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Forest Research Capacity Strengthening in Mozambique 2012-2015 (FORECAS)

Report of an Institutional Cooperation Instrument (ICI) Project

Veikko Möttönen and Sinikka Västilä (eds.)

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Preface

This publication was compiled as a joint effort between Mozambican and Finnish researchers and experts representing the three partner organisations of the project "Forest Research Capacity Strengthening in Mozambique 2012–15 (FORECAS)". The development cooperation project was initiated with the support of the Ministry for Foreign Affairs (MFA) of Finland, and its activities were financed through the Institutional Cooperation Instrument (ICI), a financing tool of the MFA of Finland designed for inter-institutional co-operation between Finnish government institutions and their counterparts in the developing countries. The three partner agencies of the ICI project are as follows: Agricultural Research Institute of Mozambique (IIAM), The Faculty of Agronomy and Forestry Engineering, Eduardo Mondlane University (FAEF-UEM) and the Finnish Forest Research Institute (Metla), since 1.1.2015 Natural Resources Institute Finland (Luke).

The purpose of the FORECAS project was "Strengthened capacity of IIAM and FAEF-UEM to conduct applied research applicable to local stakeholders, aiming at sustainable forest management in the use of natural forests". The project covered the whole (forest) research process starting from the planning of the research project, planning of the field work, field measurements, data management, statistical analysis of the data, literature search and writing the research report and dissemination of results and extension work.

Capacity building in the project was implemented by courses, workshops and seminars in Mozambique and on-the-job trainings in Finland. The project also included joint field work and measurements of permanent sample plot. One essential part of the project was equipping a wood technology laboratory in the premises of FAEF-UEM and a dendrochronology laboratory in the premises of IIAM. The training in the research techniques and methodologies was deemed crucial for the sustainable capacity building in research work to guarantee good quality research also after the end of the present project. Sustainable capacity building at the institutional level meant in addition to the developing the laboratories also improving research results dissemination, research data management and information services and proposing alternatives and tested practices for research management. The needs to strengthen the methodological knowledge base and the infrastructure of research work was combined with the short-term research needs by using the immediate research problems as cases in training of the researchers. Two research topics, namely "Growth and yield of Miombo and Mopane forests" and "The properties and use of lesser known native tree species" were chosen to be enhanced as case studies of the project.

This publication includes the description of the work that was done in different result areas of the project. In the annexes there are the manuals and preliminary research results which hopefully are useful for the partner organisations when they continue the research work in forest growth and yield and wood technology. In the end of the publication there is analysis of the project: what was achieved and what was not and the reasons for these and also some suggestions concerning the future.

Finally, we wish to thank our co-authors for their fruitful collaboration and the partner institutions of the ICI project for extending their resources and assistance. The implementation of project was steered by the Project Board which was great help for us. The financial and substance support provided by the MFA of Finland and the Finnish Embassy in Maputo is also gratefully acknowledged.

9th September 2016

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Abbreviations

DEF-UEM	Department of forest engineering in UEM
DNTF	National Directorate of Land and Forest (Direcção Nacional de Terras e Florestas)
FAEF-UEM	Faculty of Agronomy and Forest Engineering of Eduardo Mondlane University
FAO	Food and Agriculture Organization of the United Nations
FORECAS	Forest Research Capacity Strengthening in Mozambique 2012-15 Project
ICI	The Institutional Cooperation Instrument
IIAM	Agrarian Research Institute of Mozambique
IIAM-CZS	South Zonal Center in IIAM
IIAM-DARN	Directorate of Agriculture and Natural Resources in IIAM
IIAM-DCA	Directorate of Animal Sciences in IIAM
IIAM-DFDTT	Directorate of Training, Documentation and Technology Transfer in IIAM
IIAM-DPAF	Directorate of Planning, Administration and Finance in IIAM
Luke	Natural Resources Institute Finland (Luonnonvarakeskus)
MAI	Mean annual increment
MASA	Ministry of Agriculture and Food Security
Metla	Finnish Forest Research Institute
MFA	Ministry for Foreign Affairs of Finland
MINAG	Ministry of Agriculture in Mozambique (divided to MASA and MITADER in 2015)
MITADER	Ministry of Land Environmental and Rural Development
NFP	National Forestry and Wildlife Program
NGO	Non-governmental organization
NWFPs	Non-Wood Forest Products
PEDSA	Strategy of Agrarian development
SFM	Sustainable forest management
SLU	Swedish University of Agricultural Sciences
STIFIMO	Cooperation in Science, Technology and Innovation between Finland and Mozambique
SUNAFOP	Support to National Forestry Program in Mozambique
UEM	Eduardo Mondlane University
WST-UEM	Division of wood science and technology in UEM

Contents

1. Background

Esperança Chamba, Andrade Egas and Sinikka Västilä

1.1. Mozambican forests

According to the National Forest Inventory, Mozambique has about 40 million hectares of forests, of which 27 million hectares are productive, and 13 million are in protected areas. In addition to these forest areas, there are 15 million hectares of other wooded land consisting of thickets, scrubs and areas of shifting cultivation (Marzoli 2007).

The total timber volume estimated for forest and other wooded land is 1740 million m^3. The average volume for all forest strata is 37 m^3/ha, the average total trade volume is 11 m^3/ha, and the current stock for trading is 4.5 m^3/ha. The trading species that represent higher volumes are *Colophospermum mopane* (mopane), *Pterocarpus angolensis* (umbila), *Millettia stuhlmannii* (jambire), and *Afzelia quanzensis* (chanfuta). In terms of quality classes, 4% of the current trading volume belongs to precious wood species, 21% are 1st class, 44% are 2nd class, 14% are 3rd class, and 17% are 4th class (Marzoli 2007). The classification system is closely related to timber market demand so that high demand species also sold to international markets are classified as precious or first class.

There is an absence of reliable data concerning the growth of forests. It is estimated that the growth of natural forests in Mozambique varies between 0.5 and 1.5 m^3/ha/year. The allowable annual cut, based on the most recent data from the current literature, is estimated to be 520,000–640,000 m^3/year. The national forest inventory assessed the logging level as below the allowable annual cut, but this did not take illegal logging into consideration. The logging also fell on only a few species: jambire, umbila and chanfuta contributed to 78% of the volume traded. Furthermore, *Combretum imberbe* (mondzo) exceeded its potential. Promoting the diversification of trading species is therefore recommended, to avoid pressure on only a few species. An estimate analysis of individual species within each province is needed in order to reach a conclusion about logging sustainability at this level (Marzoli 2007).

Mozambique is located 10°–26° south of the equator, and has a long coastline of 2,700 km. This results in a diversity of climate conditions that in turn affects types of vegetation cover. Miombo woodlands comprise two-thirds of the forested land in the country, stretching from the north of the Limpopo River to the northern border of Mozambique (Figure 1). It is mostly found in the provinces of Niassa, Nampula, Cabo Delgado, Manica, Zambézia, Tete and Sofala, with some patches in the Gaza and Inhambane provinces. Miombo is differentiated as semi-deciduous in the coastal zone (rich in timber products and biodiversity) and in the highlands of Chimoio and Gurue, and as a simpler formation of low height and low density, which is found in Cabo Delgado, Inhambane and Niassa, where savanna woodlands and grassland are common. The provinces of Maputo, Inhambane and Nampula are the most sparsely covered in vegetation in the country. The most valuable timber species – such as *Dalbergia melanoxylon* (pau-preto), *Pterocarpus angolensis* (umbila), *Millettia stuhlmannii* (jambire), *Albizia versicolor* (tanga-tanga), *Combretum imberbe* (mondzo), *Afzelia quanzensis* (chanfuta), *Sterculia africana* (messassa encarnadom), *Julbernardia* (messassa encarnadam), *Brachystegia* spp., (messassa) and *Terminalia sericea* (inconolai) among others – are found in the miombo eco-region (Nhantumbo & Izidine 2009).

The second largest forest cover is provided by the mopane tree (*Colophospermum mopane*), and is characterised as mopane woodland which can be found between the Limpopo and Save rivers and in the highlands of the Zambezi River Basin. Other important forest resources include the montane forests and the coastal mangroves (Nhantumbo & Izidine 2009).

Mozambique has established a modest area of plantations (50,000 ha) based on *Pinus*, *Eucalyptus* and *Casuarina* species. Industrial plantations are mainly located in the Manica province, where they were established in the early 1980s. Their purpose was to save valuable hardwood timber for export and substitute cheap softwood timber from plantations for the domestic market. Non-industrial plantations used for fuel wood, mainly eucalyptus, are located near three urban areas: Maputo, Beira and Nampula (FAO 2012).

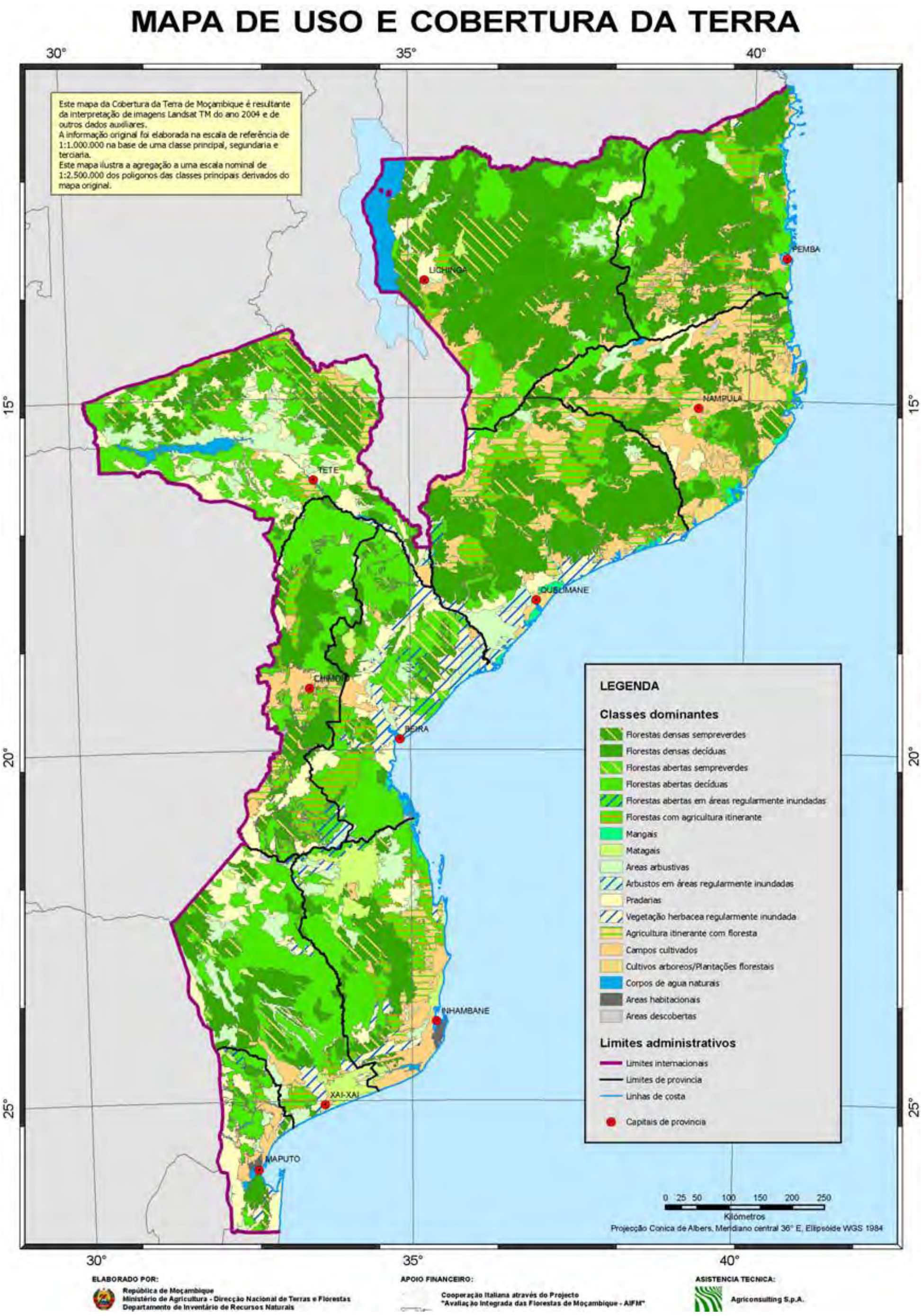

Figure 1. The forests of Mozambique, showing different vegetation cover. Source: Marzoli (2007)

The government has stopped its own plantation programme and now concentrates on promoting incentives for private plantations. Plantation problems include a lack of suitable silviculture operations, resulting in low quality timber which does not meet the needs of industry; the high cost of producing fuel wood from eucalyptus plantations, because of the cost of labour, as a result of which these plantations have been practically abandoned; and the tendency of consumers to prefer local species with high heat value over wood from the eucalyptus plantations (FAO 2012).

Forest fire is a serious problem in Mozambican forests. Approximately 40% of the country is affected by fire every year. The north western and central parts of the country are the most affected, with about 74% of these areas burnt annually. Fire has become one of the main tools for land clearing for cultivation, hunting, timber exploitation and the acquisition of other goods and services from the forest including charcoal production and honey collection, and for protecting resources from wild animals. These activities, as well as accidental fires, lead to uncontrollable wildfires. Since the road network is minimal and there are no firebreaks, fire may sweep a large area until a river halts it. Fires have a destructive impact on natural vegetation and on biodiversity. They affect many aspects of the environment, as well as people's welfare. The loss of standing timber, which is important to the national economy, is significant, but no figures are available. The effect of wildfires on natural regeneration threatens a number of species (FAO 2012).

Deforestation and forest degradation are severe problems. Agriculture (subsistence and commercial), firewood collecting and charcoal making, unsustainable logging, and mining, are among the major drivers of land-use change, including deforestation and forest degradation (Sitoe et al. 2014). Pressure on natural resources is highest around urban areas and along the main road corridors, as a result of an increase in population in these areas, which has also drastically increased the need for agricultural land, as well as for forestry and wildlife products (mainly fuelwood) (FAO 2012).

There are indications that forests are becoming less rich in species diversity and more fragmented. They may be shrinking due to the loss of trees in wildfires. The openings created in forest canopies expose plants and trees that require shade to more light, and consequently to physiological disturbance and death. Pioneer trees, which germinate under intensive sunlight, invade the space created by the elimination of shade-demanding trees, as a result of, for example fires (FAO 2012).

1.2. Forest-based products and trade

The forestry sector contributes less than 1% to the GDP and 4% of exports. This valuation omits, or grossly underestimates, the role of the informal sector in the economy. The forestry sector provides about 200,000 formal jobs. The informal sector is larger, as it involves the intermediaries transporting timber and firewood; the producers (harvesters), mostly from the rural population; and the wholesalers and retailers of the various products, who are generally located in urban areas (Nhantumbo & Izidine 2009).

Mozambique produces moderate volumes of mainly non-coniferous sawn timber. Forty per cent of the total volume of timber in Mozambique is from *Brachystegia* spp. and *Julbernardia* spp., which are the defining miombo species. Other species of high-value timber are also found in these areas and harvested to supply both the domestic and the export market (Nhantumbo & Izidine 2009).

The miombo woodlands also constitute an important source of biomass energy for rural and urban areas. The electricity coverage in the country is still small (less than 10%) and the consumption of gas is very limited, thus biomass energy supplies about 85% of the country's energy needs (Nhantumbo & Izidine 2009).

In addition to harvested timber and wood fuel, miombo woodlands also supply medicinal plants and pasture for wildlife, and their rich soil nutrients mean areas have good potential for agriculture (hence 'slash and burn' practices) (Nhantumbo & Izidine 2009). Important non-wood forest products in Mozambique include bushmeat, grass, bamboo, reeds, medicinal plants, and a variety of wild edible plants (FAO 2012). The mixture of dry and humid miombo provides different habitats for a variety of wildlife. Eighty per cent of all large mammals in Mozambique are found in the miombo woodlands, and thus all hunting areas are located within this ecosystem (Soto & Sitoe 1994). The miombo eco-region surrounds important water resources such as the Zambezi River Basin, which is shared by several other southern African countries. Local communities also protect some of the tree species as a result of their multiple uses, including their spiritual value (Nhantumbo & Izidine 2009).

1.3. Forest research

Mozambique's forest research capacity is concentrated in a few public institutions. The Agricultural Research Institute of Mozambique (IIAM) and the University of Eduardo Mondlane (UEM) carry out forest research activities in collaboration with other regional and international research institutions.

1.3.1. Agricultural Research Institute of Mozambique (IIAM)

IIAM is a public research organisation under the Ministry of Agriculture and Food Security (MASA), founded in 2004. The responsibilities of IIAM are:

- Give scientific support and advice to MASA and other public organisations regarding the design of policies for the agricultural sector in Mozambique;
- Conduct research in the areas of agriculture, forestry and animal sciences, as well as on socio-economics and the agribusiness field under the MASA;
- Production, documentation, training and technology transfer.

IIAM is composed of central and local research unities. At a central level, IIAM includes the General Directorate and four technical directorates:

- Directorate of Agriculture and Natural Resources (DARN);
- Directorate of Animal Sciences (DCA);
- Directorate of Training, Documentation and Technology Transfer (DFDTT); and
- Directorate of Planning, Administration and Finance (DPAF);

At a local level, the experimental units of IIAM are grouped in four Zonal Centres.

The vision of IIAM as per the strategy is “to be a research and innovation organisation of excellence, dynamic, motivated that contributes to the satisfaction of the food needs, development of agribusiness and sustainable use of natural resources” (Plano Estratégico do IIAM 2015). The mission is “to generate knowledge and technological solutions for sustainable development of agribusiness and food and nutritional security”.

IIAM makes an important contribution to the forestry sector by providing information for decision making on the development, use and management of forest resources. The objective in the strategy that is related to the forestry sector is “Contribute to the productive and sustainable use of natural resources and biodiversity”.

IIAM is engaged in the following main programmes:

- Evaluate and monitor the loss of biodiversity and environmental degradation;
- Develop systems for the collection, characterisation, conservation and use of germplasm;
- Develop knowledge for the management and sustainable use of natural resources;
- Increase the use of wood and non-wood forest products, and develop technologies for agro-industrial processing.

In 2009 IIAM employed 1,087 civil servants, of which 19 held PhDs, 59 held MScs and 104 held BScs. The other employees were auxiliary and administrative staff. Most of the PhDs were held in agricultural science, and these employees work for the Agronomy and Natural Resources Directorate (DARN). Only one researcher had a PhD in forest research, six held an MSc in this field, and seven held a BSc in this field. The total cost of remunerations in 2009 were about €1,863,698, the total cost of goods and services €637,722, and investments in infrastructure and equipment were €401,905.

1.3.2. The Faculty of Agronomy and Forest Engineering at Eduardo Mondlane University (FAEF-UEM)

The Faculty of Agronomy and Forest Engineering at Eduardo Mondlane University (FAEF-UEM) in Maputo is the oldest, and one of the leading institutions of higher education in agronomy and forestry. Three undergraduate courses (BSc equivalent) are offered, in agronomy, forest engineering, and agro-economics. In addition to the undergraduate level, FAEF presently has about 200 postgraduate students enrolled in MSc programmes.

The faculty has five departments: plant production, plant protection, rural engineering, economics and agrarian development, and forest engineering. The latter is responsible for graduating foresters. FAEF-UEM has also established three centres: the Machipanda Agro-Forestry Centre, located in Manica province, the Sábie Agrarian Development Centre in Maputo province and the Biotechnology Centre in Maputo, jointly run with other UEM faculties.

The Department of Forest Engineering (DEF) is structured in four divisions: I) silviculture, II) forest economics and management, III) timber harvesting and transport, and IV) wood science and technology. Currently the Department of Forest Engineering includes 21 lecturers (ten hold PhDs, seven hold MScs and four hold BScs), as well as seven researchers (six hold MScs and one holds BSc) and six technicians. The facilities include seven labs, two forest nurseries and an experimental area growing eucalyptus. Research is one of the three key activities of DEF. At least 30% of the DEF working period is assigned to research duties, which involve collaboration between lecturers, lab technicians and students.

The Division of Wood Science and Technology (WST) is responsible for research concerning wood science and technology. In terms of personnel, it has two wood technologists with doctoral degrees, one assistant lecturer and two research assistants with MScs in wood technology, and one lab technician. The research involving WST staff covers a broad range of topics such as wood anatomy, wood drying, wood properties, wood machining, wood-based panels, natural wood durability and related matters. Recently, lesser-known/used native tree species from Mozambique are at the core of the research agenda.

Human resources, especially in IIAM and in forestry research, are few and better qualifications and specialisation are needed. The financial resources allocated to forest research are limited and not sufficient to conduct research to achieve the goals of the organisations. Much of the research work has been undertaken through international project funding, which in many cases does not guarantee long-term research.

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2. Justification of the FORECAS project

Esperança Chamba, Andrade Egas and Sinikka Västilä

About 40 million hectares of Mozambique are covered by forest, and another 15 million hectares by other types of vegetation. The country has great potential in forestry, with at least 118 tree species that produce timber. Mozambique is facing challenges in the management of these valuable resources, however, in part due to demand on forest resources from the industrial sector, in particular for a few commercial species, and due to the fact that 85% of the energy needs of the population are satisfied by biomass energy. Agriculture, firewood collecting and charcoal making, illegal and unsustainable logging, forest fires, and mining are among the major drivers of land-use change, including deforestation and forest degradation. Pressure on natural resources is highest around urban areas and along the main road corridors, as a result of an increase in population in these areas. National research institutes face a great challenge when trying to find science-based answers to these problems. At the same time, the institutes also struggle with restricted staff, finance and infrastructure.

ICI projects have limited budgets so the demarcation of a project has to be clear. The purpose of the FORECAS project was "The strengthened capacity of IIAM and FAEF-UEM to conduct applied research applicable to local stakeholders, aiming at sustainable forest management in the use of natural forests". The capacity building was done along the whole research process chain:

1. By improving the skills of researchers and other personnel in undertaking research work, especially in the areas of forest growth and yield, and wood technology;
2. By enhancing information dissemination and technology transfer services; and
3. By developing support services for forestry research, such as research data management, information services and research management.

The purpose and result areas selected were based on the aims of:

- Strategic Plan for Agricultural Development PEDSA 2010–2019
- National Forestry and Wildlife Programme (NFP)
- The strategy of the Agricultural Research Institute of Mozambique (IIAM)
- The research plan of Eduardo Mondlane University (UEM)
- The project document of the previous SUNAFOP (Support to National Forestry Programme in Mozambique) programme and
- The direct need of the IIAM and FAEF-UEM research organisations.

The need to improve the methodological knowledge base and infrastructure for research work, and, on the other hand, the need for short-term research results, were combined by using the immediate research problems as cases for the training of researchers. It was decided that the FORECAS project would concentrate on two main research topics:

- The growth and yield of miombo and mopane forests. These forests cover the majority of Mozambique and there is a need for updated and accurate estimates of the productivity of natural forests. An estimate of the growing capacity of commercial tree species is the basis for the sustainable management and use of forests. The growth rate and management of natural forests also need to be known in order to assess the consequences of climate change for forests, and to determine how to mitigate the impacts of climate change.
- The wood properties and use of lesser-known native tree species. The most valuable commercial tree species are decreasing in volume due to high demand, unsustainable management practices and illegal logging operations. To lessen the pressure on these few tree species, the use of the

lesser-known native tree species should be extended and their potential for timber should be advocated. For that purpose, the technological wood properties of lesser-known native tree species were studied in this project.

Since FORECAS was mainly a capacity building project, it concentrated on current methods of studying these research questions. Some preliminary research was also undertaken as a case study, but these topics require more research, more field work and maybe joint efforts with neighbouring countries to bring together all current knowledge.

Sustainable capacity building at the institutional level meant, in addition to equipping wood technology and dendrochronology laboratories, also developing improved structures and means for the dissemination of research results, research data management and information services, and providing alternatives and tested practices for research management.

A crucial element in research work is the dissemination of research results, and supporting their use in decision making and the everyday practices of forestry officials. This is especially important in developing countries, which need concrete results and advice to improve the livelihoods of people. Information dissemination is generally the weakest point of almost any research institute in the world. Using all available media and channels in the right proportions is a challenge for the effective dissemination of research results. Information users should be categorised and different dissemination methods used in different cases, such as for other researchers compared to communities.

Research is long-term work that is based on existing research. Access to existing literature is often difficult, especially in developing countries. Researchers need direct and easy access to all kinds of information, including local, regional or international, and also the skills to use different information sources. A functional information system allows the better and faster implementation of research projects.

Efficient research data management forms the basis of successful long-term research. Documentation, storage, and access to data for a long time after its collection is crucial, especially in forest research where data is collected over long periods of time. Data collection and analysis is also often performed by a number of different people, so that data should be documented and stored so that it is complete and easy to access, even when it has been collected at different times and by different people. The collection of field data is expensive and therefore it should be available for different research issues.

The effectiveness of an organisation depends on how well the work is organised and managed. The exchange of ideas and experiences between personnel responsible for research policies, strategies, management and funding is a way to transfer good practices from one organisation to another. It also serves as good tool to strengthen cooperation between organisations, and creates a suitable starting point for continuing intercourse in joint research efforts.

3. Challenges for growth & yield research in Mozambique

3.1. Existing data on growth and yield and previous research: the baseline at project outset

Esperança Chamba, Jacob Bila, Kristian Karlsson, Pentti Niemistö and Jussi Saramäki

There has been very little research into forest growth and productivity in Mozambique. A calculation of the total allowable cut was made using data from the latest national forest inventory (Marzoli 2007). Some growth estimations were used, but the calculations have not been considered very reliable. The need for better information about growth and yield has been emphasised – especially regarding natural forests that are intensively utilised in Mozambique. The government is selling logging rights to private individuals and companies as commercial concessions. The timber volumes harvested from the concession areas are relatively small, but there is additional illegal logging going on. Local people are also clearing large areas of woodlands for agricultural use or for local demand for wood raw material (firewood, charcoal, poles). Areas with some kind of logging activities may be estimated relatively well from remotely sensed data, however, the question of sustainability needs to be addressed with better information about tree growth in general, and also with a better understanding of the regeneration processes of selectively harvested or cleared woodlands.

Some years ago, a set of permanent sample plots was established across the country by the Forest Research Centre (now part of the IIAM). The main purpose was to provide data for growth and yield research. Some information on regeneration was also collected on the same plots. The growth determination of trees is usually based on periodically repeated measurements of the same plots and trees. Most of the IIAM plots were established but never re-measured. The main objective of the 'growth & yield' part of the FORECAS project was therefore to re-measure some of the existing plots.

The permanent plots are mainly located in groups of three plots per region (Table 1). More focus was placed on the productive miombo woodlands of Zambezia, where ten plots were established. The original plan was to establish at least a few plots in all large provinces, but no plots have yet been measured in the provinces of Cabo Delgado and Nampula. The plots have been described in internal reports by the IIAM, but no scientific reports have been published based on the data.

