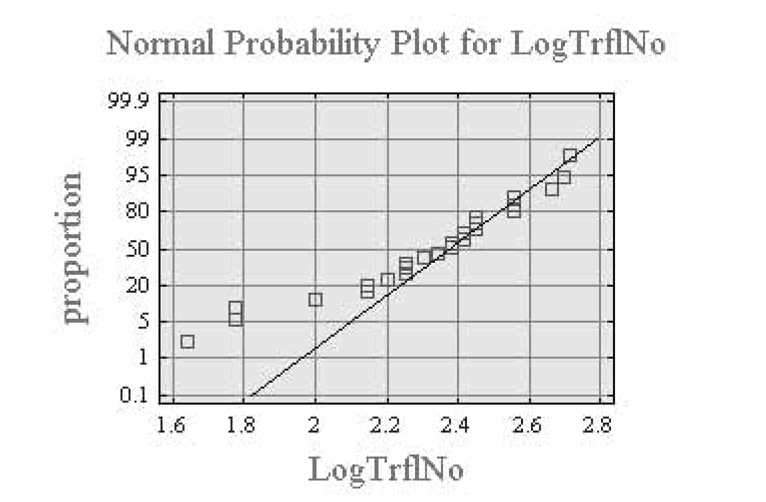

Normal Probability Plot for CropNo
proportion
99.9
99
95
80
50
20
5
1
0.1
0
20
40
60
80
100
CropNo


Normal Probability Plot for CocoaNo
proportion
99.9
99
95
80
50
20
5
1
0.1
0
40
80
120
160
200
240
CocoaNo


Normal Probability Plot for TreeflNo
proportion
99.9
99
95
80
50
20
5
1
0.1
0
100
200
300
400
500
600
TreeflNo





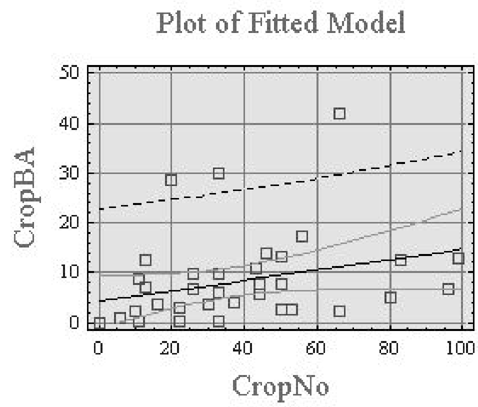


Variance check for CropNo, CocoaNo and TreeflNo
Cochran's C-test = 0.847292
p-value = 0.0

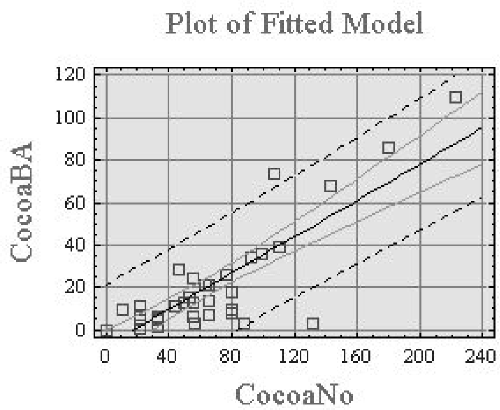
Variance check for LogCropNo, LogCocoaNo and LogTreeflNo
Cochran's C-test = 0.371824
p-value = 0.846841

Appendix 5

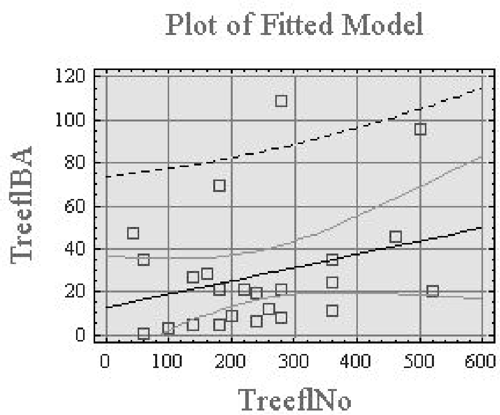
Correlation between variables number of trees per ha and basal area



Corr. coeff. : 0.294949
R-square : 8.6995



Corr. coeff. : 0.838886
R-square : 70.3729



Corr. coeff. : 0.291314
R-square : 8.4846