The land use situation in Mozambique is problematic for research field activities, because it can be difficult to maintain plots in regions where the local people are active and government control relatively weak. Many of the plots have thus been established inside forest reserves or nature reserves/national parks. The forest reserves are managed by forest administration in order to provide ecosystem services like watershed management, the prevention of landslides and soil erosion and so on, but they also provide wood material and products explicitly for government use. That means that logging may occur, but it is controlled. Local people have also been allowed to settle within some forest reserve areas, however, and that has led to increasing forest clearing. Nature reserves and national parks are strict conservation areas, where no settlements, logging or forest clearing is allowed. The first field trip for the FORECAS growth and yield team was arranged to the Moribane forest - a typical forest reserve, where untouched mountain forests still grow in the remote parts, but it is possible to see how local settlements are spreading out from the main road leading through the region. The second of the growth and yield field trips was to the Gilé nature reserve, where the only existing "roads" leading into the area were actually small tracks, and access was restricted by officials at the border. Forest rangers patrol in the area, and human activities are limited: some occasional fires may be started by illegal hunters, who also set traps and cut down single trees, but most of the area is covered with pristine, mature forest. Locating plots in this kind of supervised areas makes it possible to maintain them without disturbance, but other areas should be considered for the analysis of the specific consequences of human impact on tree growth and woodland development.

Tree and forest growth has traditionally been expressed through the annual increment (= annual average for the period, 5 or 10 years) in (tree) diameter, (stand) basal area or (stand) volume. 'Stand' values are the summarised values of the plot and they are expressed per area unit, usually per hectare. Diameter and basal area increment can be calculated directly from basic plot measurements. Additional single tree volume functions are needed for the calculation of the volume increment, but we found that no such allometric equations have been made for Mozambican tree species and regions. Some equations have been developed for miombo and mopane tree species in nearby countries, but again, it was not clear which would be most suitable to use for the trees on the IIAM plots. An additional objective was therefore added to the project plan: to measure actual single tree volumes for comparison with existing allometric equations, and also to introduce the development of new similar equations.

Today, much focus is placed on the biomass and carbon contained within forests and woodlands, and so it should be possible to convert volume and also volume increment into biomass equivalents without loss of information. This is achieved if the field work includes both biomass and volume measurements, and volume and biomass models are made using the same dataset. This idea was adopted in the growth and yield studies of the FORECAS project. An additional, very simple conversion from the woody biomass will then provide the main carbon figures, but other vegetation and soil compartments must be assessed separately for complete carbon stock or carbon balance studies. Some allometric, single tree biomass equations have been developed for regional biomass/carbon inventories in Mozambique (Pienimäki 2014). It may be possible to combine the data from those studies into a generalised biomass equation for a range of tree species and regions, but the existing material does not contain information on volume. Volume, especially stem volume, is a more appropriate concept dealing with the commercial use of timber. Even if we choose to estimate and/or express forest growth in biomass or carbon (kg/ha/a), we should still be able to convert it in to utilised wood, such as sawn timber, firewood, charcoal, construction wood like poles and beams, and so on. Future studies and research would definitely benefit from standardisation and more complete measurements compared with the work previously done.

Figure 2. Forest clearings are expanding rapidly in the Moribane forest reserve – a region where miombo woodlands change into more productive mountain forests with increasing altitude and rainfall. Photo: Kristian Karlsson.

Table 1. Existing permanent sample plots in Mozambique at the beginning of the project. The dry regions are dominated by the tree species Colophospermum *mopane* (mopane) and *Androstachys johnsonii* (mecrusse). We find humid/mountain forests with gigantic *Newtonia* sp. trees in the Moribane reserve and the valuable *Millettia stuhlmannii* tree species (jambire) in the northern parts of Sofala. 'Miombo' is the word used for *Brachystegia* tree species in some African languages.

Province	District	No.	Location	Characteristics
Zambezia	Maganja da Costa	1 2 3 4	Mocubela/Muedebo Mocubela Mocubela/Muedebo Mocubela	
	Gilé	5 6	Reserva do Gilé/Nanhope Reserva do Gilé/ Namuno	miombo
	Pebane	7 8	Reserva do Gilé/Mulela Reserva do Gilé/Mulela	
	Morrumbala	9 10	Reserva do Derre Reserva do Derre	
Gaza	Mabalane	1 2 3	Parque Nacional do Limpopo Parque Nacional do Limpopo Parque Nacional do Limpopo	mopane
	Massingir	1 2 3	Parque Nacional do Limpopo Parque Nacional do Limpopo Parque Nacional do Limpopo	
Tete	Changara	1 2 3	Chipembere … …	mopane
Inhambane	Mabote	1 2 3	Tsumbo … …	mecrusse
Sofala	Chiringoma	1 2 3	… … …	jambire
Manica	Sussundenga	1 2 3	Reserva do Moribane Reserva do Moribane Reserva do Moribane	humid/mountain
	Gondola	1 2 3	… … …	
Niassa	Nipepe	1 2 3	… … …	
Total no. of plots established >>>		34		

3.2. Permanent sample plot measurements

Esperança Chamba, Jacob Bila and Kristian Karlsson

The techniques for measuring trees are quite well known and it is also a relatively well standardised procedure. General manuals for forest inventory can be directly applied in the work on permanent sample plots, but it is still very important to document all procedures, noting any variations compared to previously existing guidelines. New features and changes from previous stages of the same work should also be noted, for example using version numbers on manual and field forms.

A few of the existing IIAM plots were re-measured, and two new plots were established as a pilot study in the Moribane forest reserve during the first FORECAS growth and yield field trip. A field manual was compiled after the trip, based on the experience gained (Annex 1). A manual was also written for the destructive sampling and measurements of trees for volume and biomass (Annex 2). These methods were used during the second field trip in a concession area close to the city of Mocuba in the province of Zambezia. Five trees were cut down, chopped into smaller pieces and measured (Figure 3), all with the support of the concession manager and with the assistance of his staff. The sample trees were the same species (Millettia stuhlmannii), but different sizes (DBH=12–37 cm). During the second field trip, three existing permanent sample plots were also re-measured in the nature reserve of Gilé. The woodlands in Gilé are more productive compared to average miombo woodlands in Mozambique, but still very typical in tree species composition and structure.

The guidelines for new permanent sample plots contain a few changes regarding the establishment phase of the old plots. Trees are still measured at different parts of a rectangular main plot according to their diameters, but these subplots will now be fixed into a specific pattern, which remains the same for all plots. New variables are now proposed for describing tree status and health. Many of the tree species regenerate from sprouts. This means that larger, even mature trees consist of multiple stems connected below the 1.3 m height. We noted a large number of this type of tree on the first new plot in Moribane. It is very likely that these trees are significantly different (in volume, volume distribution and growth features) compared to single stem trees. A variable will be used to identify these multiple stem trees. Measuring tree height is problematic in savannah woodlands, where the crowns are wide and flat, and the stems often curved or multiple, and quite irregular. Classification could help to define the accuracy level of a normal height measurement and, at the same time, describe the competitive status of the tree. These features/new variables are presented in the manual (Annex 1), but the classification codes are not yet all final.

The main- and subplot system presented is suitable for growth and yield studies including the dynamics of forest development. To cover the dynamic changes, it is necessary to monitor tree growth and mortality, but also ‘ingrowth’, which is defined as when all the small trees pass the measurement limit during one growth period. Ingrowth is not the same as regeneration. It is probably better to study actual regeneration – that is, the occurrence of seedlings and saplings – with a separate network of small plots systematically covering the whole area of the main plots. Regeneration was not included as a topic in the FORECAS project, so no guidelines were presented.

The destructive sample tree measurements are described in detail in a separate manual (annex 2). The main idea was to define and measure all compartments of the tree, but the practical work was limited to above ground parts of the trees. The techniques used will provide information of both volume and biomass. Note that, even if only volume figures are required for research, scales should still be used in the field work. They are very convenient and accurate for measuring the fresh mass of small branches in large stacks. The mass can then be converted to volume using sample piece densities. The accuracy of the scales is important: better accuracy is needed for the small sample pieces, but large capacity for the bulk measurements (Figure 3).

One of the most frequent questions during this work was how many trees/plots we need to measure. There is no simple answer, but as a rule of thumb, the target sample size should be set to about 30. This means 30 individual trees for one allometric equation (tree species/region). A smaller sample size of 15–25 may provide a good enough starting point, since resources are generally scarce. The same rule can be used for the number of plots needed for growth analysis in a specific region or certain type of forest.

The task of selecting target research areas and choosing plot locations is also a complex and difficult job. In our first case study in the Moribane forest reserve, we selected two new plot locations subjectively with the help of local guides. This method can be quite effective and justified when locating areas for experimental research, where the main effects are set by the treatment, but it is less helpful in the selection of network plots. The subjectivity involved needs to be limited in the selection. The best means of locating and selecting permanent plots for a network is to first perform an inventory of the target area. The next step is to list the inventory plots and select the appropriate ones for continuing studies according to predefined criteria. The inventory may be carried out with smaller plots and those selected for permanent monitoring are then increased in size and completed according to the manual for permanent sample plots. Two examples of inventory approaches are outlined in Annex 3. We did not have enough time to undertake complete training starting from an target area inventory, but this procedure is recommended if the network is extended, for example to the provinces of Nampula and Cabo Delgado.

Figure 3. The field measurements of our sample trees included weighing with one scale for max 300 kg with 100 g accuracy (hanging from the tree) and one scale for max 12 kg with 1 g accuracy (on the table). Small sample pieces were submerged into water for volume determination. Photo: Kristian Karlsson.

3.3. Statistical basis for experimental design and sampling and statistical analysis of research data

Jaakko Heinonen

Activity included two courses in IIAM, Maputo: **Statistical basis for experimental design and sampling course** 16.7–27.7.2012, and a joint course, **Analysis of permanent sample plot data in Miombo and Mopane and follow-up of statistical basis on experimental design and sampling** 18.11–6.12.2013.

Statistical basis for experimental design and sampling course 16.7–27.7.2012

The lecturer was Jaakko Heinonen, researcher from Metla, and the contact persons in Mozambique were Esperança Chamba and Jacob Bila, researchers from IIAM.

The purpose of the course was to provide the participants with the necessary skills in basic statistical methods for experimental designs, and the sampling and statistical analyses of data. Handouts from the course are in Annex 4.

The pre-course statistical training of the participants varied from elementary courses to some experience in applying statistical methods in practice. The SPSS statistical software was used on the course, and participants attended a basic course on SPSS before the statistical course.

Pre-course skills in statistical methods, and in English language, as well as the need for statistical methods varied greatly between participants. The course language was English. The statistical course covered basics of a wide area of statistical methodology needed in forestry and agro-forestry research. The course was demanding for all participants, and especially those whose pre-course skills in statistics or n spoken English were modest. The sessions where participants used Portuguese to discuss specific statistical applications demonstrated the effect of the chosen language on the liveliness of the discussion, however, most researchers have to be able to read statistical literature and articles in English, use the English interface of their statistical software and participate in seminars and write their reports in English, which motivated the participants to use the English language.

Local data and examples were requested before the course, but more real examples from IIAM or UEM would have been useful. Two of the participants presented their current research problems in personal consultations and the statistical topics of these researches were explained to the course. The course discussed these topics using both English and Portuguese languages.

Some of the participants assisted with the teaching by translating important topics into Portuguese and helping others to run analyses using SPSS, which was a very valuable support.

A small group of the participants planned to arrange an informal discussion group to solve the statistical problems they meet in practice. This kind of activity is very encouraging and deserves all possible support.

Analysis of permanent sample plot data in Miombo and Mopane and follow-up of statistical basis on experimental design and sampling 18.11.–6.12.2013

The lecturers were Jaakko Heinonen and Pentti Niemistö from Metla. The responsible persons in partner organisations were Esperança Chamba and Jacob Bila from IIAM.

The purpose of the follow-up of the statistical basis for experimental design and sampling was to refresh and reinforce the statistical skills of the participants.

The aim of analysing permanent sample plot data for miombo and mopane was to undertake the whole process from field data to stem and stand level growth and yield models using existing data and SPSS.

Before the course of 18–22.11.2013, Jaakko Heinonen interviewed the participants in person. The aim of the face to face meetings was to determine in detail which kind of statistical and computational skills each participant needed in their work at present and the in near future, what kind of training was needed, the characteristics of the data they were working with, or were going to work with, and which local datasets participants could access during the course. The programme for the follow-up course was finely tuned on the basis of the interviews.

The course of 23.11–6.12.2013 was a combination of lectures, personal consultations and practical work with real local data provided by the participants. The participants working with the permanent sample plot data were guided by Pentti Niemistö and worked for most of the time in a separate room. There were also joint meetings for all the participants for teaching/brushing up their basic skills in running SPSS, the basics of computing statistical analysis and interpreting the output of the analysis. Despite mainly working in two separate rooms, the interaction between all participants and both teachers was lively during the course.

Four of the participants had attended the course “Statistical basis on experimental design and sampling” in July 2012. Two were now in the group analysing permanent sample plot data, and the other two were in the follow-up group. The other participants of the follow-up group had no experience of using SPSS and only one knew the basics of statistical analysis reasonably well.

The participants of the follow-up course, with two exceptions, had their own data which they wanted to analyse. One of the participants mostly worked on designing a new experiment. Data corresponding to the design was created using computer simulation, and the statistical analysis of the design was taught and demonstrated using the simulated data. Two of the participants wanted to analyse the relationship between climate variables and growth, but data was not ready yet, and simulated data was used instead. Because of the heterogeneity of the skills and needs of the participants, personal instructions played very important role in the teaching. The English skills of some of the participants were not sufficient to follow lectures, but were sufficient for personal consultations, sometimes with the help of dictionaries. All the participants either managed to analyse their data during the course, or knew at the end of the course how to proceed to complete their analyses. According to the feedback, and in my personal opinion, the level and the working methods of the course corresponded well with the expectations of the participants, however, the interest of those participants who had very limited pre-course understanding of statistical methods and statistical computing was mainly in the technical elements of using SPSS, and on descriptive statistics and graphics.

All the participants either already had SPSS software installed on their computer or SPSS was installed at the beginning of the course. SPSS licenses were provided by the project where necessary.

Concluding remarks

Most of the participants had very limited pre-course understanding of statistical methods and statistical computing, and they need to continue systematic studies in the subject. All the participants need more practice and at least some support in their statistical analysis. Some of the young researchers especially should be encouraged to include advanced courses in statistical methods in their studies so that they can advise other researchers regarding statistical problems. Real research almost always involves specific and unique features, and an experienced researcher, and in some cases a specialist, is needed to explain how these features should be taken into account in the experiment design, sampling methods and in statistical analysis. It is recommended that IIAM and UEM cooperate to maintain and develop expertise and to obtain help from a biometrician when it is needed. Some participants on the first course planned to arrange an informal discussion group to solve statistical problems. This does not seem to have been accomplished yet, but it is recommended that informal contacts and meetings, as well as formal seminars, are supported.

It is crucial that researchers have access to appropriate statistical software. A good choice of statistical software is SPSS. It is versatile, and its menu-based user interface is easy to learn to use. In addition to the SPSS Base module, researchers need the optional Advanced module, and in some cases also the Regression module. SPSS is commercial software, and updates are not free of charge, which needs to be taken into account.

R is free software with a large and fast developing set of libraries for statistical computation and graphics. The R interface is based on scripts, and many users find it too demanding, however, since there are advanced R-libraries for many special applications, some researchers may also need R.

3.4. Growth and yield of Miombo and Mopane woodlands

Esperança Chamba, Jacob Bila, Kristian Karlsson and Pentti Niemistö

Miombo woodlands are open or closed natural forests with great variation in tree species, structure and tree size distribution. Like all savannah type woodlands, the miombo is generally described as a low productive forest ecosystem, with tree growth that is limited mainly by drought. In areas of miombo woodland, annual rainfall is between 600–1500 mm, and the climate is tropical and hot. The 'wet miombo' ecozone gradually changes to highly productive mountain forests with increasing altitude and rainfall. In the dryer regions, there is a transition from miombo into mopane woodlands with rainfall below 700 mm. A function for estimating the mean annual increment (MAI) using annual rainfall was originally developed for dry tropical conditions north of the equator (Clement 1982), but this function has been widely used in countries with miombo woodlands:

$$MAI = 0.05129+1.08171*(rain/1000)^2$$

This function and the estimated values range of 0.5–3.0 m^3/ha/a have been quoted in many presentations about savannah woodlands (FAO 2000). The function was also used to calculate the allowable cut for Mozambique at a national and provincial level. This MAI estimation provided us with an important reference level in the FORECAS project, but the main objective was to determine and analyse forest growth using measurements from the IIAM permanent sample plots. Several joint workshops were therefore organised, in which the Mozambican datasets were analysed. The number of observations was small, so it was not possible to develop models for estimation purposes. The results should be seen as mainly descriptive information about the woodlands in these specific regions of Mozambique.

The sample tree measurements were transformed piece-by-piece into volume, either using geometrical formula (Smalian) or by converting scale-measured mass with the most suitable density determination. The piece volumes were added as the total volume, as well as the volume by each compartment (Table 2). The dry biomasses will not be available until later after the project has ended, so the study was limited to volume. A large collection of Sub-Saharan allometric volume and biomass equations has been compiled and published on the initiative of the FAO (Henry et al. 2011). When comparing the total volumes calculated in the project with the published equations, a close match was found with the equation for the miombo woodlands of Chimaliro in Malawi (Abbott et al. 1997). Although the amount of test material was very small, it was concluded that the volume of individual miombo trees in central Mozambique may be calculated using the equation. Another volume equation was selected for trees on the mopane plots (eq. 369 in Henry et al. 2011) without any testing.

Table 2. Volume distribution (%) and total volume by diameter at breast height (DBH) for five individual trees measured by destructive sampling. All woody compartments above ground were included.

DBH (cm)	Stump	Bole	Other stems & branches by diameter				Total	Volume (dm^3)
			> 12 cm	12–7	7–2	2–		
12	5	61	0	4	21	8	100	94
19	3	27	28	22	13	6	100	265
26	2	58	16	12	11	2	100	628
29	3	42	22	16	12	4	100	744
37	5	44	36	10	4	2	100	1135

The plot data describes the miombo woodlands in Gilé nature reserve in Zambezia (Figure 4) and the mopane woodlands in Limpopo National Park in Gaza. The *Colophospermum mopane* trees (mopane) dominated, as 57–97% of the total basal area of the three plots studied in Gaza. A high proportion of mopane trees seemed to be a sign of low productivity. *Brachystegia boehmii* and *Julbernardia globiflora* were the main tree species in Gilé, but they were not particularly dominant, as their basal area was 26–67% of the total. The differences between mopane and miombo woodlands were quite clearly described using ordinary forest characteristics (Table 3).

Table 3. Sample plot basal area (G), total volume (V) and stem numbers (N) in the beginning of the growth period studied, also periodical averages of volume (I_v) and diameter increment (I_d).

	Gaza, plot no.			Zambezia, plot no.		
	1	**2**	**3**	**5**	**7**	**8**
G (m^2/ha)	9	16	15	15	20	13
V (m^3/ha)	45	95	71	174	218	110
N (stems/ha)	828	1048	1240	300	358	856
I_v (m^3/ha/a)	0.49	1.24	0.59	2.44	2.65	2.65
I_d (mm/a)	0.8	0.8	0.5	2.4	2.0	2.1

On a relatively dry site (no. 8 in Zambezia) a higher increment than expected was noted. This was probably caused by the presence of young, vigorous trees in one part of that plot. On the other hand, on a site with a high tree density (no. 7 in Zambezia) the *Julbernardia* trees were suppressed by *Brachystegia* trees, and this seemed to have reduced the volume increment slightly. These details are examples of relationships that need to be considered when the development of miombo woodlands is described through models in the future.

Using different conversions of the MAI-function, it could be concluded that the increments measured were higher for the Zambezia plots than in estimations based on the general rainfall-MAI relationship. The opposite was true for the dry region of Gaza, where the measured values were lower than the estimated increment. Despite the differences, the MAI-function can still be used for initial calculations of sustainability, and also in regions smaller than the provincial level. A converted version of the original rainfall-MAI function (for example, to a volume-MAI function) is more versatile. Some trial calculations combining the permanent plot data and inventory data indicated that improved growth functions can be generated even with a small numbers of growth observations, but the work will be much easier and the results more reliable if all existing plots are re-measured so that the complete dataset can be used. There are also some real benefits to gain if the network can be increased in size and coverage.

The miombo woodlands in the central parts of Mozambique are more productive than most savannah woodlands. Productivity is high enough to sustain the commercial utilisation of valuable timber. In the present situation three tree species (chanfuta, jambire, and umbila) are regularly harvested, but none of those are typical (or common) miombo tree species. The main miombo tree species *Brachystegia* and *Julbernardia* are not harvested for commercial purposes. The harvesting potential would increase greatly if more tree species could be included. Our growth measurements indicate that logging could be repeated with a relatively high intensity (22–32 stems/ha) after periods of 10–20 years, but this means that all (or most) tree species need to have a significant commercial value. The figures are more modest on dryer sites in the same region (for example 12–20 stems/ha after 15–20 years). The structure of the forest also affects the yield of timber, and in long-term development there must be sufficient regeneration of the desired tree species. Still, it is obvious that there is potential for increasing utilisation of the miombo woodlands in the central regions of Mozambique. The less productive areas to the south, north and west, are more problematic. The main focus should probably be on maintaining forest coverage, restoring cleared woodlands and improving degraded soils, but growth information is still always needed for forest management planning.

Figure 4. The growth and yield team accompanied by forest rangers, walking to plot no. 5 in Gilé nature reserve in Zambezia. Photo: Kristian Karlsson.

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3.5. Dendrochronology advances intelligent use of ecosystems and offers potential business opportunities

Mauri Timonen and Hannu Herva

The concept of dendrochronology

Dendrochronology (the science of tree rings) is the dating and study of annual rings in trees. The word comes from these roots:

- Ology: the study of;
- Chronos: time: more specifically, events and processes in the past; and
- Dendros: using trees; more specifically, the growth rings of trees.

A dendrochronologist (tree ring scientist) is an expert who uses tree rings to answer questions about the natural world and the place of humans in its functioning.

Dendrochronology is an interdisciplinary science. Its theory and techniques can be applied to many disciplines, including ecology, archaeology, climatology, geomorphology, glaciology, hydrology, fire history and entomology. Dendrochronology supports the following objectives:

- Placing the present in proper historical context,
- Better understanding of current environmental processes and conditions, and
- Better understanding of future environmental issues.

Trees grow new cells each year, arranged in concentric circles (Figure 5). The number of cells, for example in Scots pine (*Pinus sylvestris* L.), during one growing season varies from less than ten to over fifty, depending on climatic conditions (cool/warm). Annual (growth) rings are the result of these cells.

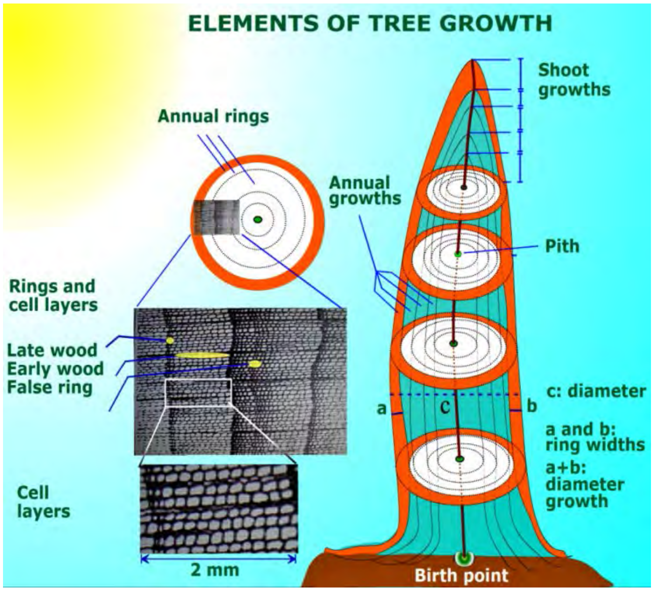

Figure 5. The main elements of tree growth are height growth, diameter growth and volume growth. Tree rings form during a growing season as a result of accumulating cell layers. Closer study of cells inside a growing season helps to understand the whole growth process.

Trees in temperate and colder climates typically grow one new tree ring every year. The age of a tree can theoretically be determined by counting the number of rings present at the birth point. This is not always the case, however, sometimes, particularly in years of drought, one or more annual rings may be missing. If the growing season is interrupted, a tree may grow a second false ring.

Tropical trees often lack annual rings. The majority of tree species in Mozambique don't produce annual rings. Only a few species, such as *Millettia stuhlmannii* (panga panga, jambire), can be used for dendrochronological studies.

Cross-dating is a method used to identify tree rings from the same calendar year from multiple trees. This approach makes it possible to identify the missing and false rings. As a result of this approach, tree rings can be properly assigned to the right calendar year. To obtain an average age-related growth curve for a single stand or for a particular region, a method called standardisation is needed to remove the age-related growth trend and the other disturbing effects (Figure 6, upper graph). In this process, a number of closely matching individual tree ring chronologies are combined into one averaged growth-age curve (standardisation model).

The final step is to compare the ring-widths observed to the corresponding values of the averaged growth model. As the proportional values (tree ring indices) are arranged by calendar year, the series of annual index averages is called a master chronology.

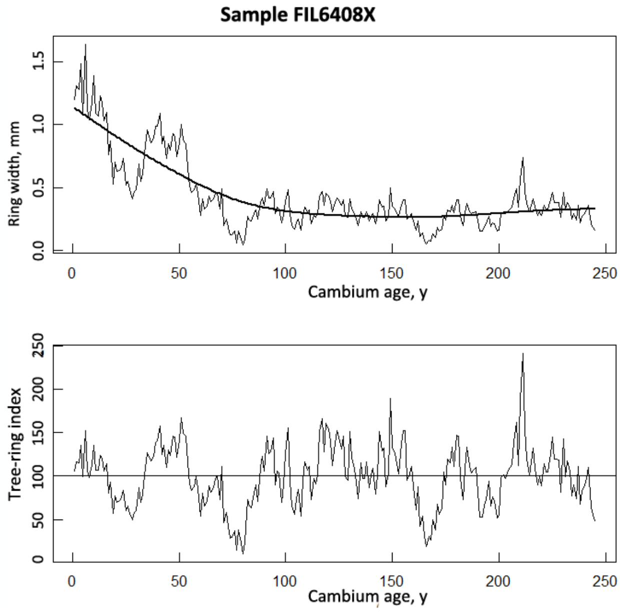

Figure 6. The graphs demonstrate the principle of standardisation based on one core sample. As the tree ring indices are arranged by calendar year, the result is called a master chronology.

Why is dendrochronology an important science for Mozambique?

Until fairly recently, comparatively few dendrochronological studies have been carried out in tropical regions (Remane & Therrell 2015). As there was little local Mozambican tree ring research, Ivan Abdul Dulá Remane deserves the honour of being described as a pioneer in Mozambican dendrochronology. He studied at the UEM (Forest Engineering) and at graduate school in Southern Illinois University, Carbondale (Department of Geography and Environmental Resources), where he finished his Master of Science degree in August 2013. His studies (Remane 2013, Remane & Therrell 2015) include, for the first time in Mozambique, exact dendroclimatic and dendroecology analyses focusing on growth dynamics and the sustainable management of forests.

Remane developed the tree ring width chronologies for two tropical hardwood tree species: *Millettia stuhlmannii* (panga panga) and *Vitex payos* (chocolate berry). He studied the history of climate variability by analysing signs of seasonal droughts found in tree rings. His results showed that the tree rings of panga panga correlate positively with monthly and seasonal precipitation: rainfall during December and February explains about 43% of chronological variability.

This climate–growth relationship increases our knowledge of climate change impacts on ecology. As these two tree species and other closely related species are widely distributed in Mozambique and adjacent areas in southern and eastern Africa, a network of chronologies throughout Southern Africa can be developed.

Remane's chronologies are also useful for reconstructing pre-instrumental rainfall variability in Mozambique. This provides important information for a country that, considering economic devel-opment, is strongly dependent on rainfall.

Panga-panga is one of the most important timber species in Mozambique. Ranked as a first class commercial timber in Mozambique, it is often harvested in an unsustainable way. Sustainable management of the species is needed for the continued use of this resource.

It is expected that the results of chronology building and dendrochronological analyses will in-crease our knowledge of long-term climatic and environmental variability. Personal training and increasing experience will gradually respond to governmental goals for developing forest ecosystems towards more sustainable management.

Dendrochronology course

Our motivation in arranging a dendrochronology course in Mozambique was technical, educational and practical. The technical part was to establish a scanner-based tree ring analysis environment for the joint use of IIAM and FAEF–UEM. The educational part was to introduce some important methods of dendrochronology. The practical part was to train course participants in working with dendrochronological tree-ring material. The following topics were included in the course programme:

- Introduction to dendrochronology;
- Tree ring analysis as a part of growth and yield studies;
- Climate connections of tree rings;
- Sampling design and fieldwork;
- Laboratory facilities: equipment and software;
- Data storage and tree ring analysis;
- Documenting and scientific reporting;
- Personal training

The joint laptop of the laboratory was loaded with useful dendrochronological material supporting the participants' self-learning targets.

Laboratory equipment and activities

We prefer a scanner-based tree ring measurement system over a microscope-based system (Figure 7). One important argument on behalf of a scanner-based system is its excellent documentation of measurements, which makes it possible to re-measure a sample and view the results later.

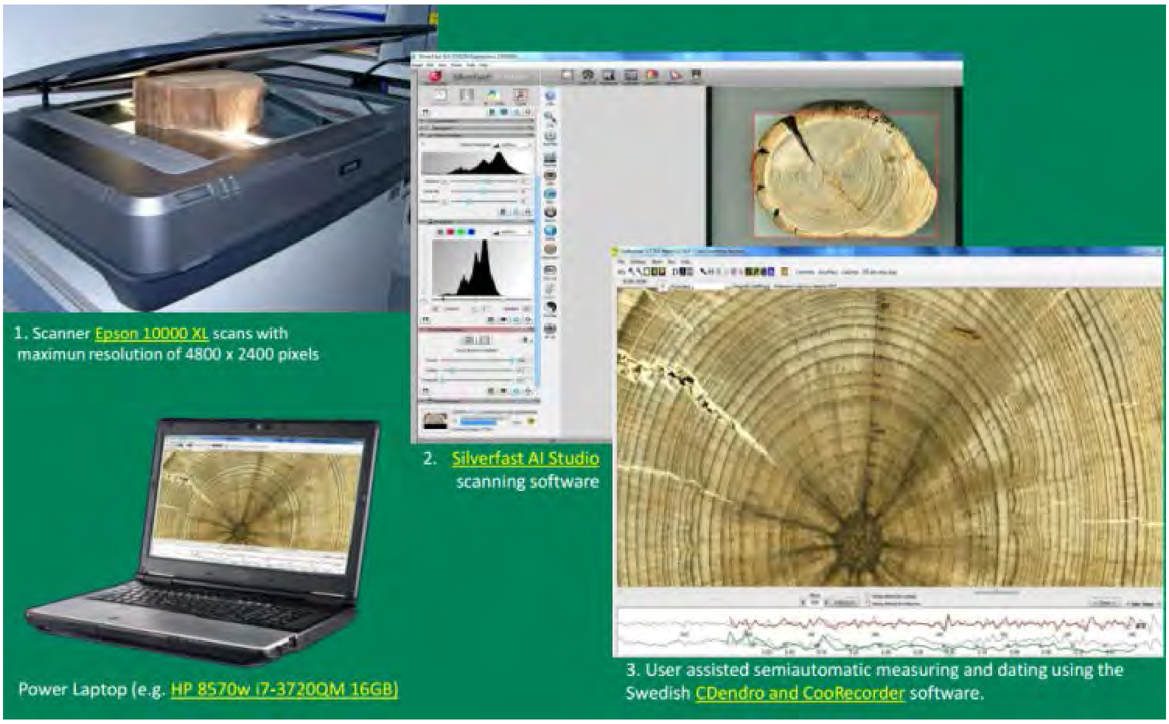

Figure 7. This tree ring analysis system, developed by Cybis Elektronik & Data AB, uses scanned disk and core images for measurements and chronology building.

Training activities

We had only five course days for teaching and training in the field and the lab, which forced us to prioritise some activities. Every course participant was familiar with all the planned training activities: theory, sampling planning, fieldwork, laboratory work and tree ring analysis.

The only problem appeared when the new A3-scanner was not available until the last course day. We were able to extend the course to noon on Saturday, however, which partly solved the problem.

The fieldwork was performed in a plantation of Michafutene, a village in the Marracuene District, Maputo Province (Figure 8). The group sampled both cores and disks (cross-sections). Increment borers were used to extract 5 mm thick cores from living trees and snags. The disks were smoothed, scanned and finally measured.

Figure 10 demonstrates the difference in preparing sample disks for measuring. It also suggests that tree ring analyses need a great deal of time and careful concentration in each phase of the process.

Conclusions

The recent activity in establishing permanent sampling plots (PSP) in Mozambique also means focusing on growth and yield studies. It is important that these studies can continue on a permanent basis, because it is not until after many years of regular monitoring that more thorough conclusions benefiting the development of Mozambican species-rich forests are possible.

In the meantime, there is a shortcut for quicker results: dendrochronology is a useful complement to PSP. It provides a simple and smart tool for finding answers to many questions. Generalising Remane's and Therrell's (2015) conclusions to some extent, dendrochronological analysis allows a better understanding of species growth dynamics and ecology. In addition, year-exact information about past climate variability helps to judge modern climate and possibly to forecast future climate. It is thus expected that dendrochronology will contribute to the more sustainable management of forest ecosystems in Mozambique.

Figure 8. The sampled forest is located in Michafutene, Marracuene District, Maputo Province. The sam-pled species were *Ambligonocarpus andogensis* (discs) and panga panga (cores). Eunice Catarina Sitoe from FAEF–UEM coring a panga panga tree.

Figure 9. Disk collection was sampled from the same tree at 2 m height intervals and the disks were smoothed using a 60, 120 and 240 Grit Sand Paper. More about sanding: http://www.rmtrr.org/basics.html#preparation.

Figure 10. The disk sample of *Ambligonocarpus andogensis* on the left was collected in the Michafutene forest. The photo of a panga panga cross-section on the right was selected from Remane's (2013) paper, p. 57. Careful smoothing with proper tools helps to identify the tree ring boundaries.

Planning a Roadmap for a Smart Future?

A modern tree ring laboratory is like a factory: it processes raw material (tree rings) and the output is processed data, reports and services. Skilled personnel, sufficient laboratory and storage space, high-quality equipment, technical and statistical software, and good documentation systems are required to make it work. For maximum performance, dendrochronological facilities should be built from a combination of scientific knowhow, innovative thinking and useful connections.

Good planning is required to keep the wheels running, now and in the future. The best way to do this is to prepare a roadmap that defines all the necessary activities and establishes a framework for coordination. We planned our first Dendrochronology Roadmap in 1994. This was a systematic approach to develop Finnish dendrochronology and its infrastructure based on the earlier history of forest research (Timonen 2015), to improve personal skills and increase international collaboration. Twelve years later, at the 7th Conference on Dendrochronology in Beijing, a pleasing announcement was made by the scientific community: Finland had been elected to host the 8th Conference on Dendrochronology in 2010. WorldDendro2010 was an excellent milestone for the Roadmap.

Times change and so do the needs. We are now in a situation where we have to consider creating a new roadmap. We wish to cooperate with the European Secretariat for Cluster Analysis (ESCA) and the S3 Platform in order to become more business-oriented. We believe that our most productive dendrochronological future will be possible through research and development (R&D) facilities and cluster-based business resources.

We suggest something similar for Mozambican dendrochronology. The task will surely be challenging, but also rewarding. It is also good to bear in mind that when working together with experienced research organisations, such as Luke, things happen much more easily, quicker and in a more goal-directed way. More details are available in the technical version of this paper (Timonen et al. 2016).

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4. Strengthening research capacity in wood science

Andrade Egas, Alberto Manhiça, Tuula Jyske, Veikko Möttönen and Erkki Verkasalo

4.1. Miombo tree species in wood technology: the baseline of knowledge at the project outset

Mozambique is a large, sparsely populated country with huge potential for agriculture and forestry. In addition to the natural indigenous forests, which cover up to 70% of the land area, there is potential to establish forest plantations that could supply wood for world-scale forest industries, including wood pulp and wood-based board, and Mozambique could thus become a large forestry nation in Africa (Green Resources 2016). The allowable cut of natural forests is currently only 520,000–640,000 m^3/year, and logging is concentrated on seven of the 118 indigenous tree species, with 67% of commercial licensed volume (in 2011). Concession areas for commercial logging now comprise eight million hectares, meaning a potential cut of 200,000 m^3 of timber a year. Unfortunately, round wood markets have been declining in recent years. In addition to concession cuttings, village people use local wood resources and there are simple license cuttings.

The sustainability of forest operations, particularly logging, and forest fires are concerns in the forest sector. According to the official data, FAEF-UEM (2013) estimated in 2012 that at least 14% of the logging volume surpassed the maximum allowable cut established by the government for the main commercial species. The majority of the harvested wood material is exported as logs. Estimates show that in 2012 almost 198,000 m^3 of logs, which means 62% of the annual licensed cut, was exported as logs rather than processed domestically. Other than logs, the main exported product in 2012 was sawn timber (265,263 m^3). Other important export products are parquet blanks exported to Europe, and railway sleepers exported to South Africa (6,243 m^3 in 2012).

The wood product industry in Mozambique is at a basic level and copes only with the domestic demand for low processed intermediate products like sawn timber, and the elementary finished products of joinery industries. The domestic processing of timber has mostly focused on the low added-value sawmilling of a limited number of high-value species to produce rough-sawn green timber. The timber product portfolio includes logs, sawn timber, railway sleepers, poles (with treatment), parquet planks, school desks, miscellaneous furniture, containers and boxes, doors and window frames, and to some extent decorative items and designed products (Actual situation… 2005; Nhancale et al. 2009). Reliable information on the production volumes of different product categories in the domestic market is needed.

According to a survey on forest concessions in four provinces in 2012, fifty per cent of 26 concessions operating sawmills operated with one machine only, the headrig, as a constraint to offer fewer but well-processed products such as boards and planks. On the other hand constraints in a number of sawmills to ensure their normal operations were also observed, since a significant number of sawmills (54%) were operating without maintenance equipment for blade sharpening and other saw maintenance operations.

In most cases the installed capacity for both harvesting and processing was higher than the current production. Data from some concessions shows that the unused capacity (idle capacity) ranges from 30 to 74% of the installed capacity in harvesting, and from 33 to 88% of the installed capacity in primary mechanical processing. Machinery throughout the production chain is outdated, and investment in modern high-tech wood processing industry (e.g. kiln drying, veneer, plywood, mouldings, joinery and furniture) is needed.

Strategic actions are required to enable sustainable harvests, and the consumption and trade of natural forest resources in the future. A restriction of exports of end or roughly-end wood products should be the first step to achieving this goal.

Although the activity of the construction sector has increased in recent years, the demand for Mozambican-made wood products remains low, because the construction companies favour cost-effective turnkey solutions. Such solutions are unattainable for small Mozambican wood product companies. The high quality raw material suitable for advanced products is mostly exported by international companies.

One of the main problems related to the wood resources of native tree species and their further processing for sawn and advanced wood products is that few of the main indigenous tree species are utilized systematically. The most licensed species are *Pterocarpus angolensis* (umbila), *Afzelia quanzensis* (chanfuta), *Millettia sthulmmannii* (jambire), *Combretum imberbe* (mondzo), *Swartzia madagascariensis* (pau-ferro), and *Colophospermum mopane* (chanate). Monzo, pau-ferro and chanate are the species most demanded in the international market. Chanfuta, umbila and jambire are the most utilized species in the domestic market. On a smaller scale, another 24 species including *Sterculia quinqueloba* (metonha), *Sterculia appendiculata* (metil), *Terminalia* sp. (messinge), *Erythrophloeum suaveolens* (missanda), *Brachystegia spiciformis* (messassa), *Julbernadia globiflora* (red messassa), *Androstachys johnsonni* (mecrusse), *Dalbergia melanoxylon* (pau-preto), *Berchemia zeyheri* (pau-rosa), *Khaya nyasica* (umbaua), and *Milicia excels* (tule) have also been used for industrial purposes in the domestic market. Domestic use is focused mainly on few species because of a lack of information and experience regarding the other tree species, and also due to the old-fashioned and conventional procedures of wood procurement practices and timber processing. The logging of only a few tree species leads to a scarcity of timber and, in the long-term, also to low quality of the raw material. According to preliminary surveys, there are several less-used tree species with a reasonable volume of annual allowable cut, and the potential for timber production and sustainable use, such as *Brachystegia spiciformis* (messassa), *Julbernardia globiflora* (red messassa), *Pericopsis angolensis* (muanga), *Burkea Africana* (mucarala), *Cordyla Africana* (mutondo), and *Acacia nigrescens* (namuno). A review of the physical, mechanical and processing properties of 52 tree species with commercial value was made by Bunster (2006), however, more detailed research on the wood properties of less known tree species is needed for the use of small and medium wood working companies, which are almost totally in charge of the economic activity related to the further processing of commercial timber.

The sampling of wood material to assess physical and mechanical properties was begun during the FORECAS project for two potential tree species: *Brachystegia spiciformis* (messassa) and *Julbernadia globiflora* (red messassa). Other prospective species will be considered in the next steps of the development projects.

4.2. Research facilities for wood science: the baseline at IIAM and UEM at the project outset

At the time of project outset, IIAM had a carpentry workplace in Maputo equipped with a surface planing machine and a combination machine for sawing, planing and moulding. Both machines were only capable of basic work with restricted accuracy. No safety equipment remained, and the machinery was not equipped with a sawdust extractor, which is essential for wood sample manufacturing. In addition, the workplace had no air conditioning and the roof was covered only with a single metal sheet, which made work efficiency vulnerable to outdoor weather conditions. IIAM did not have any equipment for wood science research. In the town of Marracuene, there were premises available for the establishment of a wood research unit, however, the location is at least 1–2 hours away from the research units in Maputo, without accommodation services, and was thus not seen as a practical choice by the project board. FAEF-UEM in Maputo already had laboratory rooms for physical and mechanical wood testing, and for anatomical analyses. The rooms were equipped with some testing machines, some probably purchased before the 1970s, and they had not been in a usable condition for many years.

4.3. Establishment of the new wood science laboratory

The laboratory equipment purchased by FORECAS was placed at the premises of FAEF-UEM. The decision about this placement was based on the locations of different options and the usability of the FAEF-UEM laboratory for both educational and research purposes. The list of the equipment to be purchased was based on the priority of building research capacity to study the anatomical, physical and mechanical properties of less-known tree species.

The wood anatomy laboratory was equipped with a microscope system including image-analysis software for the determination of tree species and their anatomical properties, and a sliding-type microtome for the sectioning of anatomical specimens. A lab hob heater-diffuser-plate, consumables and chemicals (microscope slides, cover glasses, trial tubes, petri dishes/plates, pipets, safranin, lactophenol blue, ethanol, peroxides, glycerol, Canada balsam) were also purchased, as essential for anatomical analyses.

The equipment purchased for the laboratory of wood physical and mechanical properties consisted of a universal material testing machine, spectrophotometer for analysing the reflectance spectra of wood surface, acclimatisation chamber, kiln drier, digital scale, digital callipers, hygrometer, and universal woodworking machine for sample preparation. The universal material testing machine consisted of testing tools for 3- and 4-point bending, compression, tension, hardness, and shearing. Digital lab callipers, rulers, digital chronometer, handheld wood moisture meter, thermometers, lab jack (i.e., lifting device), and glassware were also purchased.

4.4. The organised activities in the sub-component of wood science

The sub-component of wood science in the FORECAS project was aimed at (1) developing the research skills and knowledge of researchers in wood science, and (2) improving the research infrastructure by providing a wood science laboratory that enables researchers to conduct research into the wood properties of less-known tree species. The sub-component provided the launch to enhance the knowledge base beyond commonly used tree species, and disseminate the uses and potential uses, of lesser-known tree species. The following activities were arranged during the project:

- Course no. 1, Maputo, Mozambique: Basics of wood science, principles of sampling for technological properties (Course material, Annex 6)
- On-the-job training no. 1, Joensuu, Punkaharju and Vantaa, Finland: Familiarisation with measuring techniques and training on the Mozambican wood samples
- Course no. 2, Maputo, Mozambique: Measuring techniques, instruments and standards in wood science (Course material, Annex 7)
- On-the-job training no. 2, Joensuu, Finland: Applications of advanced measuring techniques and training on the Mozambican wood samples, methods of analysing data from the measurements and starting writing the report/manual on the results on the Mozambican wood samples
- Final workshop in Mozambique: 1) Properties, uses and processing technology of less-known tree species in small-/medium-scale wood industry; 2) References of research methods in other developing countries; 3) Excursion to wood products industries; 4) Evaluation of FORECAS results
- Equipping the wood technology laboratory (List of equipment, Annex 8)

Figure 11. Introducing the wood sample collection during course no. 1 in August 2012 and the assembling and commissioning of the universal material testing machine by the supplier of the equipment during course no. 2 in November 2014. (Photos: Tuula Jyske and Veikko Möttönen)

The first course consisted of lectures and practices about the anatomical, physical and mechanical properties of wood, and an introduction to a wood sample collection in the field. The course included lectures and practical laboratory exercises on **(i) the structure and function of wood**: wood formation, anatomical structure of hardwoods and softwoods, different cell types and their functions, cell wall structure, wood fibre properties, heartwood formation, chemical composition of wood, and chemical properties of wood; **(ii) physical properties of wood**: wood density, moisture content (MC), wood fibre saturation point (FSP), water vapour sorption, equilibrium moisture content (EMC), determination of density and moisture content, and wood thermal properties; **(iii) mechanical properties of wood**: wood elastic properties, modulus of elasticity (MOE), wood strength properties, modulus of rupture (MOR), tensile strength, hardness, cracking, knots, slope of grain, annual ring orientation, reaction wood, juvenile wood, and compression failure; **(iv) wood biological degradation**: mould and stain fungi, decay, insect damages, and timber protection; **(v) wood drying**: drying methods, drying mechanism, drying stresses, dry kilns, kiln schedules, drying defects, and moisture content of dried timber; and **(vi) the principles of sampling for technological properties**: selection of tree species and sample trees, collection of wood samples, storage of wood samples, and preparation of wood specimens for testing. The lectures and practical sessions broadened the knowledge-base of the participants, allowing them to continue self-studying the literature on less-known tree species and their application possibilities. Between the first course and the first on-the-job training, trainees became familiar with the relevant literature and manuals of wood science, selected the tree species of interest and collected the necessary wood samples.

During the first on-the-job training in Finland, the attendants were familiarised with basic laboratory research methods and trained themselves using wood specimens from Finland. The detailed topics of the training included wood material preparation for machining: drying, conditioning, sawing and planning; the preparing and testing of specimens for bending, compression and hardness, and tensile strength; and the preparing and analysing of specimens for anatomical properties such as fibre length and cell size. The attendants had also the opportunity to follow selected lectures in the Wood Materials Science Master's Programme at the University of Eastern Finland, Joensuu that were relevant to the objectives of FORECAS. The attendants joined short excursions to forests in the vicinity of Joensuu to get an impression of timber quality and its relationship to silviculture.

Between the first on-the-job training and the second course, the trainees implemented the preliminary instrumentation of the wood technology laboratory and the first test runs with tree species of interest in Maputo. The second course consisted mainly of practical training on the equipment of the wood laboratory. The standards and measuring techniques for the determination of the anatomical, physical and technical properties of wood were taught and discussed. The detailed topics included: the commissioning and training of the universal material testing machine; measuring the bending strength of wood; measuring the Brinell hardness of wood; preparing wood sections with microtome; analysing wood sections with microscopes; practicing using a resistance moisture meter and a spectrophotometer for the colour analysis of wood.

During and after the second course and the second on-the-job training in Finland, the trainees deepened their knowledge of measuring and testing techniques, became familiar with the relevant methods of data analysis and reporting, and completed the collection of a sample set from Mozambique. A manual on the relevant measurement techniques for the technological and anatomical properties of wood was prepared in association with the second course (Annex 7).

Figure 12. On-the-job training in Finland in November 2015 was focused on the preparation of wood specimens for mechanical analysis and on testing methods of long term durability. (Photos: Veikko Möttönen)

4.5. Final workshop on properties, uses and processing technology of lesser known tree species in the small/medium scale wood industry: developing wood product industries in Mozambique

The week of the final workshop in Maputo, Mozambique started by focusing on the objectives and procedures shared between the responsible partners from Mozambique and Finland.

The first day of the workshop concentrated on the presentation and discussion of FORECAS activities, experiences, results and further plans in the field of research and development. There was also an introduction to research in wood science and technology and relevant research programmes at Luke in Finland, paying attention to their applicability regarding organisation, operative management and contents in Mozambique. The hosts also organised a visit to the new laboratory of wood anatomy and wood mechanical testing at FAEF-UEM.

Two reference projects with parallel objectives concerning physical availability and social constraints, wood technological characteristics and potentials of use on lesser used tree species were also introduced to give a picture of different ways to approach the topic and enable an evaluation of the applicability of these methods in countries like Mozambique. The projects were from Colombia and Costa Rica, and accomplished as PhD projects in Germany and the USA, respectively.

A new methodology to select suitable hardwood tree species for specified wooden products was introduced. This was recently developed by a Swedish-German research team. The methodology combines processes based on quality function deployment and multivariate data analysis in a three-step workflow, and takes different criteria into consideration, however, an expansion of the underlying tree species dataset will be necessary to improve the performance of the method.

During the second workshop day, the hosts organised an industry excursion to two wood industry plants in Matola: the sawmill and woodworking factory of SECAMA and a flooring factory of Colosso. The visitors had an opportunity to meet the managers of the companies, absorb information about current and future markets, demand and competition trends of wood products and introduce their own research and testing capacity. The excursion was followed by a lecture on physical and chemical wood modification and the thermal modification of wood products in Finland.

The third workshop day began with an introduction to Finnish wood value chains related to the business activities among small and medium-scale industries, and hardwood use in particular. The main use of hardwood in Finland is in plywood, wood pulp, paper and paperboards run by large-scale industries. Small and medium-scale companies manufacture sawn goods, flooring and other interior materials, home and office furniture, kitchen cabinets, decorative veneers, and firewood products and fuel chips.

Figure 13. A woodworking company SECAMA in Matola was visited during the final workshop on wood science. (Photos: Veikko Möttönen)

FAEF-UEM presented the projects of the MSc programme in Wood Technology and the activities to be achieved in the Laboratory of Wood Technology. The programme aims to build the capacity of FAEF-UEM to run the MSc in Wood Technology independently. The programme is now run in collaboration between FAEF-UEM and two universities from Sweden, Luleå University of Technology, Skelleftea Campus (LTU) and Swedish University of Agricultural Sciences, Forest Products (SLU). Centro Ciencia Viva from Portugal also participates in teaching activities. The first session (2013-2015) includes seven MSc students (five active, October 2015). The future objectives include five graduates from the second session (2015-2016), and ten students from the third session to complete the required credits for an MSc dissertation (after their BSc). Funding comes from the Swedish International Development Cooperation (Sida) programme. Improvements in teaching infrastructure are also in planning/procurement, including wood drying, wood-based panels, wood energy technology and wood-based chemicals. As an example of studies on lesser-known hardwood tree species, a project was presented on the effects of climatic conditions on air wood drying of Messassa.

The fourth workshop day was opened with a presentation on forest plantations and related research topics in Mozambique. Forest plantations are seen as having great potential, with a projection of production on 386 000 hectares that could enable more than five million m^3/year during the next 10 years (c.f. with the current allowable cut of natural forests of 0.5 to 0.6 million m^3/year). The plantations consist of the newly introduced foreign tree species of Pinus and Eucalyptus, and are owned by the seven main international forest plantation companies. The following potential products from their timber were listed: 1) energy (firewood and charcoal), 2) poles for electricity and communication service, 3) sawn wood, 4) veneer and plywood, 5) wood chips for wood panels, 6) pulp and paper. There is a clear need for the development of wood industries using this resource in the near future. Highly trained people and research in wood technology should be key issues here, and the close collaboration of UEM with the emerging forest/wood companies through the MSc in Wood Technology should be enhanced.

The emphasis in how to implement the results of FORECAS has been on the next steps of laboratory activities and infrastructure development. The measurement and testing laboratory should be promoted to Mozambican wood industry companies so that they are aware of the service capacity, and will offer research, development and testing work. The infrastructure should be further developed to facilitate research and testing of the long-term durability (esp. decay, discoloration and termite resistance) and drying of wood products. Topics related to the needs of industries should be stressed, including a multi-disciplinary approach.

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5. Strengthening the capacity for information dissemination and technology transfer services including a description of the baseline at the project outset

Erkki Kauhanen

5.1. Background

IIAM is a public research organisation that, at the beginning of the project, was under the then Ministry of Agriculture (MINAG). Its tasks include scientific advice and policy support in issues related to the agricultural sector of Mozambique, the research and production of information materials, documentation, training and technology transfer. At the central level, IIAM has one General Directorate and four technical directorates: the Directorate of Planning, Administration and Finance (DPAF); Directorate of Animal Sciences (DCA); Directorate of Agriculture and Natural Resources (DARN); and the Directorate of Training, Documentation and Technology Transfer (DFDTT). IIAM has also a Centre of Socio-Economic Studies (CESE).

IIAM's vision is to "be a research and innovation organisation of excellence, dynamic, motivated that contributes to the satisfaction of the food needs, development of agribusiness and sustainable use of natural resources". The mission of IIAM is to "generate knowledge and technological solutions for the sustainable development of agribusiness and food and nutritional security". Forestry is included in the concept of agribusiness. The most direct reference to forestry in the above statements involves the sustainable use of natural resources. This is in line with the national policy documents that define the agricultural development and extension policy (e.g. PROAGRI I and PROAGRI II, and MINAG´s publications "Concept, principles and strategy of the Green Revolution in Mozambique" and "Extension Master Plan 2007–2016", PEDSA) in Mozambique. The Mozambican agricultural development vision is based on the familiar economy, supported by the government, the commercial sector and NGOs, so that local resources are taken into effective, and at the same time sustainable, use. Widespread poverty means that the emphasis is on food crops.

On the other hand, the importance of forests for the livelihood of the predominantly agricultural rural population is already substantial, as the producer of firewood, charcoal, timber, and NWFPs. The weight of the forestry sector as a producer of income may also increase in the future, when the demand for efficiency in forestry production will boost professionalism in the sector. Eco-tourism, which has some potential in many parts of the country, will also involve a push towards more money-based forestry and rural economy.

The Directorate of Training, Documentation and Technology Transfer (DFDTT) is responsible for the communication activities of IIAM. Under the directorate there are separate departments for Technology Transfer, Training, and Documentation, Information and Communication. The latter is further divided in two sections, Documentation and Communication & Marketing. This structure reflects the largely similar organisation within MINAG at the national level and in the provinces. Lower down, in the districts and at the local level, these functions are gradually more combined as the size of the offices gets smaller. In the field, the people who undertake the practical extension work with farmers and their associations usually act as extension agents both in agriculture and in forestry. This is one of the cornerstones of the unified extension system. It provides the framework in which the different extension providers from the public and private sector all interact. The extension strategy is based on the strategy for the second national investment programme for the agricultural sector, PROAGRI II 2006–2010, the Extension Master Plan 2007–2016, and the National Agricultural Extension Programme 2007–2014, PRONEA. At the time of the project, the extension service under MINAG had about 1000 extension field officers.

In the final evaluation report of PROAGRI I (Final evaluation of the first phase of the national Agricultural Development Programme PROAGRI (1999–2005) (PricewaterhouseCoopers 2007), the extension component of the implementation of the strategic programme is analysed as follows: "The major concern is the lack of improved linkages between research and extension… research and extension services continue to have their own agendas and priorities. The lack of effective functional linkages results from an environment where there is a fragmented approach to decision-making and implementation. Generally there are no formal structures for coordinating the interaction between research and extension, either for planning or for evaluation…".

The above evaluators of PROAGRI I continue to say that the "…weak research-extension link is unsustainable (and) there is a need for research scientists to also prioritize the promotion of utilization of their research. The potential contribution of the research results and technologies to the country's economy and social welfare of the communities is very high. It is our view that researchers need to move beyond the confines of their research stations and laboratories and look into downstream aspects of market and consumption on a value chain approach in collaboration with extension, private sector and policy makers."

The crucial point is that, especially when there is a chronic lack of resources, it is extremely important to maximise the social impact of research. The social impact that research can have is produced only through communicative interaction between the science community and the users of the scientific information. In order to make this interaction effective, communication needs should be addressed in the planning phase of every research project. This means, among other things, that resource allocation for documentation, training, extension and other information dissemination should be an integral part of research project planning, and it should be in a policy-driven balance with resource allocation to the research itself.

Publications in scientific journals are valued much more in the scientific subculture, than popularised articles or leaflets, or training courses, where science-based information is made available to ordinary people in practical and easily understandable terms. This has research-political implications, as it often guides scientists to prefer research questions that are deemed interesting from a purely scientific (international) point of view, as opposed to the (more local) questions that are important from the practical point of view of developing the livelihoods of ordinary people. This often leads scientists to shun extension work, which is exactly what the final evaluation report of PROAGRI I discovered: "…within the research component… there is lack of a holistic approach to the results generated. From our interviews, most of researchers feel that their role terminates once they produce a report on their research findings and the rest is the responsibility of extension agents and producers… it is crucial that researchers "care" about the promotion, utilization and the contribution technologies bring to the country's economy." It is one of the biggest continuous challenges of a scientific research institution, to balance these two often conflicting needs so that both value systems are served. In order to manage this challenge, institutes such as IIAM need strong internal policy guidelines that are turned into reality through operational procedures. This is especially important in projects with external funding. Including an extension component in the project plan should be a prerequisite for accepting a project proposal and the funding plan. Communication personnel should be included in all phases of every research project.

5.2. Missions

During the FORECAS project, three visits were made to Mozambique, by Dr Erkki Kauhanen. Communication officer Marjatta Joutsimäki participated in the second mission. The purpose of the planning mission to Mozambique, from November 21st to December 7th, 2012 was to assess the information dissemination and technology transfer function of IIAM and to draft a plan for its development. For that purpose the following institutions were visited: the MINAG National Directorate for Agricultural Extension, MINAG National Directorate for Land and Forest, IIAM Headquarters in Maputo, Forest Research Station in Marracuene, the Eduardo Mondlane University (UEM) Department of Forest Engineering, and the University Library. Sixteen people at these institutions were interviewed. The critical analysis of the PROAGRI I evaluation report was strongly supported by the findings of the mission. Discussions with representatives of the Directorate of Training, Documentation and Technology Transfer and the Department of Agriculture and Natural Resources, and other available material showed that the same basic problem persisted. The coordination of the numerous communication activities of different DFDTT departments in relation to research projects run by DARN was deficient, which made it practically impossible to develop a unified extension framework for the forestry research function of IIAM.

On the basis of the findings, a number of proposals and recommendations were made that aim to increase the profile of forest and forestry research both inside IIAM and nationally, as well as internationally:

1. Creation of a national forestry portal through which all important information about Mozambican forests, forestry and forest research could be reached.
2. Creation of a photo archive that could be used to create content for the forestry portal, scientific publications and dissemination material and that would act as a repository for photographic material that is accumulated in research projects. A copyright policy for photographic materials of the institute would be needed for the archive.
3. Building of a forestry path, a field demonstration site situated in forested area, with special information spots along the path, where facts and principles of sustainable forest management (SFM) are demonstrated. A forestry path is an especially suitable tool for disseminating information on forests, forestry, biodiversity, conservation, and forest products and other forest use, for groups such as school children, students, teachers, extension workers, farmers, and journalists, but if well planned and maintained, it can also become a tourist attraction.
4. Making a communication plan mandatory for all research projects, and a communication component an essential part of all research budgets.
5. Promoting the networking of forestry professionals, e.g. by founding a national professional forestry association that would connect all the researchers of IIAM and ex-forestry students of the UEM, and could also serve as a content producer for the national forestry portal.
6. Revising the communication strategy of IIAM, where the different tasks of communication are currently divided between too many actors and departments, which makes it difficult to develop the communication function of the institute.

Three of the proposals made after the fact finding mission were identified by IIAM as the most promising development targets: 1) building the photo archive, 2) developing the forestry portal; and 3) introducing the concept of forestry path to IIAM's extension work. During the second mission, from May 7th to May 17th, 2013, the IIAM Headquarters in Maputo, Forest Research Station in Marracuene, and the village of Goba near the border of Swaziland, were visited and three workshops given: on 09.05.2013, workshops on the forestry portal and the photo archive, and on 13.05.2013 a workshop on the forestry path. The three projects received strong support from both the communication experts and the participating scientists. The practical implementation of the photo archive was started during the visit, and the skeleton of the forestry portal was built. Two possible sites for the first forestry path were examined and one of them, in Goba, proposed by IIAM, was deemed as having good potential. A meeting with the local village community was organised, and the potential project was discussed. It was accepted and strongly supported by the local people.

In the photo archive workshop, the need for a well-organised photo archive was discussed and generally recognised. The marketing and communication officer was tasked with responsibility for the technical implementation of the portal. It was agreed that Metla's experts will provide a draft proposal for the policy of use and copyright issues connected to the archive and the policy will be discussed and decided by the relevant directors of IIAM. After the workshop, the properties of various available free photo management software packages were discussed. XnView was subsequently installed on the communication officer's computer and its properties were demonstrated and tested. The next steps in building the photo archive were discussed:

- Drafting the necessary policies;
- Making the necessary organisational decisions and communicating them to the personnel. This includes officially setting up a task force to coordinate the project; and
- Organising the collection of already existing photographic materials from the people who currently maintain them.

The point of departure in the workshop on the forestry portal was the observation that all research institutes in the world face the danger of a negative feedback loop from bad finances via poor visibility to low social and economic impact, and back to even worse finances.

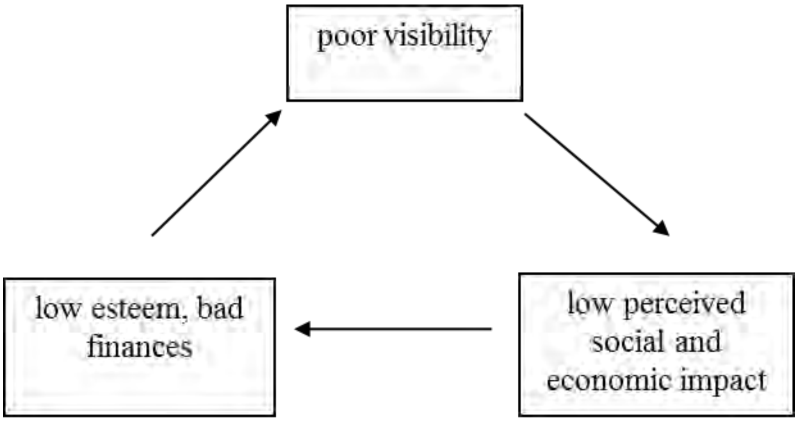


Figure 14. The negative feedback loop of bad finances, poor visibility and low perceived impact.

As finances are dependent on the perceived legitimacy and value of the institute for society, the only place where an institute stuck in the negative feedback loop can usually intervene on their own initiative, is poor visibility. To break the loop, visibility must be improved so that the social and economic value of the institute's work is generally perceived. This is a necessary but not always sufficient condition for the negative feedback to begin to turn positive so that more resources start coming in. A well-functioning internet portal is a good and cost effective means of raising visibility and a profile.

The need for the portal was discussed and recognised in the workshop, and it was given strong support by the management. The content and the structure of the portal were discussed. After the workshop, the basic structure of the portal was planned, and the next steps in building it were agreed upon.

Sixteen persons from IIAM, UEM and MINAG participated in the forestry path workshop. The concept of the forestry path was presented and thoroughly discussed and it was received favourably. The general conclusion was that the method is well applicable and useful for extension work in Mozambique. A number of important general themes were recognised in the discussion, where there is an objective need for information, and that could be demonstrated using a forestry path approach. A task force to continue the planning of a possible forestry path was discussed. The Finnish experts proposed that the same task force would plan the forestry portal, the photo archive, and the forestry path, because all three are intimately connected, and both the photo archive and the forestry portal would be instrumental in different phases of the forestry path project.

In view of locating possible sites for the forestry path, a field trip was made to the Marracuene research station, however, discussions between the director of the station, Mrs Esmeraldina Salomão Cuco, researcher Horacia Celina Mula, and communication experts Carlos Filimone, Marjatta Joutsimäki and Erkki Kauhanen led to the conclusion that, against expectations, Marracuene would not be suitable for the forestry path project, because forest diversity in the area is poor, most of the better sites in the location are conservation areas and therefore too vulnerable to be made the target of frequent visits by outsiders, and because of the earlier experience of researchers that targets in this area are vulnerable to destruction by unintended visitors. The forest-based economy in the area is also negligible.

After a consultation during the forestry path workshop with DFDTT director Feliciano Mazuze and Mrs Esmeraldina Cuco, a potential location for the path was identified in the village of Goba, in the district of Namaacha, near the border to Swaziland. The area has more biodiversity, but is situated in the countryside where wood and timber have a certain economic importance. Because of intensive coal production in previous decades, the area suffers from deforestation, and the principles of sustainable forestry and methods of reforestation need to be disseminated. Mrs Cuco has previously worked in the area and has personal connections with the people in the village, which will be a great asset, if the path is built there.

A field trip was made to Goba, on May 15th, 2013. A village meeting was organised, in which approximately fifteen local residents took part, among them the village chief, the local representative of MINAG, and the local forestry extension worker. The concept of the forest path was discussed, and the villagers expressed their support for the prospect of having it built in their area. The properties of the area were discussed and the villagers came up with two possible sites for the path. These were inspected. One was deemed almost ideal in view of the project. The next steps for the three projects were proposed in the mission report and they were subsequently agreed upon in correspondence. Among other things it was agreed that the IIAM team would produce a report on the planned forestry path and the resources available there, with the locals of Goba.

During the mission Finnish experts voiced a worry that too much of the implementation rested on too few shoulders in IIAM, and that the responsibilities should preferably be redistributed. The implementation also needs strong commitment from the directors, so that one of them clearly takes on responsibility.

During the third mission, from May 12th to May 20th, 2014, three days were spent in the village of Goba. As proposed in the previous report, the forestry path project had held a field seminar with the local people of Goba in November, 2013. During the seminar, the experts of IIAM, together with the villagers, produced a map of the potential resources of the forest area where the forestry path is planned. The work is reported in the IIAM paper Relatório de Diagnóstico das Potencialidades de Transferência de Tecnologias e Conhecimentos Florestais na Localidade de Goba (2013). The paper presents a floristic analysis of the most important tree species in the area, as well as culturally interesting sites that could be included in the path. Together with an earlier paper, Inventário Florestal de Goba, and the village development plan, O Plano de Maneio dos Recursos Naturais de Goba (2000), this paper lays a good foundation for the more detailed planning of the forestry path.

During the mission we continued discussions with the village leaders and the local forestry association Associação Ntava Yedzu representatives. The villagers again expressed strong commitment and will to proceed with the project. They hoped that the project would revitalise the association, which was founded after an FAO project in the area, but had lost much of its original impetus. For example the use of the remaining few forest resources for coal production was no longer controlled. Earlier, the association employed two people who ensured that coal production was only in designated areas. Now, the supervision had stopped, and during our field trip we saw several coal burners in delicate areas where coal burning is forbidden. They were not aware of the protected status of all areas adjacent to lakes and rivers. One of the main goals of the forestry path project is specifically to raise the awareness of local people regarding the acceptable use of forest resources in view of the sustainability of forestry.

We also examined the possible route of the forestry path from Lake Tchawene (Goba de la Fronteira) to Lake Boten (Goba) and took satellite navigation points along the route. It was noted that the path could easily be built mostly using already existing trails. Only in a few places did the trail need to be cleared of ground vegetation to make it safer or easier to walk.

The idea was to build demonstration sites along the path with information posters about the tree species and other local flora and fauna, forestry issues exemplified by the site, the relevant features of local geology and so on. In 2–3 places along the path simple shades would be constructed to offer visitors a scenic place for resting. In the demonstration sites, the principles of sustainable forestry in the local context could be explained and demonstrated verbally, pictorially, and also, in some cases, through practical examples.

At the time of this visit (May, 2014) the dirt road from Goba to Lake Boten was in a rather bad condition after an unusually wet rainy season, and apparently the condition of the road cannot be guaranteed in the future either. It was concluded that the path should start in Goba de la Fronteira, adjacent to the border station which is accessible along a tarmac road, and it should form a closed loop with the turning point at Lake Boten. The first leg of the path could be from Goba de la Fronteira to Lake Tchawen, following the lush river valley, and from there to Lake Boten along the dry forest which clearly exemplifies the local forestry type where the more valuable tree species have been mostly destroyed and is in need of reforestation. The last leg would be from Lake Boten back to Goba de la Fronteira, following the high trails in the hills over the river valley. This would make the length of the main trail some 5+ km, depending on the exact route chosen. The trail would be quite scenic, yet all the main problems and possibilities of the sustainable forestry could be readily demonstrated along it.

We visited two schools during the mission, Escola Primaria Completa da Goba (Headmaster Sergio Mathe) and Escola Secundaria de Changalane (Chef de la Secretaria Agostinho André), and discussed the possible forestry path project. One of the main ideas of the project would be to activate the local community so that they learn to recognise and understand the local forestry resources, and can identify the means by which a forestry resource could be restored from its current state, as caused by the earlier destructive forestry. The schools would be ideal partners for producing posters and other information materials along the path, but also through the internet. In the ideal case, the schools would have a partner school in Finland, where Finnish school children and Mozambican school children could compare their experiences of the forest and discuss forest use and sustainability in these two different geographic and social/economic contexts. The headmasters and teachers of the schools expressed great interest in the project and said that they would willingly participate. We also visited a private tree nursery in Goba and the district tree nursery in Changalane. It was agreed that the local tree species and their seedling production would be a good presentation topic along the forestry path.

The findings of the last mission were:

- It was obvious that in the photo archive project and development of the forestry portal, most of the risks anticipated in the second mission report had actualised and the projects had advanced too slowly since the last mission, however, the forestry path project had proceeded well. The local coordination group for the three projects had been established as proposed, and the group had met several times.
- Our local counterpart reported that the construction of, and content production for, the forestry portal had started and the new internet pages had been published in the spring of 2014, but the IIAM internet site was “hijacked” and the pages had to be closed down. Because backups of the institute’s pages were performed at overly-long intervals, the work done with the new pages was lost, but had been started anew. The material collected from the researchers for the new pages was not lost, however, so the material collection does not have to be repeated. The Technical Director said that the new pages would achieve operational status sometime during summer 2014. The collection of materials for the photo archive had also been started, but the input of the materials into the system had proceeded slowly, because the same person who is responsible for the development of the net pages, is also the only worker here, and was already overburdened by responsibilities.

Although the forestry portal and the photo archive project were late in schedule, the Technical Director assured us that they were proceeding, so no extra measures were needed. It was emphasised that it was imperative that the local coordinating group chaired by the Technical Director took a firmer hold of the projects. It would be advisable to allocate more human resources to them. In discussions about the forestry path project it was agreed that the forestry path would benefit the local community in many ways and the community is committed to it.

It was proposed that the forestry path project should be coordinated and headed locally by a person who is well acquainted with the people and conditions in the village. As there is one person available in IIAM who fit this description, Mrs Esmeraldina Cuco, and as the Technical Director was busy with preparing the photo archive and the net portal projects, responsibility for the forestry path project would probably be best given to Mrs Cuco. If that could not be arranged, it would not be advisable to proceed with the forest path project before the net portal and the photo archive projects were ready, because the forest path project will take even more time and effort than the forestry portal and the photo archive. The next steps of the forestry path project were discussed.

In correspondence during the summer and autumn of 2014 it became obvious that the forestry portal and the photo archive project had not moved from the situation in spring. There was correspondence for the forestry path project suggesting that one more mission would be made to the village before the beginning of the rainy season to finalise the forestry path plans in the field with the villagers before the end of the FORECAS project. This, however, did not happen, because the Finnish expert caught influenza at the critical moment and the mission had to be postponed so much that it was no longer feasible because of the wet conditions in the field.

5.3. Analysis of the situation as of the end of 2015

It is clear that the forestry portal has not moved from the phase when the structure was agreed upon. There has been some modest revamping of the IIAM's internet site, but the research partition that should contain the forestry portal has not been worked upon. The photo archive has not been built.

It seems that the commitment of the management, which was quite strong during the second mission in 2013 when the projects were agreed upon, was not as strong in the end, and the person responsible for both the photo archive and the forestry portal, was either not tasked with the agreed projects or was not able to perform them. This may reflect the fact that the personnel resources allocated to managing the internet functions at IIAM are too small for such a big organisation.

In the final evaluation report of phase 1 of the national Agricultural Development Programme PROAGRI (1999-2005) by PricewaterhouseCoopers in 2007, it was stated that in the extension component of the implementation of the national strategic program: "…the major concern is the lack of improved linkages between research and extension… research and extension services continue to have their own agendas and priorities. The lack of effective functional linkages results from an environment where there is a fragmented approach to decision-making and implementation. Generally there are no formal structures for coordinating the interaction between research and extension, either for planning or for evaluation…"

The situation remains the same. This reflects certain fundamental problems in the organisation, not only in resources but also in work culture and management procedures. Together they constitute a negative feedback circle. The lack of resources is an objective fact, but on the other hand, especially when there is a chronic lack of resources, it is important to maximise the social impact of research. This takes place only through communicative interaction with the users of the scientific information. This feeds positive resource development. Resource allocation for documentation, training, extension and other information dissemination should be an integral part of research project planning, and it should be in policy-driven balance with resource allocation to research itself.

In this case, however, the resources needed to perform the agreed development steps were small and it was agreed together that they were available in the organisation. It was thus probably the commitment of the organisation to the forestry portal and the photo archive that fell down.

This reflects a basic problem in project planning that should be taken into consideration in the future. All advances in the agreed measures took place immediately before, during and immediately after the visits of experts to the organisation. The long intervals between visits and the short period of their presence did not adequately support the motivation of the organisation and the commitment of the management. If a more continuous presence is not possible, it may be that through some arrangement, possibly with a local NGO or other actor, a continuous gentle "push" could be maintained. The need for this kind of "push-effect" is by no means peculiar to IIAM, but is typical of any organisation anywhere in the world, where some change is needed. The objective need for a forestry portal in IIAM is still there, the steps to produce it are known and simple, and the effort required is not large. It simply should be done. The same is true of the photo archive, which is a small but crucial tool for any big research organisation that strives for excellence, ease and cost savings in efficient research communication.

The planning of the forestry path component proceeded about as well as it could during the project period, with three short missions. The concept was introduced and discussed at IIAM and in the ministry, a suitable place for the path was identified by IIAM, and the local community expressed strong support, however, apparently because there was a later change of mind about the suitability of the location, the path was not included in the second phase of the project.

The forestry path as a concept would be a very good addition to the toolbox of forestry dissemination work in Mozambique, however, and similar tools are widely used in agricultural dissemination. Local forestry is in bad shape, and a path project would activate the villagers and make them again more conscious of the resource they have, and the need to take care of, and develop it. As part of the network of nature paths nearby, on the other side of the Swaziland border, the forestry path in Goba would offer visitors a different and more practical and socially and economically conscious view of local and wider African forest issues. Nationally, 2-3 similar paths in well-chosen locations and forest types would offer a valuable resource for the training of forestry dissemination professionals in sustainable forest management. Hopefully the idea can be revisited in some other connection.

6. Strengthening support services for forestry research including the baseline at the project outset

6.1. Research data management

Pauli Leppänen and Jukka Pöntinen

The objective of the task was to improve research data management. Functioning research data management forms the basis of successful long-term research. Especially in forest research, where data is collected over long periods of time, the documentation, storage, and access to data long after its collection is crucial. Data collection is also often undertaken by persons other than those who will analyse it, which is why data should be documented and stored so that it is complete and easy to access, even when it has been collected at different times and by different people. A data management system was created and developed through a pilot project, which also trains users in IIAM and UEM to create similar databases for future needs.

The common practice in partner organisations is that research data is kept on the laptops of individual researchers who do not always want it to be publicly available. The reuse of collected data requires data policy decisions at organisational levels. The continuous marketing of the benefits of reuse is required. A minimum level should be making descriptions or at least the locations of collected datasets publicly available.

Two training periods for research data management were arranged (in 2012 and 2013) in Finland for two persons (one from IIAM and one from UEM) to obtain basic skills to work with databases and build a database based on the forest research data collected in Mozambique. Much time was spent in learning the basics of databases and database programming. The quality of the data used in the training was a problem since the trainees who were not researchers themselves could only work with the data they were given to process. During the second training a laptop was prepared to 'act as a web server' to demonstrate database reporting. Some ten reports were developed. The principles of how to make new simple reports were learned, practiced and documented. The laptop was taken to Mozambique to be used in further (database and reporting) development and demonstrations to local researchers. The original idea to build a small operational database with basic reporting facilities for demonstrational purposes was not realised due the lack of real life data. The training had to be done on a general level.

The construction of a multiuser database and the software to query and update it will require the work of experienced professionals. Several years of database development and maintenance and several years of coding experience is needed for building applications. The two main participants in the project simply do not have enough time or professional support available to build information systems in a short time, however, working regularly creating database tables, organising, managing and querying data will provide a better understanding of what is needed and what is possible. This is a valuable asset in writing requirements for information systems and communicating with people coding applications full time.

The final workshop In Maputo in 2014 was aimed to "market" the idea and benefits of collecting data and organising it into databases. "Databases require long-time commitment and require continuous work, they are for organization(s), not for a single person" was the message that was emphasised. Two concrete ideas for future development were presented in the workshop:

- Geospatial data to be transferred to a geospatial server for an easier access, and
- A database of forest experiments, where basic information of experiments and their locations is easily found.

6.2. Information services

Americo Humulane and Jarmo Saarikko

6.2.1. Objectives of the task

The objective of the task was to improve information services (e.g. the library). Indicators associated with information services are 1) ”support services for forestry research in IIAM and UEM are developed to adequate level”, and 2) ”cooperation between IIAM / UEM and the end users increased”.

Research is long-term work that is based on existing research. There is much research information in the written reports, but finding it is a challenge for researchers and research institutions. Access to existing literature is often difficult, especially in developing countries. Finding all relevant national reports is also often very demanding.

Researchers need direct and easy access to all kinds of information, be it local, regional or international. The starting point is a library system with access to a wide range of information sources, both printed and electronic. Functional information systems mean the better and faster implementation of research projects. The total effectiveness of the research organisation improves, which can be seen in an increased number of research reports and citations.

A planning mission to Mozambique was conducted from 26–30 November 2012 to analyse the state of the current library services, the current level of knowledge and knowhow, and to make a practical and realistic assessment of the resources available. The objective was to produce, together with counterparts in Mozambique, a realistic and practical development plan for the library services. Organisations visited included IIAM/DFDTT, IIAM/CZS Forest Research Centre (CIF), IIAM/DARN, IIAM/GD, UEM/FAEF, UEM/Central Library, MINAG/CDA, WHO Maputo Office, MCT/STIFIMO-project, the Finnish Embassy, and the Kepa Maputo office. Altogether 23 people were interviewed or spoken with during the trip. The output of the activity was a development plan of library services, and a detailed plan for on-the-job-training, and the means of verification are IIAM and UEM annual reports, training and teaching reports, minutes of the meetings, lists of participants in different activities, and information included in the project web page.

A travel report (Metla DocID 313580) of the observations and recommendations of further actions was delivered February 2014.

6.2.2. Recommendations and further actions

The recommendations were combined into six groups, starting with the printed library collection, continuing to electronic collections and improving access to them, however, as several of these services need a functioning infrastructure so as to be operable, some action points are also focused on that.

Library collection development

The DFDTT should create a collection policy for the Institute that would cover both the printed and electronic collections. The policy would define how and what kind of material will be purchased, what material will be kept in the library collections and what material should be discarded and how. The policy should define the purpose and objectives of the libraries and how they would be maintained and resourced. The policy could describe the potential of the central library to serve the IIAM staff outside Maputo in the Zonal Centres and field stations. How is the collection managed? Should the literature in the offices be considered part of the collection and thus be registered in the library database? Should all staff publications be submitted to the library, either as print or electronically?

The collection policy should define who is coordinating electronic subscriptions and who handles all problems related to subscriptions. Usually this is the library.

Printed collections

Because there is no national repository library, all the agriculture and forest related books dealing with Mozambique, or printed in Mozambique or nearby countries with similar climates, and which are not available electronically should be kept in the IIAM Main Library as a national repository special collection. The repository function could be planned together with the UEM Central Library and UEM/FAEF.

If the IIAM main library was well-networked with the university libraries, then having one bigger library collection with proper and trained library staff instead of smaller specific libraries (animal science, forestry) should be considered. It is a current international trend to combine smaller libraries into larger units.

Joining the national library consortium

The IIAM library collection would benefit from collaboration with the UEM library collection. If the IIAM library joined the library consortium of higher education and research institutes, it would be possible to develop inter-library lending (ILL) between the libraries, which makes collection usage more cost-effective and provides IIAM researchers with better access to the larger university libraries, both in Mozambique but possibly also in neighbouring countries.

Library database

UEM and other libraries of higher education have updated their software from WinISIS to “abcd” which uses the same database format but is more developed. IIAM libraries should look into the option of updating their database to “abcd”. The library database could be hosted by the UEM Central Library as an online service. As the database would be accessed through the internet it would be possible to combine all the IIAM regional library databases into a single IIAM library database accessible from all IIAM locations. As the format is the same, it would still be possible to export the dataset for inclusion in the MINAG collaborative database.

ERM – Electronic Resource Management

The DFDTT/Documentation/IIAM Main Library should take on responsibility for the electronic resource management of the institute. This would mean coordinating or administrating the subscriptions and accounts to various electronic online services purchased or acquired by the institute, its units and projects. This information could be managed in electronic form as an access controlled Excel document, for example. Part of this service would be also to keep track of and report annually on the use of these resources.

Institutional Repository

IIAM has been participating in several national and international collaborations to create online repositories of documents. None of these were established or mandated by the Institute Directors as the official repository of the institute. Many institutional documents and publications are “published” by posting them on the institute website without accompanying bibliographic information, or connection to project or author information.

IIAM/DFDTT should consider establishing an institutional open access online repository for IIAM. The technical arrangement would be easiest to organise as part of the national multi-institutional repository in Mozambique, SABER, Repositório Científico de Moçambique, maintained by the UEM Central Library. This would be possible without additional payments. If the IIAM would like to establish the repository by itself, this could be done with the assistance and repository software from EMBRAPA.

All the publications of IIAM on the IIAM website should be moved to this institutional repository so that they can have proper bibliographic metadata and be indexed by library search engines, in addition to Google and others. All publications in the repository receive a permanent “handle” with which it would be easy to link to them within the IIAM website, publications or elsewhere.

Improved access to resources

The links to various e-collections, services and databases should be organised as a single starting point at the IIAM website, easily accessible from the home pages under the name “Biblioteca”.

Access to resources created in the IIAM would be promoted by creating an open access policy and posting all research publications on the institutional repository. The repository would thus form a registry of publications of the institute.

The search engine "Summon" by SerialsSolutions has become available to low-income developing countries at minimal or no cost, and should thus be implemented. This is an extremely valuable asset providing more targeted access to publications than Google Scholar.

Human resources – Knowledge manager

There is a clear need to have a person with a research background and some training in information and knowledge management to manage the large printed and electronic collections and the possible research support services that the IIAM main library would be able to provide to improve the quality of research. The easiest way to recruit at no cost would be to locate a researcher or other specialist within the IIAM who is interested and willing to change their work objectives to research support services. The institute could provide possibilities for additional training at university level. Similar recruitment has been done in KEFRI (Kenyan Forest Research Institute).

Training for researchers

Several courses were suggested to support library and research staff towards the better use of services. There are regular courses and scholarships available for training library staff. For example the International Network for the Availability of Scientific Publications (INASP), and its Programme for the Enhancement of Research Information (PERii) arranges such opportunities. Courses on electronic resources or scientific writing were suggested under the FORECAS project. The latter was accomplished in 2015.

ICT infrastructure

A rather simple way to solve many internet access and e-mail problems would be for the IIAM to join the governmental govnet.mz network coordinated by the Ministry of Science and Technology (MCT). The use of services created by the MCT/STIFIMO/Morenet project could provide better access for the regional offices and locations of IIAM. By joining the MCT/Govnet IIAM could provide each staff member with an official e-mail address for official correspondence with publishers, funders, and so on.

Forest research networking

The Food, Agriculture and Natural Resources (FANR) Directorate of the Southern African Development Community (SADC) have had programmes to fund various types of research development.

Networking with forest researchers – the International Union of Forest Research Organisations - Special Programme for Developing Countries IUFRO-SPCD and its African regional network FORNESSA have provided their member organisations with various types of professional training. The members are all forest research organisations and this thus provides an opportunity for IIAM forestry researchers to obtain better tools for collaborating with other forest researchers within the Sub-Saharan region and elsewhere, studying Mozambican woods and forests. The SPCD programme would provide support with the full cost of the membership fees. These networks may provide professional contacts to research support staff in other institutions.

Links to additional information

IIAM: http://www.iiam.gov.mz/
UEM/Central Library: http://www.dsd.uem.mz/
'abcd' software: http://www.abcdlibrary.com.br/?page_id=161
Repositorio Saber: http://www.saber.ac.mz/ [not accessible in January 2016]
EMBRAPA repositorio institutional Alice: http://www.alice.cnptia.embrapa.br/ (a working example)
KEFRI online repository: http://41.215.78.76:8282/ (a working example)
KEFRI knowledge management officer 2015: http://jobwebkenya.com/jobs/kefri-knowledge-management-officer/ (example of a job description)

6.3. Research management

Esperança Chamba, Veikko Möttönen and Sinikka Västilä

The objective of this sub-component in the FORECAS project was to improve forest research management. The execution of the research process requires the successful implementation of functional research management practices. Effectiveness and sustainability in research management also need strong commitment and support from the directors of organisations and institutional policy decisions. Primarily, training in the research management practices was through the regular follow-up of project progress and budgets.

Organisations can learn from the experiences of similar organisations. The exchange of ideas and experiences between personnel responsible for research policies, strategies and management is effective way to transfer good practices from one organisation to another and 'oil' them to work more effectively. It also serves as good tool to strengthen cooperation between organisations and creates a suitable starting point for continuing intercourse in joint research efforts. Networking with neighbouring countries with similar conditions is fruitful and improves the chances of finding research funding. Organising meetings with (research) managers in the partner country organisations and in the neighbouring countries increases the exchange of ideas and networking.

Under research management, two activities, a networking meeting and a benchmarking meeting, were arranged at the end of the project in 2015, aiming to establish regular contact between research organisations regionally and internationally.

A networking meeting arranged in Maputo was meant to bring together research directors and researchers from neighbouring countries in the south and east Africa region. In addition to Mozambican and Finnish representatives, a total of ten representatives from the neighbouring countries of Malawi, South Africa, Tanzania, Zambia and Zimbabwe attended the meeting. The aim of the networking meeting was that it would create concrete ideas - either domestic, bilateral or multilateral - for further co-operation. The ideas which arose during the discussion of country-specific presentations were:

- Enhance collaboration in forest productivity and wood research topics because conditions are similar across the region;
- The private sector needs greater exchange of existing results: some less known tree species are used in other countries;
- The private sector needs results to inform end users;
- In addition to wood-based products, exploring research on other sources from forests is also needed: leaves, mushrooms, edible plants, human and animal feeding, wild fruits and berries, biomolecules;
- Climate change effects;
- Site classification, areas that have values for wood production etc.;
- Cooperation of donors.

During the networking meeting, the following selected, potentially fruitful topics were also discussed:

- Example of the implementation of a long-term research project in Africa (FoodAfrica);
- Joint research projects;
- Exchange of the research results;
- Exchange of research data;
- Compilations of publication pool for non-peer reviewed working papers which are now lost in many cases; and
- Other exchange of experiences and good practices.

After the country presentations, a panel discussion was arranged. The pre-set questions for the panel discussion were:

- What were the most important joint research issues for all South-Eastern African agri-forest sector?
- What are the needs and possibilities for joint projects?
- What are the funding possibilities? National and international?
- Is there a possibility to gather and utilise common regional data, e.g. for growth models or for wood mechanical properties? The use of VMI permanent sample plot and/or ground truth sample plot information, jointly?
- How should existing research results be distributed and made available for all researchers and other users of information? Contacts and the exchange of literature with library services between countries and use, digitising and cataloguing so-called grey literature in different countries. A common literature database? This could be something in which international financiers were interested.
- What other means there are to promote everyday cooperation, e.g. joint courses, exchange of researchers?

The networking meeting panellists pointed out the vast area of miombo forests covering the region in South-eastern Africa. Joint research projects, for example, on the use of less-known tree species, land productivity, and the effects of climate change are needed. Joint efforts in capacity building and the exchange of existing research results were also seen as important. Research should also focus on the balance between the uses of agricultural and forest land. A new approach could be to study the use of forestry nature in the more sustainable way for the production of edible plants, animal feeding and food production. In addition to traditional wood-based products, new sources of nutrition and medicinal raw material, for example biomolecules, should be investigated. Possible sources for funding joint research projects were also discussed. In that regard, the cooperation of the donors is needed. The representative of industry in the panel pointed out the importance of the dissemination of research results, which are needed to inform customers and other end users, especially when launching new products made of less known tree species.

The benchmarking meeting arranged in Finland aimed to present the Finnish forest research, its different actors and ways of doing things, to the directors of Mozambican forest research institutes. An introduction to forestry and agriculture related research topics and laboratories at Luke's units in Vantaa and Jokioinen was given.

Both regional and national networking meetings are planned in the second phase of the project. It is planned to invite more industry participants to participate in the national and regional network meetings in the second phase of the project, which can be seen as activities for the dissemination of research results and technology transfer. In order to get joint research projects established, the national networking and regional networking between neighbour countries will also be supported in the second phase of the project.

The final project board meeting of the FORECAS project was arranged in November 2015 at the Luke Vantaa unit.

7. Conclusions and future vision

Esperança Chamba, Andrade Egas, Veikko Möttönen and Sinikka Västilä

The FORECAS project has been jointly implemented by the Agricultural Research Institute of Mozambique (IIAM), Faculty of Agronomy and Forestry Engineering, Eduardo Mondlane University (FAEF-UEM), and Natural Resources Institute Finland (Luke). The priority areas selected for FORECAS were partly defined in IIAM's strategy and in the research plan of UEM. They also arose from the direct needs of the research institutes IIAM and UEM.

The overall objective of the project was taken from the objective of sub-component 1.3 of the Support to National Forestry Programme in Mozambique (SUNAFOP) (2009-2012): "Improved information and knowledge on native tree species silviculture, forest management and wood industry, and better understanding on the role of forest management in climate change adaption and mitigation". The specified purpose of FORECAS was the "Strengthened capacity of IIAM and FAEF-UEM to conduct applied research applicable to local stakeholders, aiming at sustainable forest management in the use of natural forests". As a result, it was expected that both knowledge and tools could be applied directly to fulfill IIAM's and UEM's mission.

This project aimed to promote the potential of forestry research in selected research areas. The idea was that actual research work can be made more effective by using applicable research methods, but also by improving the support services and research administration. According to that idea, the project was divided into parts that deal on one hand with actual research work capability and the dissemination of research results, and on the other hand with the structures for supporting and administering research.

Three parts were created, each of them producing one result:

1. Research capacity of selected priority areas, growth and yield and wood science, improved
2. Capacity for information dissemination and technology transfer services improved
3. Support services for forestry research improved

This capacity building project included training activities to update and improve the knowledge of Mozambican researchers and other relevant stakeholders, and the provision of equipment and materials to conduct research considered in the project. Forest research in Mozambique thus aimed to achieve a better ability to respond to the demands of the Ministry of Agriculture, the private sector and local communities concerning the areas under this project. The project would also, in the long term, contribute to the environmental protection and well-being of the communities and the whole society of Mozambique.

The activities in Result Area 1 consisted of courses and on-the-job training in the selected priority areas. In relation to growth and yield studies, permanent sample plot series were established and measured, a dendrochronology laboratory was established, and courses/workshops on related topics (SPSS; statistics; data analysis; tree ring sampling and analysis) were organised. In relation to wood science, the wood technology laboratory was equipped with apparatus enabling the determination of the physical and mechanical properties of wood, as well as the determination of the anatomical characteristics of wood and the identification of tree species. Two courses (basic wood science; measuring techniques, instruments and standards) and two on-the-job training sessions (measuring techniques; analysing of wood properties) were arranged.

The activities in Result Area 2 consisted of one planning mission, and two workshops for developing information dissemination and technology transfer skills. In Result Area 3, one workshop on research data management and two on-the-job training periods on the creation and management of databases were arranged. For information services, a planning mission and courses on information (library) system, scientific writing and writing research proposals were arranged. A networking meeting and a benchmarking meeting were also arranged, related to research management.

The personnel of the partner organisations usually take part in many projects at the same time, or are at least preparing the next while participating in the ongoing. As a consequence, the timetable tended to stretch, which caused problems with the implementation of activities; however, the activities were mainly carried out according to the plan. The main problem of capacity building in support services for research (research data management and information services) is that database development, coding, and maintenance needs several years of experience. This would demand time and resources, and most of all the support of directors, in order to be implemented during this project. There was a lack of real Mozambican research data regarding capacity building in research data management, which could have been used in training sessions to make them more suitable for the partner organisations. In these cases, compensatory data was used and the training had to be done at a general level.

Another problem was the very slow and complicated procurement and delivery process of wood science laboratory equipment. Customs formalities in Mozambique differ from European practices. As a rule, the suppliers require an advance payment before the shipment of equipment, which is basically a risk for all partners. Smaller problems included a language barrier (Portuguese/English), sometimes poor ICT infrastructure, and problems in the practical financial and procurement issues, such as in the book keeping of the advance payments. The severity of these smaller problems decreased during the course of project. A permanent presence of local support would have lessened these administrative problems and probably also improved the commitment and the success of activities, but such support ceased when the Support to National Forestry Programme in Mozambique (SUNAFOP) ended.

Capacity building was strengthened through an improvement of the methodological knowledge base and infrastructure for research work. In addition, the need for short-term research results was combined by using the immediate research problems as cases in the training of researchers. Structures in data management and information services were improved, and alternatives and tested practices for research management were provided. Based on the achievements of the project, the chosen methods of capacity building were successful. The number of people trained in the various courses, workshops and on-the-job training sessions, and the commissioning of advanced infrastructure in their work indicates the improvement of the research capacity at IIAM and UEM.

The sustainability of the results achieved in FORECAS is dependent on the commitment of the key persons and directors of the institutes, and also on success in obtaining funding for research and development projects in the future. Joint projects between the institutions and companies in the wood industry sector and other stakeholders can create continuity in the development of research quality and knowledge capital. In this respect, regional and international networking is very important.

The cross-cutting objectives of the project were poverty alleviation, gender issues, environmental protection and good governance. The project has not had a direct effect on poverty alleviation, but indirectly, the improved knowledge of native tree species and their wood properties will enhance the use of natural forests and the local wood products industry, offering job opportunities. Gender equity was emphasised by promoting the incorporation of female professionals, stakeholders and decision makers in all capacity building activities of the project. Although there were participants from the both genders in many activities, the initial goal of at least 25% of women in each capacity building event was not achieved, because the proportion of women among the students and personnel in the partner organisations is low, especially in wood sciences. Good governance was practiced in project management by emphasising the role and project ownership of the partners, by clear rules in procurement and book keeping, and with open communication. The project had strong environmental focus. Enhanced knowledge about the growth and yield of miombo and mopane tree species allows for a better foundation for the sustainable management and the use of natural forests. The pressure on natural forests is high, and timber utilization is reliant on a few tree species with high commercial value. To reduce this pressure, there is a need to promote adequate use of all tree species available, by applying appropriate principles for a sustainable forest management.

Maintaining the capacity built during the FORECAS project requires a continuation of cooperation between Luke and the partner organisations. One of the main critical issues is the laboratory's ability to function and offer services to potential paying customers. To achieve this, the personnel of the organisations need to gain experience in joint research and development projects with the stakeholders. In the first phase, the partner organisations could solve targeted research questions arising from the wood working companies as small R&D and MSc student projects. The personnel in partner organisations need further training in research methodology, as well as in the dissemination and reporting of the research results.

The future priorities for cooperation should be targeted to the research capacity building of wood material and growth and yield issues related to less known tree species, and to improving the capacity for utilising the wood laboratory for research services to the potential customers. The networking of research organisations, governmental institutions and private sector (industry) should be promoted, especially in the eastern-southern Africa region. The awareness of decision makers of the sustainable use of forests should be improved.

Annexes

Permanent sample plot measurements

A manual for field work in the FORECAS project at IIAM in Mozambique

Compiled by: Bila, J., Chamba, E., Karlsson, K.

First edition: 1.7.2014
Revised:
Revised:

Introduction

A program for establishing permanent sample plots for growth and yield research was initiated in Mozambique more than ten years ago. The information from the first measurements of those plots has been used in reports, but only a few of the plots have been re-measured so far. The plots were located across the country, but the total number of plots is relatively small. Information from permanent sample plots can be used for growth calculation, but more data must be collected. The need for growth estimations, growth models or even traditional yield tables has been emphazised over and over again since the last NFI inventory was finalized in 2007.

The Finnish Forest Institute was engaged in the FORECAS cooperation project for developing research in Mozambique starting in 2012. Providing support for growth & yield research was set out as a main objective and the existing network of permanent plots was seen as a key element.

The FORECAS project has supported re-measurement of the existing plots, but the procedures for establishing and measuring new plots have been changed to some extent. The main principles have been to …

- keep the main plot outlines
- put the partial plots on fixed locations (not placed subjectively)
- register more classification variables…
    - stools
    - status
    - condition
    - stem/canopy – height classification
- do additional destructive sampling for volume, biomass and tree rings

The destructive sampling is done outside the permanent plots, and may actually not be related to the PSP network by location at all. Concession areas can be used for that work or any type of forest research areas as well. Selection of new plot locations and additional research sites is beyond the scope of this manual.

The new data should be compatible with the information collected previously. Still, the data will contain more detail, and good tools & some training will ensure more accurate measurements in the future. The manual is intended for permanent plots established for growth & yield purposes. However, the information is quite general and should provide the basic descriptions of forests and woodlands needed for most research topics and approaches. Technically speaking, the measurements are the same that are used in forest inventory – with a few exceptions only. Some manuals for forest inventory of dry tropical regions are listed as references. They contain additional instructions for forest land classification and other types of sampling and measurements that can be useful. It is always better to adapt existing definitions and procedures than inventing completely new ones. Here we have noted the most essential measurements needed for describing woodlands on the plot level.

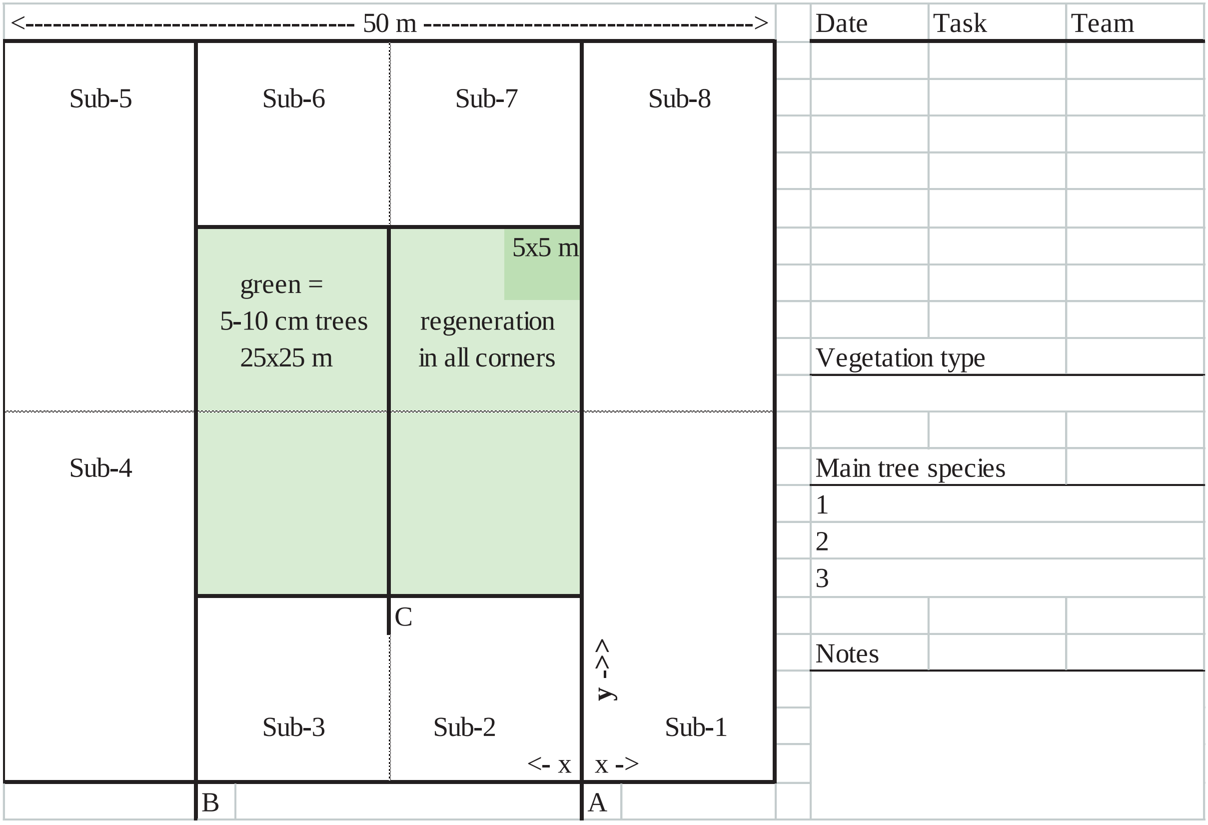


Figure 1. Plot dimensions and layout adjusted for new plot establishment. A and B are starting points for base lines along which measurements are done, one sub-plot at the time. C is the base line for the small tree plot. Letters x and y are indicating coordinate readings for tree position. Additional information can be entered on an “empty” drawing: like notes on the right, slope, base line heading, cross-plot measurements etc. etc.

Plot establishment and layout

Trees are recorded, mapped and measured, in the following manner:

- i) Main plot 50 x 50 m (sub-plots 1-8)
  - all trees ≥ 10 cm are recorded and measured
- ii) Small trees on 25 x 25 m (sub-plot 9-10)
  - all trees ≥ 5 cm are recorded and measured
- iii) Regeneration is registered on 5 x 5 m plots (sub-plots 11-14)
- iv) An optional plot 25 x 25 m may be marked for destructive sampling outside the main 50 x 50 m area

The outer corners and the baselines of the plot are marked with poles. GPS position is registered by circulating the main plot area and saving that trail separately to the disk. The trail leading to the plot from the main road or any well-known location can also be recorded and saved as a separate trail. The GPS information will be uploaded to a computer for storage and may be exported to GIS applications. Even relatively inexpensive GPS devices are capable of extra accurate positioning of waypoints and that feature can also be used for corner poles or the starting points of the base lines of the main plot.

Additional information should be marked on the drawing sheet, which is a schematic presentation of the plot area. Verify the positions of the different sub-plots. Also mark the compass direction of the base lines on the drawing, and indicate any slope degree & direction. Anything clearly notable should be marked on the drawing to make it easier to locate the plot on the next visit. Measuring the diagonal distance across the plot (if there is a Vertex) can be made to check that the plot is the right-angled. Plots that are not absolutely right-angled have different area coverage than 2500 m^2 and 625 m^2 respectively, and if so, the exact area can be calculated to get correct per-ha-values. Slope correction (for exact area) may also be considered, but it is not usually necessary for growth and yield studies. It may be considered if some plots are located on steep slopes, while others in the same plot network are on located in a flat terrain.

The measurements are made on one sub-plot at the time advancing along the base lines. A tree is on the plot if the estimated centre point of its base is inside the plot boundary. All live and dead trees within the sample plot's borders are recorded when the plot is established. Dead trees are usually measured and classified only on their first occurrence, not repeatedly. For growth and yield studies, dead trees are usually recorded if the stem is solid. It may be without bark at the DBH position, but should not show signs of further decay. Additional guidelines may be provided for dead trees and woody debris if biomass or carbon studies are made using the permanent plots.

Palms are recorded as trees, lianas (climbers) and bamboos are not registered on the plots. Species names are recorded in the field for all trees. If a tree species is unknown to the crew, the botanist or the team leader can take a photo of the particular tree and determine the species later. Samples of leaves, bark, flowers and fruits can also be collected for identification.

The main steps for measuring the trees are described for each variable on the data sheet that is used. Measuring diameter and height are the most crucial single tasks in this work.

DATA SHEET FOR TREES

Plot number, date & team leader on top of the sheet

Number of measurement

First (1), second (2), third (3) measurement, etc...

Sub plot

Number of sub-plot indicating tree locations within the main plot.

1-8	trees ≥ 10 cm DBH
9-10	trees ≥ 5 and < 10 cm DBH
(11-14	regeneration, < 5 cm DBH on separate data form)

Tree number

Tree number, starting from number 1

Stool

Number code that is indicating whether tree stems are the same individual (~coppice stems)

a) The stems are connected at stump height (above ground, below 1.3 m) or

b) The distance from a single stem to the others is less than 2-3 times the stem diameter (or maybe 0.5 m?)

Coordinates

Tree position within the sub-plot…

X, the distance right/left from base line (cm)

Y, the distance from plot or sub-plot border (cm)

Maximum value for Y is 50 m or 25 m depending on the selected reference line

Species names

Scientific and/or common name, if species is completely unknown, enter a code for the new spieces of just mark it as '?'

Technical quality

Code values according to classification, only applied on trees with 'Bole Height'

0 not applied
1 5m de bole sem curvature
2 5m ou infrior de bole com duas bifurcacoes
3 inferior a 5m com 3 curvaturas
4 ?
5 ?
6 ?

compare: Quality from NFI Kenya

1 Living tree, good quality long branch-free stem
2 Living tree, 50–70% of stem volume with economic potential.
3 Living tree, less than 50% of stem volume with economic potential
4 Dead tree (standing)

CONSIDER multiple stems above 1.3 m should be in noted with the 'Technical quality' class, multiple stems below 1.3 are registered with the 'stools' variable. Probably quite important!

Status

Code values indicating live/dead/missing trees according to classification…

0 live tree
1 dead tree
2 ingrowth (first occurrence in re-measurement)
3 stump
4 missing (in re-measurement)

Damage 1

Code values indicating condition of trees based their visual appearance…

0 no visible damage
1 tree top dead (dry)
2 large branches broken (also for main stem inside canopy)
3 ? <- OR leaning here?
4 stem broken (below canopy, above 1.3 m)
5 stem injury < 25% (of circumference)

6 stem injury > 25%
7 defoliation
8 curved stem (~bended towards ground) <-MAYBE leaning / tilted tree here?
9 root neck injury
10 tree fallen down or stem broken below 1.3 m

NOTE: trees may be live trees or dead, according to status code. Damage is usually registered only if some permanent effect on the tree condition is expected.

Internal damage by termites is estimated with codes 5-6 describing the signs on the tree surface analogously with 'injury'.

Damage 2

Code values indicating how the visual damage was caused…

0 not known
1 fire
2 human (logging, pruning, cutting)
3 animal
4 insects
5 fungi
6 abiotic (wind, drought)
7 competition

Cause may be specified by species name etc. in the 'remarks' column

Tree diameter, DBH (mm)

Tree diameter is measured over bark, at 1.3 m height above the ground with the exception of particular cases mentioned below. A 1.3 m stick should be used when determining the breast height up from the ground level. If a tree is leaning in flat terrain, the measurement point is at that side where tree leans (**Figure 1**).

Measurement may be carried out using a diameter tape or with the use of a caliper. Both devices should have metric scale and the smallest unit in millimeters. Diameter is recorded in millimeters.

If a caliper is used, the measurement is always carried out at right angles, also for non-circular shape trees, but care should be taken to avoid conscious bias in measuring irregular shaped trees. Make sure the caliper tightly holds the stem, in order to prevent the caliper clasps from grasping without compressing the bark.

Diameter tapes are best for irregular diameter trees to ensure consistency of measurements. If the diameter tape is used, make sure it is not twisted and is well stretched around the tree in a perpendicular position to the stem. Remove climbers and loose bark before taking measurements. Nothing must prevent a direct contact between the tape and the bark of the tree to be measured.

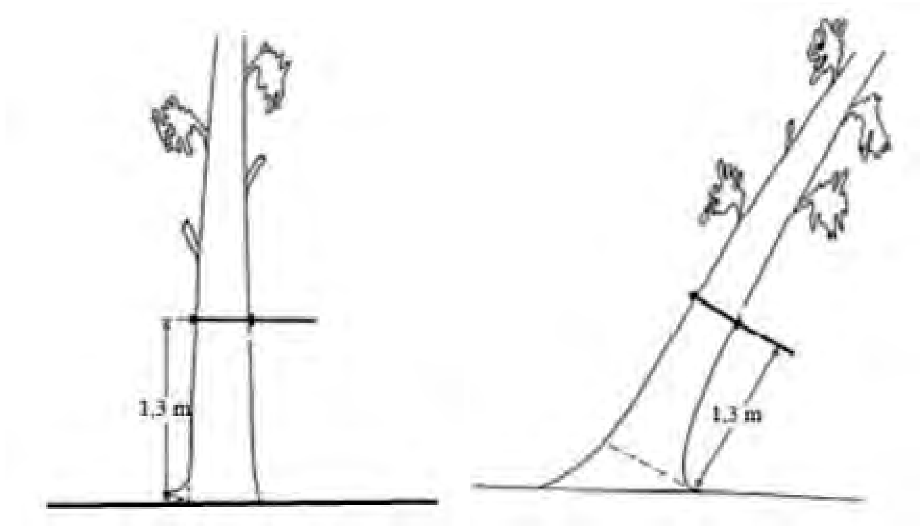


Figure 1. Diameter measurement in flat terrain.

When a tree is growing on slope, the measurement point is located at the upper side of slope (**Figure 2**).

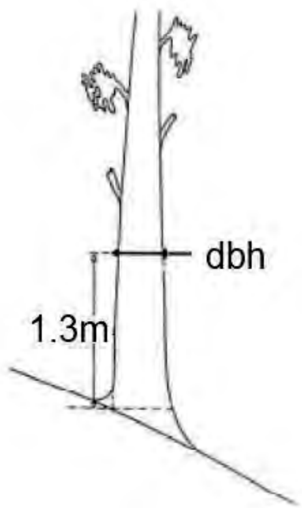


Figure 2. Diameter measurement of tree on slope.

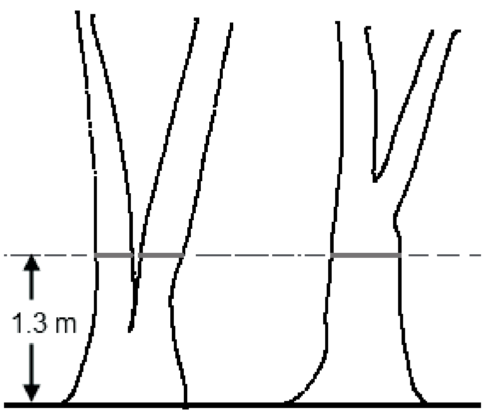


Figure 3. Diameter measurement points for forked tree**.**

DBH measurements of forked trees: The first thing is to determine the point where the tree forks.

a) If the fork originates (the point where the core is divided) below 1.3 m height, each stem reaching the required diameter limit will be considered as a separate stem to be measured, and the diameter is measured at 1.3 m height.

A fork can be dead or alive. Record this information with 'status' and if possible describe cause of death with damage classification.

b) If a fork originates at 1.3 m or a higher, the tree will be counted as a single tree. The diameter measurement is thus carried out **below** the forks' intersection point, just below the bulge that could influence the DBH. The actual point for measurement is marked and the height is recorded in the 'remarks' column.

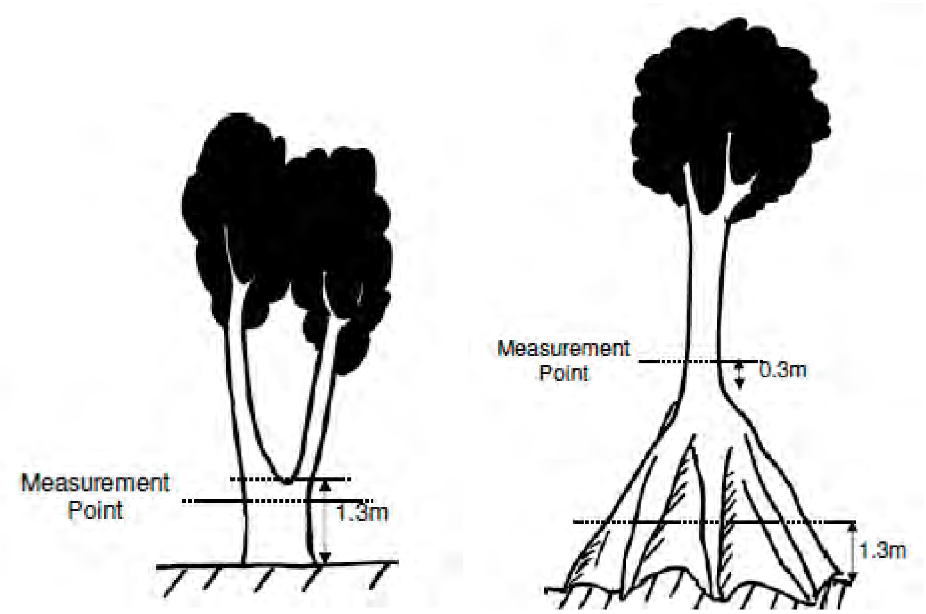
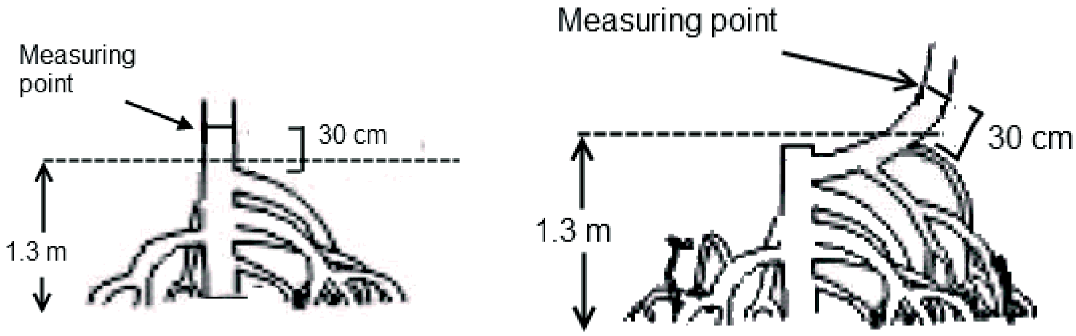


Figure 4. Examples of forks' intersection exactly at the 1.3 m height (left)

Figure 5. Diameter measurement of a tree with large buttress (right).

Trees with an enlarged stem base or buttressed tree: diameter measurement is made at 30 cm above the enlargement or main width of buttress, if the buttress/enlargement reaches more than 90 cm height above the ground (see Figure 17).

Trees with aerial roots exceeding 130 cm from the ground: diameter is measured 30 cm above the upper root (see **Figure 6**). Among *Rhizophora* genus (mangrove) there are some species which usually contain prop roots above 130 cm from the ground. Some upper roots are well established in the mangrove mud, while others have just started forming, or are formed from within the canopy. Therefore only roots originating from the central stem and touching the mangrove soil or permanent water body are considered, when pointing out the 'upper root'.



a) Growing mangrove stem b) Cut mangrove stem

Figure 6. Diameter measurement of a tree with aerial roots**.**

Trees with irregular shape at 1.3 m level: Trees with bulges, wounds, hollows and branches, or other reasons causing irregular shape at the breast height, are to be measured above or beneath the deformation - the actual point of measurement is marked and the height is recorded in the column 'remarks'. The diameter of a tree with a horizontally protruding stem should be measured 1.3 m along the stem, even if this is less than 1.3 m above the floor. A case of damaged and broken stem where the DBH measurement is done below 1.3 m is presented in **Figure 7**.

CHECK: horizontally protruding tree?

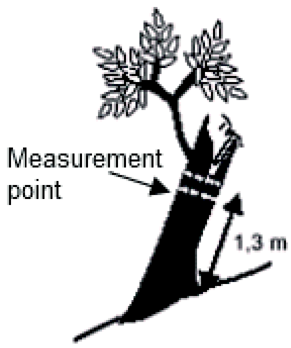


Figure 7. Diameter measurement of damaged and broken stem.

Bole height (dm)

Bole height refers to the merchantable height that is defined as the distance from the base of the tree to the first occurrence of branching or some other defect. Bole height is recorded in decimeters and measured only on trees with a DBH $\geq$ 20 cm.

CONSIDER: is DBH 20 cm a suitable limit?

Total height (dm)

Total height is measured from the seeding (base) point to the top of the tree. If the seeding point is higher than the ground level (e.g. in case where a tree growing on the top of a stone), the tree height is measured from the seeding point. Total height is recorded in decimeters.

Tree height measurement may be carried out by means of several instruments. The Suunto hypsometer and a Haglöfs Vertex are used by the field teams. Additionally, a 5-10 m (telescopic) pole may be used for ‘Bole Heights’ and the total heights of small trees.

The Vertex device is using the same principle as the Suunto hypsometer, but does some calculation based on the location of a transponder, which is placed at the reference point (usually at the base of the tree and 1.3 m above the base/seeding point). A quick guide for using the Vertex is included in Appendix 2. The full manual is available in English and should be consulted for calibration procedures and advanced settings.

The distance from the tree (or reference point) and viewing angles must be carefully selected in different situations in order to achieve accurate height values. Team members should get training using trees with known heights and located in different surroundings.

Classification for additional ‘height’ description

1) visible top or main stem in canopy, stem straight and canopy symmetrical, trees with clear main stem and branches
2) no top or main stem visible in canopy, stem up-right (short), canopy symmetrical (wide; rounded or flat)
3) stem clearly bending off and/or canopy asymmetrical (one-sided; rounded of flat)
4) very irregular stem and branching, horizontally growing trees, also trees with stem broken above 1.3 m

Classes 1-2 are dominant trees in the canopy layer. Class 3 trees are usually suppressed trees and/or coppice trees. Note that, measured ‘tree height’ is close to ‘main stem length’ only for class 1 trees.

All trees may be tilted by some external force like wind or elephants etc. Exact height determination should then include a correction based on the leaning (Figure 10c).

Trees fallen down are classified and measured “as if standing up-right”, but with the damage code=10 and actual live-dead status.

Trees that do not have a clearly visible top are measured for **‘canopy height’** rather than tree stem height. The ‘height’ determined is the vertical distance between ground and top canopy outline (additional photos or illustrations, Appendix 3).

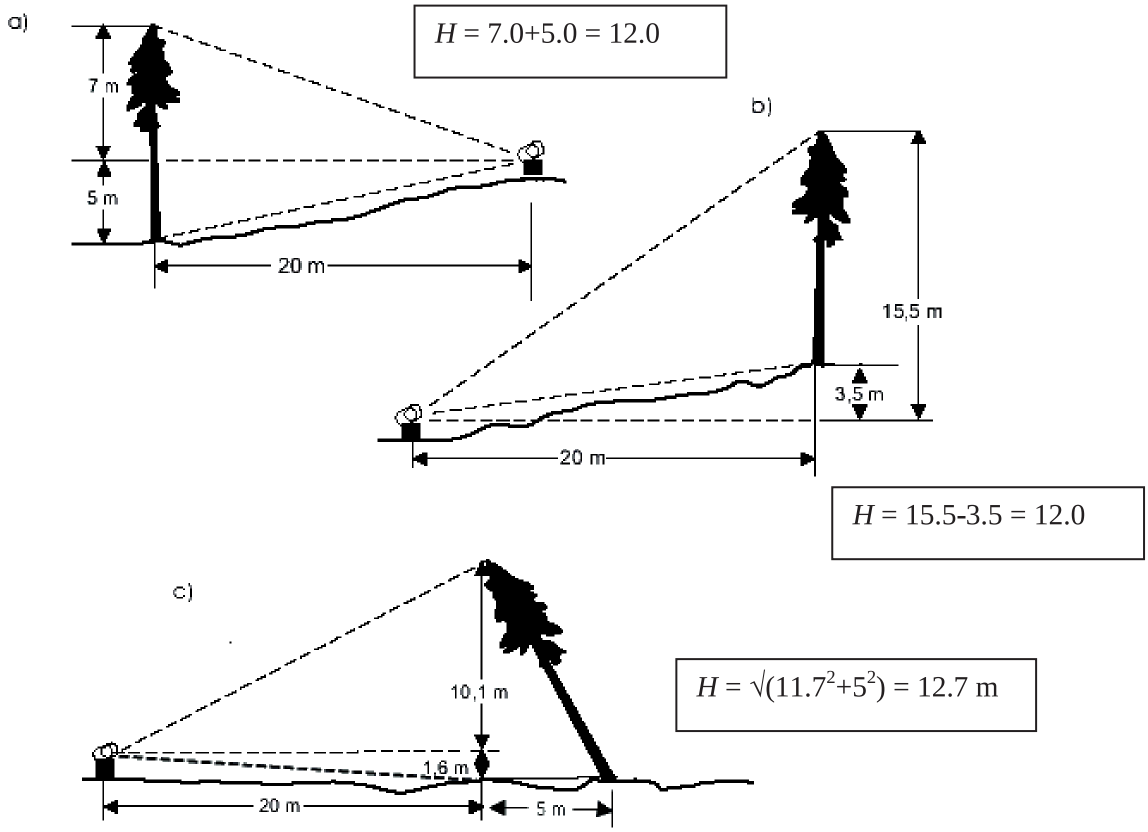


Figure 8. Tree height measurements with a Suunto device.

Notes on Figure 10: You can get the height of a tree…

a) By adding the results above and below the horizontal measurement (7.0+5.0)*;*

b) By subtracting from the total the difference between the base of the tree and the horizontal line (15.5-3.5);

c) By applying the Pythagorean theorem. Measure first the height of the tree top, then measure the horizontal distance from the stump point to the top point projected on the horizontal level. Apply equation: $H = \sqrt{(\text{Height}^2+\text{Distance}^2)}$

Re-measuring the permanent plots

Re-measurements should be done 5 to 10 years after plot establishment or previous measurement. The existing information is printed on a tree data sheet with additional empty space for the new information. It is essential that the data has been checked in detail for actual errors and also for illogical combinations of values. Suspicious values should be high-lighted on the form to enable checking in the field. The old data may have circumference instead of DBH, so that must be altered if the present way of measuring is ‘diameter’.

The first thing to do when the old plot has been located is to check how the sub-plots are situated. Re-measuring may be a waste of time and efforts if there is uncertainty in sub-plots and tree locations. The individual trees must match for the new measurement compared to the previous one. Uncertainty may be accepted for just a few trees on the plot. You constantly need to compare the new values with the old ones. Old values should be corrected if errors are found – high-light the value, put the “best possible correction” in the ‘remarks’ column.

Empty tree data sheets are needed for new trees, i.e. trees that previously were smaller than the diameter limit given for the plot. New trees are coded with status = 2 and given numbers incremented from the highest existing tree number. However, trees on the small-tree-plot (previously < 10 cm), that now have passed the 10 cm limit, do no need to be re-coded and entered into the main plot data set. They are just re-measured. All completely new trees should be entered with a full set of measurements.

Usually, there is no need to measure trees that were already dead the previous time. Diameter and other columns may be left empty for trees noted as dead in the previous measurement. Previously live trees that have died should be measured and the diameter should logically be larger or at least the same as before. The actual diameter may not be correct if the bark has fallen off or if the stem is injured. In these cases, the old value should be entered as the present diameter. The principle is that no “negative growth” is registered. Mortality is recognized only with changes in the number of trees, not by dimensions getting smaller.

The need to measure new values of the height of trees must be determined separately on each plot. Mature trees probably grow mainly wider and not at all taller. Small trees and trees in newly opened canopy space may have a clear and rapid height development.

Diameter point at 1.3 m should be marked clearly, and the painting refreshed at re-measurement, or even more often if someone is visiting the plot. It should be possible to locate the 1.3 m mark relatively well if the paint has disappeared, therefore, always use a 1.3 m stick to locate ‘breast height’. Any other BH used must be noted in the ‘remarks’ column.

References:

Manual for integrated field data collection. Forestry Department, FAO, NFMA Working Paper No.37/E Rome, 2012, 175 p.

NATIONAL FORESTRY RESOURCES MONITORING AND ASSESSMENT OF TANZANIA (NAFORMA). Field Manual, Biophysical survey. NAFORMA document M01-2010, 96 p.

Field Manual, Biophysical Pilot Survey, IC-FRA Kenya document, August 2013, 82 p.

Appendix 1a. Field form for TREES, used on both main plot and small-tree plot. The printed data sheet for field use should have larger cells for writing in values.

1	Time	Sub	Tree	Stool	X (cm)	Y (cm)	Species		Quality		Damage		DBH	H	Height	Bole H	Remarks
2	N°	N°	N°	N°	Dist.	Dirc.	N. vernacular	N. cientifico	Status		1	2	(mm)	cl	(dm)	(dm)	
3																	
4																	
5																	
6																	
7																	
8																	
9																	
10																	
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25																	
26																	
27																	

Appendix 1b. Data form for a permanent plot established in the Moribane forest 2013. Note the use of the 'stools' variable – same number for stems connected (stool 22 maybe an error).

1	Time	Sub	Tree	Stool	X (cm)	Y (cm)	Species		Quality		Damage		DBH	H	Height	Bole H	Remarks
2	N°	N°	N°	N°	Dist.	Dirc.	N. vernacular	N. cientifico	Status		1	2	(mm)	cl	(dm)	(dm)	
3	1	1	1	1	1.4	0.3		HM-910	4	0	9	6	16.0		12.0	4.0	
4	1	1	2	1	1.7	0.3		HM-910	4	0	9	6	26.0		13.0	4.0	
5	1	1	3	1	1.7	1.0		HM-910	4	0	9	6	17.5		10.0	3.5	
6	1	1	4		4.4	2.3	Mupepera	Pteleopsis myrtfolia	3	0	9	4	38.0		27.0	4.0	
7	1	1	5		4.9	5.8	Mupheia	Markhamia obtusifolia	3	0	9	4	14.1		10.0	4.0	
8	1	1	6		7.1	2.1	Mupheia	Markhamia obtusifolia	4	0	9	4	11.6		9.0	3.0	
9	1	1	7	7	0.6	8.0	Mudjerenge	Albizia adianthfolia	4	0	9	1	40.2		26.9	4.5	
10	1	1	8	7	1.0	8.3	Mudjerenge	Albizia adianthfolia	4	0	9	1	63.1		26.9	4.5	
11	1	1	9	9	1.8	9.0	Mussara	Millettia stuhlmannii	3	0	0		19.0		12.0	5.0	
12	1	1	10	9	2.1	9.3	Mussara	Millettia stuhlmannii	3	0	0		34.4		13.0	3.5	
13	1	1	11		8.4	9.0	Mudjerenge	Albizia adianthfolia	3	0	1	0	15.8		8.0	5.0	
14	1	1	12		10.9	9.8	Mupepera	Pteleopsis myrtfolia	4	0	0		33.5		12.0	6.0	
15	1	1	13		11.1	9.9	Mupepera	Pteleopsis myrtfolia	4	0	0		32.1		17.0	6.5	
16	1	1	14		0.7	11.0	Mussara	Millettia stuhlmannii	3	0	0		19.5		15.8	6.0	
17	1	1	15		0.6	12.0	DS-1		3	1	0		35.4		11.5	5.0	
18	1	1	16		10.6	20.7	Mupepera	Pteleopsis myrtfolia	3	0	0		29.0		11.0	5.0	
19	1	1	17		11.6	20.9	Muphungo		4	0	5	4	49.0		5.4	5.4	
20	1	8	18		10.6	2.2	Mussara	Millettia stuhlmannii	3	1	4	4	24.2		9.0	4.1	
21	1	8	19	19	1.1	8.2	Mussara	Millettia stuhlmannii	2	0	0		26.1		15.0	4.5	
22	1	8	20	19	1.4	8.1	Mussara	Millettia stuhlmannii	3	0		4	10.3		8.0	4.0	
23	1	8	21	19	1.3	8.3	Mussara	Millettia stuhlmannii	3	0	0		25.1		15.0	4.5	
24	1	8	22	22	4.1	9.9	Mussara	Millettia stuhlmannii	3	0	9	4	19.1		10.0	5.0	
25	1	8	23	22	9.3	10.9	Mussara	Millettia stuhlmannii	3	0	0		13.3		9.8	3.0	
26	1	8	24		9.4	12.3	Muparanhanga		3	0	0		13.2		9.0	3.0	
27	1	8	25		5.7	13.3	Mudjerenge	Albizia adianthfolia	3	0		4	43.7		13.0	5.0	

Appendix 1c. Same data form as in Appendix 1b, but now prepared for re-measurement.

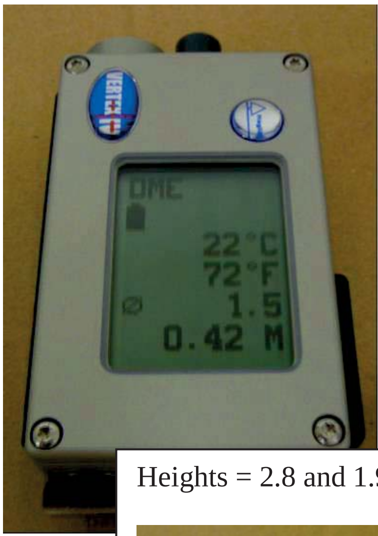
1	Time	Sub	Tree	Stool	X (cm)	Y (cm)	Species		Quality		Damage		DBH	H	Height	Bole H	Remarks
2	N°	N°	N°	N°	Dist.	Dirc.	N. vernacular	N. cientifico		Status	1	2	(mm)	cl	(dm)	(dm)	
3	1	1	1	1	1.4	0.3		HM-910	4	0	9	6	16.0		12.0	4.0	
28	**2**	**1**	**1**	**1**	**1.4**	**0.3**		**HM-910**									
4	1	1	2	1	1.7	0.3		HM-910	4	0	9	6	26.0		13.0	4.0	
29	**2**	**1**	**2**	**1**	**1.7**	**0.3**		**HM-910**									
5	1	1	3	1	1.7	1.0		HM-910	4	0	9	6	17.5		10.0	3.5	
30	**2**	**1**	**3**	**1**	**1.7**	**1.0**		**HM-910**									
6	1	1	4		4.4	2.3	Mupepera	Pteleopsis myrtfolia	3	0	9	4	38.0		27.0	4.0	
31	**2**	**1**	**4**		**4.4**	**2.3**	**Mupepera**	**Pteleopsis myrtfolia**									
7	1	1	5		4.9	5.8	Mupheia	Markhamia obtusifolia	3	0	9	4	14.1		10.0	4.0	
32	**2**	**1**	**5**		**4.9**	**5.8**	**Mupheia**	**Markhamia obtusifolia**									
8	1	1	6		7.1	2.1	Mupheia	Markhamia obtusifolia	4	0	9	4	11.6		9.0	3.0	
33	**2**	**1**	**6**		**7.1**	**2.1**	**Mupheia**	**Markhamia obtusifolia**									
9	1	1	7	7	0.6	8.0	Mudjerenge	Albizia adianthfolia	4	0	9	1	40.2		26.9	4.5	
34	**2**	**1**	**7**	**7**	**0.6**	**8.0**	**Mudjerenge**	**Albizia adianthfolia**									
10	1	1	8	7	1.0	8.3	Mudjerenge	Albizia adianthfolia	4	0	9	1	63.1		26.9	4.5	
35	**2**	**1**	**8**	**7**	**1.0**	**8.3**	**Mudjerenge**	**Albizia adianthfolia**									
11	1	1	9	9	1.8	9.0	Mussara	Millettia stuhlmannii	3	0	0		19.0		12.0	5.0	
36	**2**	**1**	**9**	**9**	**1.8**	**9.0**	**Mussara**	**Millettia stuhlmannii**									
12	1	1	10	9	2.1	9.3	Mussara	Millettia stuhlmannii	3	0	0		34.4		13.0	3.5	
37	**2**	**1**	**10**	**9**	**2.1**	**9.3**	**Mussara**	**Millettia stuhlmannii**									
13	1	1	11		8.4	9.0	Mudjerenge	Albizia adianthfolia	3	0	1	0	15.8		8.0	5.0	
38	**2**	**1**	**11**		**8.4**	**9.0**	**Mudjerenge**	**Albizia adianthfolia**									
14	1	1	12		10.9	9.8	Mupepera	Pteleopsis myrtfolia	4	0	0		33.5		12.0	6.0	
39	**2**	**1**	**12**		**10.9**	**9.8**	**Mupepera**	**Pteleopsis myrtfolia**									
15	1	1	13		11.1	9.9	Mupepera	Pteleopsis myrtfolia	4	0	0		32.1		17.0	6.5	

Appendix 2. Quick guide for using the Vertex height meter device.

What you <u>must</u> know…

0. transponder on / off
1. calibration (see manual) check every day when starting – more often if changes in environment

Distance = 0.42 m



2. distance quickly (device flat in your hand)
    a. transponder is on
    b. device is off
    c. point to transponder
    d. press < DME
    e. read m at the bottom
3. height measurement (device upright)
    a. transponder is on
    b. device is off
    c. press ON >> HEIGHT is selected
    d. aim at transponder, press ON
    e. aim at tree top, press ON
    f. aim at next height (bole), press ON
    g. etc.
    h. read heights H1, H2, …
    i. press both < arrows > for new measurement (if device not powered-off)
    (that is the same as ”one level up” and ”power-off” on top level)

Heights = 2.8 and 1.9 m

Transponder location (default 1.3 m) can be changed, also pivot-value (see manual)

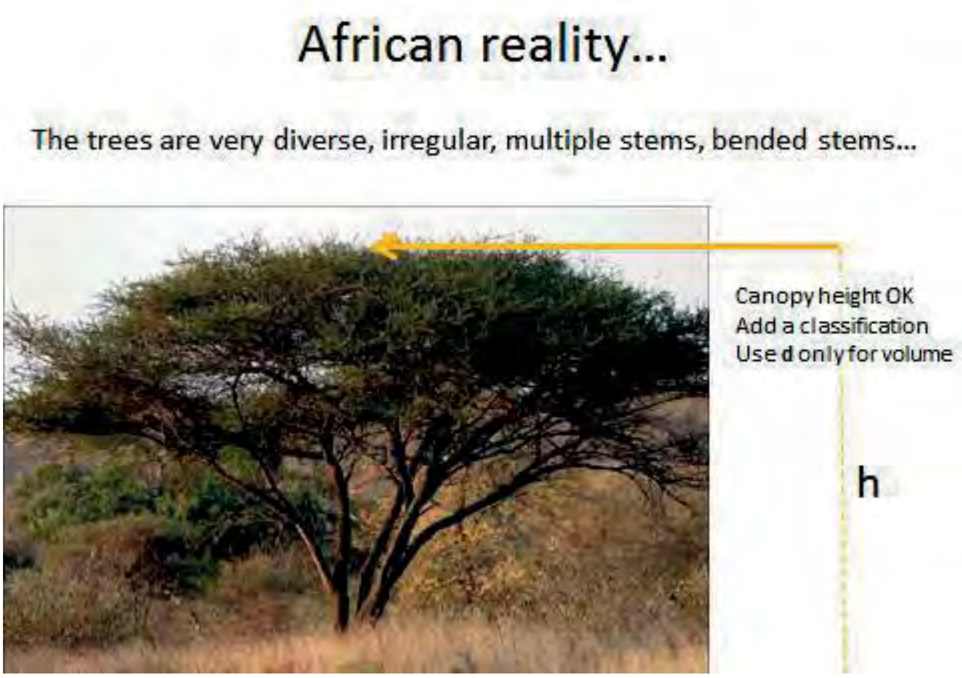
Other features, advanced model (see manual)..,

- Minimum diameter function for relascope plots
- Bluetooth connection to other devices (field computer)

Transponder does not consume much battery, but it does not switch off automatically

Device will turn off automatically –> low battery consumption

Appendix 3. Illustrations of height growth patterns.



…also indicate multiple stems on the data sheet.

Large ‘Umbila’ species trees with relatively clear tree tops…

Destructive sampling for determination of volume and biomass of trees

A manual for field work in the FORECAS project at IIAM in Mozambique

Compiled by: Bila, J., Chamba, E., Karlsson, K.

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Introduction

Allometric volume equations are used in the estimation of tree volumes on permanent sample plots. The volume increment of trees is calculated as the difference in volumes between two consecutive measurements, usually with a 5 to 10 years growth period. It is important to have unbiased and reliable volume equations because the volume estimation will influence the increment determination, not only the amount of wood, e.g. the growing stock. Initial studies of existing allometric volume equations for dry tropical woodlands show a large degree of variation for the estimated values depending on the models used. The variation is related to tree species and geographical location but it has not been possible to model this variation for prediction purposes. There are obviously also some differences in the definitions of the woody compartments that are estimated with the equations. The methods used have not always been adequately described in publications, but there seems to be some differences in the methods used in data collection and analysis in different studies. Therefore, there is the need to adopt clear definitions and concepts for developing new volume equations, as well as standardized methods for data collection, measurements and analysis.

Increased concern for the terrestrial carbon balance and activities related to REDD initiatives are requiring more information of biomass and of the carbon pools of forests and woodlands. Some new allometric equations have been made for biomass estimation - also within Mozambique, but the needs for improvements are still similar to what we see regarding volume equations. The obvious solution is be to determine both volume and biomass (carbon) using the same data, e.g. measurements from exactly the same trees. This would allow for an exact conversion between the two quantities.

Determining biomass and volume of trees is very complex and time consuming. The traditional forest mensuration approach would include detailed measurements of stem sections, separation of sapwood, heartwood and bark, and sometimes detailed descriptions of the canopy architecture (the branching). This manual is presenting a somewhat simplified way for determining volume and biomass. Still, all relevant woody compartments are measured separately, and results may be calculated for each compartment or any combination. The present work is limited to the above ground compartments, but below ground parts can be included when resources allow for it.

The methods described here have perhaps mainly been used in Finland and Europe for coppice forests and small size trees harvested for bioenergy utilization. The same approach seems to have been used in studies in African regions and the FAO guidelines are also similar. Using and adapting this type of measurements for Mozambique is based on the idea that many tree species of the natural miombo and mopane woodlands have very irregular growth patterns. Trees often have multiple stems, sometimes only short regular stems – and stem taper is not very essential in describing the tree. The amount of wood may also be very large in branches compared to the main stem. Timber is cut using only a few species and from very large trees, DBH > 40-50 cm. The amount bark does not matter very much. On the other hand, the amount of wood per diameter class is quite important, even down to the 2 cm limit for branches and on all sizes of trees.

The presentation is dealing only with the measurements of single trees. The number of trees needed for research, also the selection of the trees, as well as the selection of study areas is beyond the scope of this publication.

Notes on the approach

Data will be collected on both biomass and volume. Mass determination - weighing - will actually be used as a simple way on estimating the volume of small stems and branches and also for irregular tree parts (Table 1). In order to produce data for biomass equations, some samples need to be dried at 105 degrees in an oven. That may be difficult to achieve due to long distances from the field to the lab, and also because of limited resources in general. However, weighing branches, stem sections and samples out in the field is relatively easy and accurate, so the methods can be used even if the dry biomass eventually cannot be measured.

Table 1. An outline indicating how the quantities of different compartments will be either measured directly or converted using density (sample piece for fresh mass and volume).

Compartment	volume		fresh mass
leaves, flowers & fruits	no		x
small branches		«	x
large branches	x		x
main stem			
regular (small-medium)	x		x
all irregular shapes		«	x
large stem pieces	x	»	
below ground	…		…
x = measured quantity			
« using technical density for conversion			
no separation of bark and wood			

Only the below ground parts of trees are not yet included in the measurements. The results can be calculated for all woody parts separately or combined and also separated by main stem and branches. 7 cm is used for separating large branches from small branches. That is the same limit as recommended by the FAO, but additionally two other diameter limits are applied. The low limit of 2 cm diameter has been used in some studies in Africa for defining ‘total tree volume’. The higher limit 12 cm diameter is introduced here in order to make the measurements less laborious.

A list of compartments and the codes used on the data sheet:

Code	Compartment
A	Stump
B	**B**ole
C	All stems, from bole to d=12 cm
12	12 cm > d > 7 cm
7	7 cm > d < 2 cm
2	d < 2
D	**D**ead branches
E	L**ea**ves, flowers
F	**F**ruits, cones, pods

Initial procedures

Once a tree has been selected for cutting, it should be measured still standing up and according to the manual for PSP measurements. The actual PSP data sheet is used. It may be necessary to measure a complete 25 x 25 m plot if additional information is needed to support the data from the destructive sampling. That may be the case if tree rings are to be analyzed for increment assessment and modeling.

The 1.3 m position should be marked clearly around the stem before felling the selected tree and the felling area should be cleared from vegetation and obstacles that may interfere with the cutting of the sample tree. It is good to examine the tree in order identify the main stem before it is felled. If possible, some digital photos should be taken of the tree. A clear view is needed so that growth pattern, canopy architecture and morphology are revealed by the photographing.

Sampling & measurements, overview

1. Cut the tree
2. Mark the main stem, find the top
3. Collect leaves etc.
4. Cut 2 cm branches – weighing – measure sample branches
5. Cut 2-7 cm branches – weighing – measure sample branches
6. Cut 7-12 cm branches – weighing – measure sample branches
7. Cut >12 cm branches – arrange, sample – measure and weigh – measure lab-samples
8. Additional marking of the stem
9. Cut stem sections – diameters – weighing – measures sample discs
10. Dead branches set aside earlier – weighing – measure sample pieces

Sampling & measurements, step by step

After felling, the main stem should be finally determined and made clearly visible. Any foreign branches and debris should be removed from around the sample tree. The length of the top of the main stem < 2 cm will be measured. Then, it is cut and included with the 2 cm branches for bulk mass determination.

The real sampling is then started with the collection of leaves – fruits – smallest branches (2 cm) more or less simultaneously. Leaves & fruits will go into containers and the mass determined as soon as any container gets full. Best suitable scale should be used. The branches can be put into containers or bundled for weighing. The mass of the empty containers (also any bundle material) can be registered separately and entered on the data sheet OR the ‘tare function’ of the digital scales may be used if that option is available and found suitable. Data sheet for BULK MASS determination is used.

These compartments of the tree are very sensitive to drying out, so the work should proceed rapidly and it is best done in shade. It is also good if the material can be kept off the ground with tarpaulins and also covered by tarpaulins in case of rain.

If dead branches are encountered, they can be cut off and stored at a separate location. They will be weighed and sampled at the end of the work, since they are not so sensitive to drying out.

When all bulk masses of the 2 cm branches are registered, sample branches (5-10) will be selected and cut into 20-30 cm pieces for mass & volume measurements. The data sheet for SAMPLE PIECES is used. Some of the samples will be bagged & labeled for lab processing.

> *The 'water immersion' method should be used for volume measurements. The readings are taken from the scale. 1 g water equals 1 ml of volume so the results are quite accurate. A regular 'water-displacement' method results in readings of 10 ml on a narrow 2 liter vessel, so it is not so good. Measuring dimensions (diameter x length) and using formulas for geometrical shapes will give reasonably good values only on large and regular shaped objects.*

The work will proceed with the cutting of 2-7 cm branches, still continuing leaves-fruits collection if needed. Best not to start this until all 2 cm sample branches have been measured. Samples (5-10) of the 2-7 cm branches will be selected, when all of the bulk mass has been registered. One about 15 cm long piece of wood should be cut from "both ends" of the branch for mass & volume measurements, and yet one more in the center. Some of the samples will be bagged & labeled for the lab processing.

The procedure is repeated in a similar way for the 7-12 cm branches. The sample pieces may now be about 10-15 cm long, again from both ends of the selected branches – largest and smallest diameter.

NOTE: the length and number of the small sample pieces may need to be adjusted, so that the fresh mass is at least 200-300 g for each sample. Each sample must contain parts of the branches with varying diameters, but the pieces are about equally long.

CONSIDER: the number of sample branches? 5-10 for fresh mass, 3 to the lab?

Final stage of canopy compartment measurements: Branches larger than 12 cm will be measured individually after cutting them into suitable size pieces. 2 m may be set as main length. All pieces can be cut, laid out a tarpaulin and arranged approximately by size 'small-to-large'. From this set of organized branches lab-sample branches (3) can be selected systematically.

Diameters and length are measured, also mass determined for the whole individual piece. Data will be entered on the data sheet 'BRANCHES 12 cm'. The procedure with a sample piece measurement may be applied if the branch is too heavy for weighing in full size. Branches with very irregular shape may get the volume by estimation from the technical density of other branches (average) rather than basing it on obscure figures of length and diameter. This should be noted on the data sheet. Sample discs should be cut and measured from the large branch pieces selected at the beginning of this stage.

Guidelines for cutting discs:

d (cm)	thickness (cm)
40	4
30	5
20	7
10	10

The point of 1.3 m is already marked on the main stem and d=2 cm of the top is cut off. Additionally the position with d=7 cm and d=12 should be marked on the main stem, also the ending point of the 'bole', if it is reached earlier (~lower) than the d=12 cm point of the stem. The work can then proceed starting from the base of the tree by cutting each section according to given length and measuring diameters at the cutting position. Fixed positions for measurements are the "breast height" 130 cm, and located from that reference point also the positions 65 & 200 cm. After the 200 cm position, regular 2 m sections will be cut (1 m section may be considered on large trees). Any stem defect at the outlined cutting position can be avoided by moving the cutting point (1-2 dm) to a regular part of the stem. The real position must be noted on data sheet. Very irregular parts of the stem may be separated and the volume eventually determined using the density of nearby sections. The need for such estimation is indicated on the data sheet. Any outlined (and regular shaped) section shorter than 50 cm can be included in the previous or following section as long as the 'compartment' division is not altered.

Mass will be measured for the whole stem section if it is reasonable easy to do. With really heavy stem sections, a sample piece procedure may be used, cutting a 2-6 cm thick disc for both volume & mass measurements. Two sample discs will always be cut, then measured for volume and mass – and also bagged and labeled for lab processing. The first of those discs is cut at the 1.3 m position and the second one at the end of the 'bole' (or the d=12 cm position). The MAIN STEM data sheet is being used for the sections and also for the disc measurements.

CONSIDER: only two main stem discs to the lab – should there be more?
- take one more disc if the distance between 'bole-end' and d=12 cm is at least 2 m?

If the stump collar is quite wide compared to the stump diameter (lowest cutting position), then these additional wide parts may be cut off with a chain saw and weighed. The mass will be entered on the BULK MASS data sheet.

The last step is to process the dead branches. The mass will be entered on the BULK MASS data sheet and sample branch pieces (3) selected for mass & volume measurements, then also bagged & labeled for lab processing. The sample pieces should be picked from different size dead branches. NOTE: Using the water-immersion method for the volume of dead wood pieces may be problematic if the relatively dry wood is absorbing water.

In the lab

At least 15 samples per tree will be sent to the lab for determination of dry mass. Some initial work and preparation of the samples in needed at the lab. All samples must be adequately marked in field and contained in some kind of bag, box or container. Consult the field team if there something unclear.

Paper bags can be better than plastic bags due moisture condensing in plastic ones. Sticky substances can also be a problem. Pieces of bark can have fallen off the sample pieces, but everything must be collected for weighing. The sample pieces should be dried in a heated (105 degrees C) and ventilated cabinet. The samples are regularly weighed until the dry mass remains constant. As a guideline: leaves may be dry after 24 hours, small wood samples after 48 hour and larger discs after 3 days.

Additional measurements of the samples may include determination of the basic density of the wood without bark. It is additional information and not used in the calculation of the biomass. It should be noted that determination of the carbon content and other elements requires different initial treatment of the samples.

Additional notes

The methods described here can be used in concession areas to measure trees without cutting the valuable timber into pieces. The sections would then be changed according to the length of the logs and sample discs cut at the end of each log. The logs can be too heavy for the scales and are difficult to lift anyway.

If additional sampling is made for wood property research etc. then all available discs and samples should be entered for biomass and volume determination. This will improve the reliability and make it possible to study then influence of varying sampling intensities on the results.

It is probably good to alter the methods if the research is on plantation trees (pine, eucalypts). In those cases: intensified sampling of the stem (sections at % heights, and discs from all sections) and maybe less work with the canopy. A manual with more detailed stem analysis etc. has been written for field work related to the national forest inventory in Kenya.

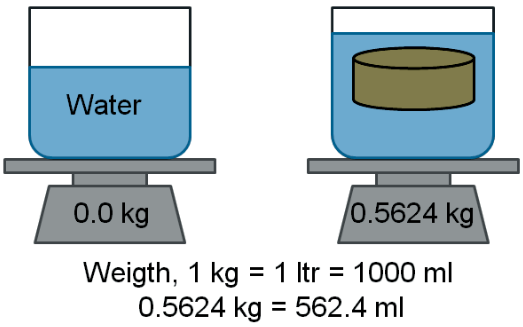
Equipment

usual tree/plot measurement devices and tools
table or bench (need to be levelled horizontally)
scale 12 kg, 1 g resolution
scale 300 kg, 100 g resolution, + rope etc. for suspending scale from tree or tripod
other scales, spring and/or digital
(30-60 kg digital, with 1-2 g resolution would be convenient)

Tools for cutting…
- chain-saw for stem and large branches only
- saw blades are better than panga
- axe for splitting large discs

Volume from immersion in water, tools >>>
also sticks and rack for "hands-off" readings of the scale

Containers, bags, rope, strings, permanent ink pens
etc. etc.



Terminology

Technical density = the relation between fresh mass and volume in field measurements. It is specific to the sample piece composition (bark/sapwood/heartwood etc.) and different than 'basic density', which usually is referring to pure, homogenous materials.

Bole = stem sections between stump and the lowest branch (living?)
- best to not use any stem scares or defection as the limit here

Other manuals:

Tree analyses data for modelling biomass and volume, Field Manual, IC-FRA Kenya document, April 2014, 12 p.

Appendix 1. Data sheet for main stem sections.

Appendix 2. Data sheet for sample pieces.

Appendix 3. Data sheet for large branches.

Appendix 4. Data sheet for bulk mass of different compartments, ‘tare’ = weight of empty vessel.

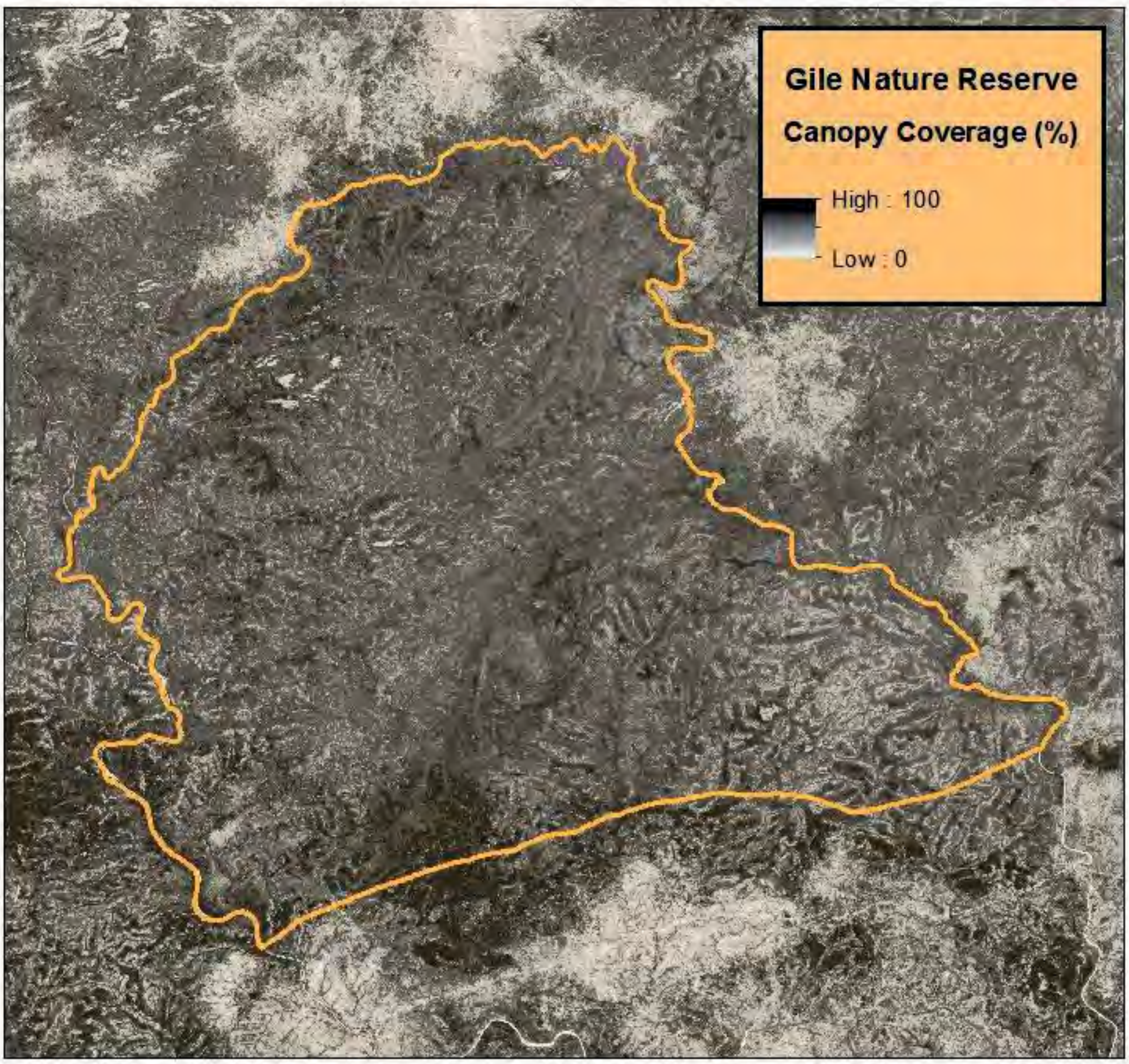
Using inventory information for establishing PSP networks

Kristian Karlsson

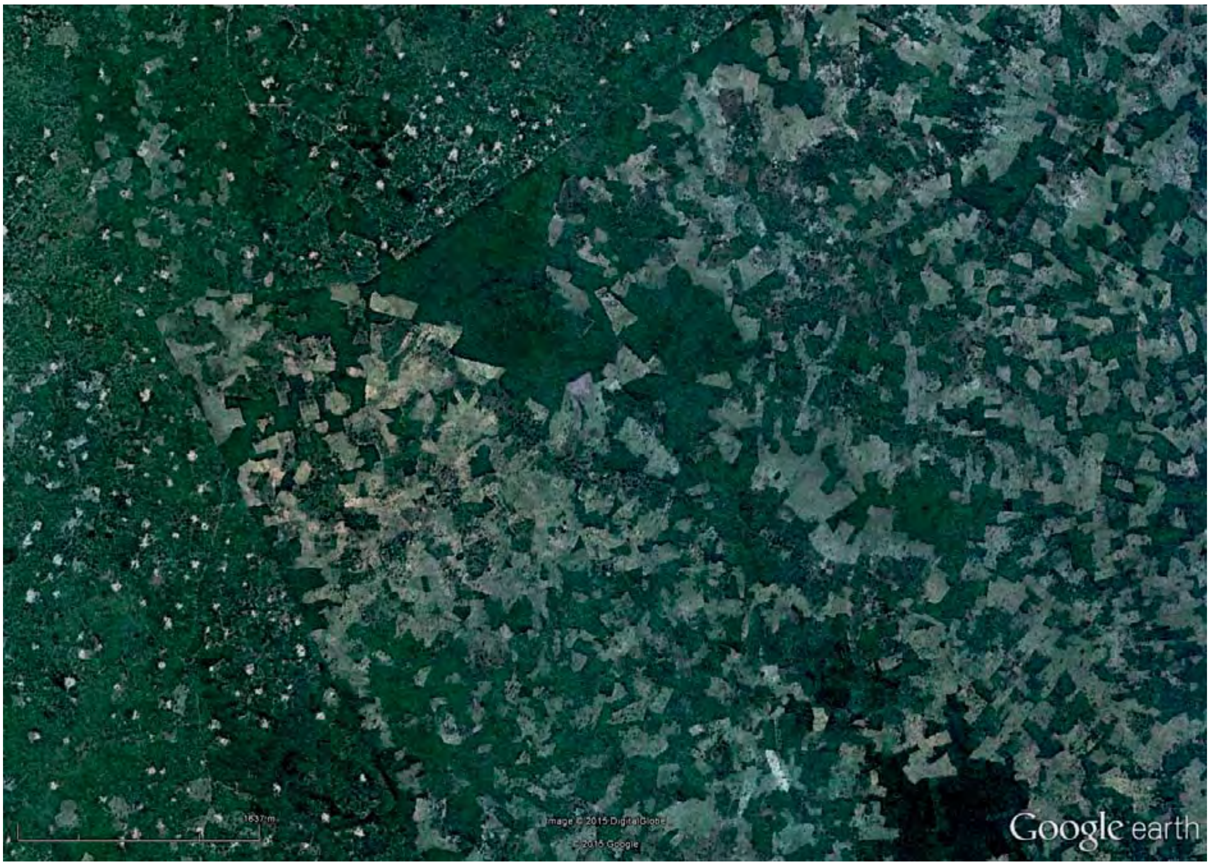
The image below shows a high resolution (30x30 m pixel) interpretation of canopy coverage in Gilé in the central parts of Mozambique. The light coloured areas outside the border are populated regions. The volume of the three existing permanent sample plots re-measured in 2014 corrspond quite well with this estimation of canopy coverage. New plot locations could be selected using the image data.

The first stage sample would be selected according to canopy cover values by classes. The sampling may be limited to a certain maximum distance from the main trail, or that distance can be used for further stratification. Individual pixels can be used as sampling units, but it is also possible to aggregate pixels into larger sampling units based on their values. The inventory will provide a basic relation between e.g. measured volume and estimated canopy coverage, but also gives us additional information of tree species and tree size distribution representative for the region.

A second sample would be selected from the first one after the inital field measurements and then established and marked as permanent sample plots. Observations made on the permanent sample plots can be (loosely) related to the whole area through the original image classification. The growth information will eventually mainly be expressed as increment in relation to forest stocking, tree species and woodland structure.



The second image is showing us forest clearings in a forest reserve in Mozambique. Local people live outside the reserve (white dots to the left in the picture). Inside the reserve, we can see recent and past forest clearings of some type and we can determine the outlines for those areas. An estimation of the change in canopy coverage based on satellite images will provide us with a time stamp for recent clearcuts (within the last 10-12 years or so). With that information, a sample could be selected from different ”age-classes” of regrowing forests for measuring on the ground. In this case, the inventory field measurements would already contain actual growth information in the formula of biomass accumulation over time. Additionally, permanent sample plots may be established for more detailed monitoring with a second stage sampling procedure.



Many regions of the world are today presented with images of high resolution and good quality in the Google on-line map services. The forestry team of the FAO has developed some tools utilizing Google earth (OpenForis toolbox, available at http://www.fao.org/forestry/fma/openforis/en/). With those software tools, you can first design a complete inventory with clustered plot locations. Then, an interpretation of the land-use categories etc. would be done using only Google images in the first stage sampling procedure. Further stages lead to sampling for actual field measurements. This approach is mainly focusing on the analysis of land-use changes and carbon stock assessment. It is not so useful in two examples above, because the target areas were containing only one single type of land-use. Note also that the canopy cover data mentioned is a numerical data set that can be used directly in analysis and processed further with advances methods. Any visual classification /interpretation of images is quite limited compared to that.

Statistical basis on experimental design and sampling –course 16.-27.7.2012
Jaakko Heinonen

Statistical methods of experimental design

1 Introduction

Planned experiments are used in order to compare treatment effects.

An experiment comprises experimental units, e.g. sample plots, and different treatments are applied to different plots.
For example, the treatments might be weeding methods on newly planted areas.

After an appropriate time from treatments, the response variable(s) are measured from the units and the values are saved to a file.

It may also be important to measure some other variables (covariates, concomitant variables), which are useful in the statistical analyses of the responses.
For example, the initial height of the seedlings before planting may explain some part of the differences between the plants and the height and the density of grass in the end of the experiment may explain some part of the treatment effects.
Note:
If the statistical model for the response includes covariates,
the interpretation of the results is different depending on if the treatments have effect on the values of then covariates or not.
For example, treatments have no effect on the initial height of the plants and adding the initial height in the model does not change the interpretation of the test result of the treatment effect.
However, if the treatments have effect on the values of the covariate, the interpretation of the result is more complicated. Assume for example that the treatments have effect on the height and density of grass in the end of the experiment. If the height and density of grass are added in the model and they are statistically significant but the weeding method is not, the interpretation is **not** that there is no treatment effect.

In the designing an experiment we are concerned with

(i) the treatments to be compared,
(ii) the specification of the experimental units (plots etc),
(iii) the rules for allocating treatments to units,
(iv) specifying details of how the experiment is to be managed and,
(v) specifying the variables to be recorded and the degree of precision of recording for each variable.

The results include random variation.

The variability is inherent in

(i) experimental material,
(ii) in the environment within which the experiment is being run, and
(iii) in how he experiment is managed.

Requirements of a good experiment (Cox, 1958):

(i) absence of systematic error,
(ii) precision (if an effect is large enough to be important, the experiment should result should be significant also statistically)
(iii) a wide range of validity for the conclusions that are to be drawn,
(iv) simplicity,
(v) availability of proper statistical analysis which, without artificial assumptions, permits calculation of the uncertainty in the estimates of the treatment-to treatment differences in response.

2 Methods

2.1 The 3 R's

There are three basic principles that help to satisfy these requirements,
"the **3 R's** of experimental design".
(The 3 R's come from the English words reading, writing and arithmetic, which are the basic skills that schoolchildren must learn).

- replication
- randomization and
- blocking.

Replication means that the treatment is applied to more than one unit.
Replication enables the estimation of experimental error and uncertainty in the estimates.

Randomization is a procedure for allocating treatments to the units.
The purpose of randomization is that the experiment can provide unbiased estimates of the treatment effects.
Randomization avoids the biases that can arise from the subjective allocation of treatments to plots.

Because of randomization:

- No treatment is favored (important especially in medical research). The randomization documents are also a proof that the researcher did not favor any treatment.
- There are usually unknown factors that are not controlled in an experiment but that have some effects on the results. Randomization tends the average the effects of unit differences and unknown factors in such a way that the treatment comparisons are unbiased.
- Assumptions of statistical analyses are better justified (e.g. uncorrelated residuals).

Not all factors can be randomized:

Assume that plant seedlings of two tree species to compare their growth. It is not possible to have a homogenous set of seedlings and randomize the tree species among the seedlings. Species is an intrinsic property of a seedling and it cannot be randomized. In statistical analysis the intrinsic properties are treated the same way as the randomized treatments but the interpretation of the results must be more cautious. For example, the storing conditions may have been different for different species and that may have effect on the growth differences.
Time is one ‘treatment’ in many experiments, but the order of time points cannot be randomized. The result of this is that the residual terms of the same unit tend to be correlated, which must be taken into account in the statistical analyses.

Blocking is grouping the plots into blocks, usually each containing the same number of plots (=units).

The purpose of blocking is to reduce experimental error (= random residual variation) in the variables to be studied.

The aim is to capture as much as possible of the variation that is independent of the treatment effects to the variation between blocks.

Plots that would likely to give similar results in the absence of treatments are grouped together within blocks.

The differences between blocks are due to the differences between the plots and the environment of the plots and the variability introduced by how the experiment is managed.

E.g., two groups are working on an experiment and one group is more careful than the other.

Then the difference between the groups should be included among the differences between the blocks.

This is achieved if each group always takes care of their own blocks only.

Also, the effect of the different timing of management operations can be included in the between-blocks variation if the whole block is managed at the same time.

Examples of block designs

In **completely randomized design** there are no blocks.
E.g. 3 treatments A, B and C with 3 replicates allocated to 9 plots

A C B B A
C B A C

The most common design is the **randomized complete block design** (= randomized block design = complete block design). In this design each block contains exactly one plot for each treatment and the random allocation of treatments in any block is independent of that in any other block.

For example,

Block 1	Block 2	Block 3
A C B	B A C	C B A

In randomized block design there is one block factor.
In row and column designs there are two block factors, the row factor and the column factor. In the Latin square design the number of rows = the number of columns = the number of treatments.
Each treatment occurs exactly once on each row and on each column.
An example of the allocation of five treatments A, B, C, D and E:

B D A E C
C B D A E
A E C D B
E A B C D
D C E B A

2.2 Treatment structures

The treatments of an experiment may be structured.
There may be for example different rates of fertilizer.
Also, a set of treatments may include standard or control treatment.
Perhaps the most important type of treatment structure is the factorial treatment structure, which permits simultaneous study of different treatment factors each at different levels.

E.g. Two levels of fertilizer (A and B) and three weeding methods (a, b and c) in two blocks.

Block 1	Block 2
Aa Ba	Bb Ab
Bc Ab	Ac Ba
Ac Bb	Bc Aa

The advantages of the factorial design compared to the one factor design are:

- The plots are used several times to determine the main effect of every factor, in other words the effect is averaged over the levels of the other factors.

- Only a factorial experiment can yield information on interactions between factors, that is, how the response of one factor depends on the level of another factor.

- Factorial experiments provide a wider inductive basis for conclusions about the effects of the factor, because the effect is tested on the different levels of the other factors.

-Factorial treatments should be combined so that each level of a factor occurs together with each combination of the levels of the other factors. Otherwise it may happen that some interesting effects cannot be tested.

Note: Also a factorial treatment effects can be analyzed as a oneway – treatment structure. In that case each treatment-code in data file corresponds to a combination of levels of all the factors. For more details see handout ‘Statistical methods’

2.3 More designs

A factorial experiment may have a **split-plot design**.
In the simplest version of a split-plot design there are two factors, A and B.
The levels of A are allocated to main plots (= whole plots).
Each whole plot contains one sub-plot for each level of B.

There are three possible **reasons for using split-plot design**:

(i) It may be undesirable or impossible to apply the levels of some factor or factors to small plots.

(ii) An experimenter may wish to add a further factor or further factors into an existing experiment, with the levels of the new factor or factors assigned to the sub-plots of the existing plots.

(iii) The use of sub-plots provides greater precision for factors assigned to the sub-plots, and for interactions involving these factors.

E.g. Whole plot treatments A and B, sub-plot treatments a, b and c, 2 blocks, 4 whole plots and 3 sub-plots in each whole plot.

Block 1		Block 2	
Aa	Bc	Bb	Aa
Ac	Bb	Ba	Ac
Ab	Ba	Bc	Ab

Sometimes the number of treatments needed in an experiment is greater than the most appropriate number of plots per block.

This leads to the use of **incomplete blocks**, i.e. blocks which contain only a subset of the treatments.
In designs with incomplete blocks all blocks are of the same size.

The best-known example of a non-factorial incomplete block design is **balanced incomplete block design**.
In this all treatments are equally replicated and each pair of treatments occur together in the same number of blocks.

E.g. an experiment of 6 blocks and 3 treatments (A, B and C) could be

Block					
1	2	3	4	5	6
A	C	A	B	A	B
B	D	C	D	D	C

Here each pair of blocks is a complete block (resolvable design). The block pairs are 1,2 and 3,4 and 5,6.

2.4 More about replicates

2.4.1 Balanced designs

Balanced design means that the sample sizes of the different levels of a treatment are equal and in factorial design the sample size of all combinations of levels of different factors are equal. In block designs also the number of units is equal in all the blocks.

Balanced designs are preferred because the same number of replicates in balanced design result more powerful tests for the treatment effect than unbalanced designs.

The statistical tests of balanced designs are also more robust than the tests of unbalanced designs in the sense that they allow larger deviation from the distribution assumptions.

2.4.2 The number of replicates

A statistically significant effect is not the same thing as important effect from scientific point of view.

However small an effect, it turns out statistically significant if the number of replicates is large enough.

A large and important effect turns not out statistically significant if the number of replicates is too small.

There are two criteria for the number of replicates (in addition to the costs):

a) the width of the confidence interval for the treatment effects and
b) the power of the tests.

<u>Example</u>

Assume that the average height growth of tree saplings is m_t on the (hypothetical) population of treated forest sites and it is m_c on untreated forest sites. The true treatment effect is then $d = m_t - m_c$.

A completely randomized experiment includes 10 treated plots and 10 untreated plots (n=10).
The mean observed growth on treated plots is $\bar{x}_t$ and the mean observed growth on control plots is $\bar{x}_c$.
An estimate for the treatment effect d is then $e = \bar{x}_t - \bar{x}_c$.

Let us assume that in this experiment e = 0.7 and the distribution of the plot mean values are a normal distribution.

Plot mean values are uncorrelated, so the estimate for the sampling variance of the difference e is $s^2 = 2s_m^2/n$, where s_m^2 = the observed variance of the sample means. Let be s_m^2 =2 and s=$\sqrt{2s_m^2}$ = 2.

Confidence interval

The distribution of the statistic $t = \dfrac{e-d}{s/\sqrt{n}}$ is t-distribution with 2n-2 degrees of freedom.. Because of this the interval e $\pm t_{\alpha/2}s\sqrt{10}$ covers the true effect d with probability (1-α), where $t_{\alpha/2}$ is the α/2 percentage point of the t-distribution with n-2 degrees of freedom.

If α = 0.05, then $t_{0.025}$ = -2.1, and the confidence interval for d is 0.7 ± 2.1*2/$\sqrt{10}$ = 0.7 ± 1.33 = (-.63, 2.03).

Note: Compare this interval to the interval for one mean value in handout 'Statistical analysis' .

Test for the effect, type I error, Type II error and the power of the test

If the 1-α level confidence interval includes zero (=0),
the significance level of the test is > α and the effect is not significant on level α .
And if zero is not included, the effect is significant on that level.
Type I error is the error we make if we reject the null hypotheses H_0 when it should not be rejected.

We make a **Type II error** if we do not reject H_0 in the case it is false.

The power of a test is 1- probability of type II error = the probability that we reject H_0 in the case it is false.

<u>Example</u>

Let us assume that an effect is interesting only if the size of the effect is at least 2 units. If the size of the true effect is =2, what is then the probability that the effect will turn out to be significant at 5 % significance level.

H_0 is rejected if $t = \dfrac{e}{s/\sqrt{n}}$ >-$t_{0.025}$ = 2.1.

This happens if $t_d = \dfrac{e-d}{s/\sqrt{n}} > 2.1 - \dfrac{d}{s/\sqrt{n}} = -1.06$.

The distribution of statistic t_d is t-distribution with n2-2 degrees of freedom.
The probability of rejecting H_0 = the power of the test is P(t_d >-1.06) = 0.85.

The power of a test depends on the true value d.
If d = 0.7, the power of the test = 0.17, which means that the probability to reject H_0 is only 0.17.

Before the experiment, an approximation for the value of variance s_m^2 can be based on experience, pilot data or literature.

Formulas for the sample size are given in the chapter ‘The sample size’ in handout ‘Statistical analyses.

In the case of a complex design the effect of the number of replicates on tests and confidence intervals can be examined by a simulation method:

1) Create an artificial data that corresponds to the design of the experiment without the values of the response variable.
2) Generate the values of the response variable using the model that corresponds to the design, the minimum interesting size of treatment effects and your estimate for the size of the residual variance.
3) Compute your tests and confidence intervals the same way they are computed in the case of real data.
4) Record the confidence intervals and the significance levels of the tests.
5) Go back to 2)
6) After the loop has been repeated a few times the recorded values show how significant test results and how large confidence intervals can be expected from the experiment.
   The proportion of times a test result is significant is an estimate for the power of the test, but this estimate is reasonable only if the loop has been repeated tens of times.

2.5 How to randomize

Assume that there are 9 plots, three treatments A,B and C and three replicates.

Start with systematic allocation of treatments.

1 2 3 4 5 6 7 8 9
A A A B B B C C C

Put the plot numbers to a random order (=random permutation of the numbers).

E.g.

1 2 3 4 5 6 7 8 9
3 2 9 6 8 4 1 7 5

The interpretation is that
plot 1 gets the treatment of plot 3 in the systematic allocation = A,
plot 2 keeps its previous treatment = A,
plot 3 gets the treatment of plot 9 in the systematic allocation = C,
plot 4 gets the treatment of plot 6 in the systematic allocation = C,
and so on.

The new allocation of treatments to plots is

1 2 3 4 5 6 7 8 9
A A C B C B A C B

In a completely randomised design this has to done once.
In a randomised blocks design each block has to be randomised independently from the other blocks.
In a randomized block split-plot design the whole plot treatment is randomized within each block and the sub-plot treatments are randomized within each whole plot.

<u>How to find a random order ?</u>

There are several methods.
E.g.

1. Use a computer programme.
   E.g. 1^0. Create a data of one variable, say ID. The values of the variable ID are 1,2,3,…,n. 2^0. Generate random numbers from uniform distribution. 3^0. Sort data according to the random numbers. 4^0. The values of variable ID are now in a random order.
2. Use a table of random digits. Follow one column until you have found all the numbers. The order you get for the numbers is the random order you want.
3. Shuffle a pack of cards. Use the order of the cards.

Literature:

D.R.Cox and N. Reid.2000.The theory of the design of experiments.Chapman&Hall/CRC.

Statistical basis on experimental design and sampling –course 16.-27.7.2012
Jaakko Heinonen

The Basic sampling methods.

1. Introduction

Sampling and experimental design are two branches of statistics, which deal with the problem of obtaining empirical observations from a population. Experimental designs are applied when some part of the population is treated in a specified way and we want to estimate the effect of the treatment. The population may be finite or infinite, concrete or hypothetical.

Sampling theory is applied in observational studies. The population is concrete and it consists of a finite number N of units, e.g. people or trees, which can be identified and labelled. The value of one or more variables is associated with each unit. The values of the variable that we are interested in are unknown and fixed, not random. We may have also auxiliary variables, which are utilized in sample selection and/or in estimation. The values of the auxiliary variables are fixed and they can be either known or unknown before the sampling. We use capital letters for the values associated with the population units, e.g. Y_1, Y_2, Y_3,....Y_N and X_1, X_2, X_3, ..., X_N. Non-capital letters, e.g. y_1, y_2, y_3,...,y_n and x_1, x_2, x_3,...x_n, where n is the sample size, are used for the values associated with the units selected to the sample.

For example the population under study consists of all the woodland estates in a country. The variable values we are interested in are Y_i = the total area of sampling stands of estate i and X_i = the total forest area of estate i, i=1,2,3,...,N. Typical inference problems include how to estimate the <u>total</u> area Y of sampling stands of the estates, $Y=Y_1+Y_2+...+Y_N = \sum_{i=1}^{N} Y_i$, the <u>mean</u> area $\overline{Y}$ of sampling stands, $\overline{Y} = 1/N \sum_{i=1}^{N} Y_i$, and the <u>proportion</u> R of sapling stands, R = Y/X. = $\overline{Y}/\overline{X}$. Here X is the total forest area and $\overline{X}$ is the mean forest area of the estates. The <u>accuracy of the estimates</u> is also an important question.

<u>Analytical</u> sampling studies deal with estimation and testing the differences between two or more populations or analysing the relationships between two or more variables. The analysis of data differs from a more usual analysis in that also the sampling method (sampling design) is taken into account.

1.1. Principal steps in a sample survey.

Cochran lists eleven principal steps in a sample survey. The applications of sampling methods may differ in many respects while the steps may at times be exactly those described by Cochran, at other times the connection between the actual problem and the list of steps is not straightforward. However, the list may prove to be useful.

1. Objectives of the survey.

If the objectives of the study have not been stated clearly, it is very difficult to make reasonable choices between different alternatives at the different phases of the study.

2. Population to be sampled.
The population to be sampled (the sampled population) is not always exactly the population about which the information is wanted (the target population). For example in telephone interviews the sampled population consists of people whose phone number is in the telephone book but the target population consists of the adults in the town. The statistical inference concerns the sampled population. Judgements of to which extent the conclusions will apply also to the target population must be based on other sources of information.

3. Data to be collected.
All data should be relevant to the purpose of the survey. It may be tempting to ask too many questions in questionnaires and some of them are never analysed properly. Too long a questionnaire lowers the quality of the answers. Too many variables in a field study may lead to a smaller sample size and/or larger measurement errors.

4. Degree of precision desired.
There is always uncertainty is in the results of a survey because only a part of the population is examined; there may also be some measurement errors. The uncertainty can be reduced by taking a larger sample and using better instruments of measurement. However, both of these increase the costs. The decision about the amount of error in the result that can be tolerated must be made before the survey is carried out.

5. Methods of measurement.
There may be a choice of the measuring instrument and there may be several methods of approaching the population. In questionnaires, for example, the population may be approached by mail, by phone, by personal visit, or by a combination of these.

6. The frame.
Before selecting the sample, the population must be divided into parts that are called sampling units. Every element (unit) of the population must belong to exactly one sampling unit. If we select sample trees from a plot, the unit is a tree. If we sample people in a town, the unit might be a person or a family or all persons living in the same block. In sampling an agricultural crop, the unit might be a field, a farm, or a specified area of land. The sampling units are identified and listed. The list of the sampling units is called a frame and a sample is selected from the frame. A good frame may be hard to come by if the population is specialised, as the case is with population of people who keep hens.

7. Selection of the sample.
The sampling method (sampling design) can very often be selected from several alternatives. Estimates of the size of sample are made for each method, and costs are compared before the decision is made.

8. The pre-test.
It is useful to test the questionnaire and the field methods on a small scale. This not only often results in improvements but it may also reveal problems that are serious in large scale, for example, we may find out that the costs are much greater than expected.

9. Organisation of the fieldwork.

The personnel must be trained in the methods of measurement and adequately supervised in their work. Early checking of the quality of the returns is invaluable. Plans may be needed for handling the nonresponse (the failure to obtain information from certain of the units in the sample).

10. Summary and analysis of the data.
The data is entered into the computer and checked for possible typing and coding errors. Estimates are computed. There may be available different methods of estimation for the same data. The confidence intervals of the parameters, or other measures of accuracy of the estimates, should also be computed and reported.

11. Information gained for future surveys.
The more information we have initially about the population, the easier it is to device a sample that will give accurate estimates. Each completed sample is a potential guide to improved future sampling.
Because things never go exactly as planned in complex survey, the sampler also learns to recognise mistakes in process and to avoid them in future surveys.

2 Statistical inference.

If the sample has been selected by probability sampling inference from the sample to the population is possible by statistical methods. This means that the selection probabilities of all the possible samples are known or can be computed - at least in principle.

Let the parameter of interest be the population mean and the estimator of the parameter the sample mean.

Because of probability sampling the sample mean $\bar{y}_s = \sum_{i=1}^{n} y_i$ is a random variable. Its expected value is
$E(\bar{y}) = \sum_s P(s)\ \bar{y}_s$ and the (sampling) variance $V(\bar{y}) = \sum_s P(s)\ (\bar{y}_s - E(\bar{y}))^2$,
where the sum is over all the possible samples s and P(s) is the probability that sample s is selected. (The expected value of a random variable is its weighted mean value of over all possible samples when the weight of a sample s is the selection probability P(s)).

If the sample size n is large enough, the sample mean has approximately normal distribution and the confidence interval for the population mean is $\bar{y} \pm 1.96\sqrt{v(\bar{y})}$, where $v(\bar{y})$ is the estimator of the variance $V(\bar{y})$.

The expected value of an estimator can be computed if we know the selection probabilities of each unit. The variance of an estimator can be computed if we know both the selection probabilities each unit and the selection probabilities of each pair of units. In practice sampling and estimation are based on these selection probabilities.

The sampling method and the estimator should be such that the estimate computed from the sample were as reliable as possible. If possible an estimator should be unbiased. (The bias of an estimator of a population parameter is the expected value of the estimator minus the true value of the parameter). The variance of an estimator and the confidence interval for the estimated parameter should be as small as possible, when the costs are taken into account.

One criterion for the estimator is consistency. An estimator is consistent if its value is equal to the parameter when all the units of the population are included in the sample. The sample mean is a consistent estimator of the population mean but it is unbiased only if each unit in the population has the same selection probability (= sampling probability, = the probability that the unit is included in a sample). If the sampling fraction is small, consistency does not play an important role but its importance grows as the sampling fraction approaches one.

3 Simple random sampling SRS.

In simple random sampling the sampling probability of each unit is equal to n/N, where N is the size of the population size and n is the size of the sample.

SRS without replacement can be selected for example so that at first all the units in the population are numbered from 1 to N. After that n different numbers are selected randomly from the numbers 1,2,3,...,N using random number tables or a computer programme or some other method. For instance: A sample of size n can be selected so that at first the list (frame) of the N units is arranged into a random order and then n first units in the ordered list are selected..

There are two versions of the sampling methods, sampling without replacement and sampling with replacement. In sampling without replacement a unit can be selected to a sample only once. In sampling with replacement a unit can be selected to the same sample several times. A simple random sample with replacement can be selected so that an independent random number between 1 and N is selected n times and a unit by the number k is selected as many times as the number k is selected. If the same unit is selected several times the number of different units in the sample is smaller than n. The statistical properties of estimators are easier to deduce in sampling with replacement and in sampling without replacement these results can be utilised in deducing the statistical properties of estimators. In practice the samples are selected without replacement whenever it is possible.

3.1 Estimation of the population mean and the population total.

In simple random sampling the sample mean is an unbiased estimator of the population mean. The variance of the sample mean is

$V(\bar{y})=(1-n/N)1/n\ S^2$, where $S^2=1/(N-1)\sum_{i=1}^{N}(Y_i-\bar{Y})^2$ is the variance of the values in the population and (1-n/N) is the finite population correction (fpc).
When the sample size n increases, the finite population correction and the coefficient 1/n decreases and hence the variance of the sample mean decreases. When the sampling fraction n/N approaches 1, the variance approaches 0. If the sampling fraction is so small that fpc can be neglected, the decrease of the variance is proportional to 1/n.

An unbiased estimator of the variance is

$v(\bar{y})=(1-n/N)1/n\ s^2$, where $s^2=1/(n-1)\sum_{i=1}^{n}(y_i-\bar{y}_s)^2$ is the variance of the sample and an unbiased estimator of S^2.

The confidence interval for the population mean is $\bar{y} \pm 1.96\sqrt{v(\bar{y})}$.

The estimator of the population total is $\hat{Y} = N\bar{y}$. Its variance is $V(\hat{Y})=N^2 V(\bar{y})$ and the confidence interval of the population total is $\bar{y} \pm 1.96\ N \sqrt{v(\bar{y})}$.

3.2 Estimation of proportions.

The proportion of units that belong to a specified class (e.g. the proportion of children from all people), can be estimated by sample mean when the value Y_i is 1 if person i is a child and it is 0 if person i is an adult, i=1,2,3,...,N. In this case, the exact distribution of the estimator is the hypergeometric distribution. If both the number of children and the number of adults are large, the distribution can be approximated by binomial distribution. If the sample size is large, the distribution can be approximated by normal distribution. The distribution of the estimators of the proportions of more than two classes can be approximated by multinomial distribution or by normal distribution.

3.3. Estimation of ratio.

In simple random sampling the estimator of the ratio R=Y/X ($=\bar{Y}/\bar{X}$) is r=y/x ($=\bar{y}/\bar{x}$), where y and x are sample totals, $y = y_1 + y_2 + y_3 + ... + y_n$ and $x = x_1 + x_2 + x_3 + ... + x_n$.

For example the ratio of the total area of the sapling stands to the total forest area of all the woodland estates is R=Y/X, where Y is the total area of the sapling stands of all the woodland estates and X is the total forest area of all the woodland estates. The estimator of ratio R is r=y/x, where y is the total area of the sapling stands in a sample and x is the total forest area of the woodland estates in a sample.

Both the nominator and the denominator of the estimator r are random variables. In small samples the distribution of the estimator is skewed and the estimator biased. The precision of a biased estimator is described by the mean squared error MSE=variance+bias^2. Both the MSE and the variance of the ratio estimator can be approximated by

$$MSE \cong V(r) \cong (1-n/N)(1/n)(1/\bar{X}^2)\ 1/(N-1)\sum_{i=1}^{N} (Y_i - RX_i)^2.$$

If the population mean $\bar{X}$ is known, MSE and variance are estimated by

$$v(r) = (1-n/N)(1/n)\ (1/\bar{X}^2)\ 1/(n-1) \sum_{i=1}^{n} (y_i - rx_i)^2.$$

If $\bar{X}$ is unknown, it is replaced by the sample mean $\bar{x}$ in the estimator v(r).

The formula of the MSE shows that besides the sample size and the sampling fraction, the value of the MSE depends on how well the model $Y_i = RX_i$ describes the relationship between the values Y_i and X_i in the population. The bias of the estimator r depends on this too. However, the bias decreases when the size of the sample increases and at least in large samples the estimator is unbiased.

3.4 The estimation of the sample size.

The bigger the sample size is, the more precise the estimate. The computation of the sample size n is based on the biggest allowed estimation error. For example, when the population mean is estimated by the sample mean, we can give the condition

$$\Pr\left(\frac{|\bar{y} - \bar{Y}|}{\bar{Y}} \geq r\right) = a,$$

where Pr means probability, r is the biggest allowed relative error and a is a small number. Foe example, if r = 0.1 and a = 0.05, the condition tells us that the relative error is bigger than 0.1 in 5 % of all the possible samples and in 95 % of all the possible samples it is smaller than 0.1.

Let a = 0.05. The condition given above can be written as $\Pr(|\bar{y} - \bar{Y}| \geq \bar{Y} r) = 0.05$. The distribution of the sample mean is approximated by normal distribution and in normal distribution $\Pr(|\bar{y} - \bar{Y}| \geq 2\sigma) = 0.05$.
Both the conditions are satisfied if $\bar{Y} r = 2\sigma$. By replacing σ with the formula of the standard error (= the square root of the variance) of the mean, we get the condition
$\bar{Y} r = 2\sqrt{(1 - n/N)(1/n)}\ S$, and by solving the sample size, we get

$$n = \frac{(2/r)^2 (S/\bar{Y})^2}{1 + (1/N)(2/r)^2 (S/\bar{Y})^2}.$$

For this n, the coefficient of the variation of the sample mean is approximately r/2. Coefficient of variation ($S/\bar{Y}$) is unknown and its value must be estimated from previous studies, by a pilot survey, or it must be guessed.

In normal distribution, if a=0.05, the limit 2σ is more precisely 1.96σ, but 2σ is precise enough for this purpose. If the probability a is different from 0.05, e.g. 0.01, the coefficient preceding σ must be changed correspondingly. If the condition leads to a small sample size, the coefficient is often taken from t-distribution instead of normal distribution. The degree of freedom of the t-distribution is n-1, and because n is not known, the solution must be iterated if the t-distribution is used.

When the biggest allowed error is given for the absolute error instead of the relative error, we can use condition $\Pr(|\bar{y} - \bar{Y}| \geq d) = a$. If, again, a=0.05, we get the formula
$n = (2/d)^2S^2/(1+1/N(2/d)^2S^2)$. For this sample size n the standard error of the sample mean is approximately d/2.

3.5 Ratio estimator.

Consider that we want to estimate the total area of the sapling stands of the woodland estates. If the area of the sapling stands is approximately proportional to the size of the woodland estate, the ratio estimator with size as the auxiliary variable is more efficient than the estimator based on the sample mean (ratio estimator has smaller variance and smaller mean squared error).

In SRS the ratio estimator of the total Y is $\hat{Y}_r = rX$. In our example r=y/x is the proportion of sapling stands in a sample, and X is the total area of the woodland estates in the population.

The ratio estimator of the total Y is equal to the estimator of the ratio multiplied by the total X. Although it is biased, the bias decreases as the sample size increases. The mean squared error (and variance) of the ratio estimator is approximated by

$MSE(\hat{Y}_r) \cong X^2 V(r) \cong N^2(1-n/N)(1/n)\, 1/(N-1) \sum_{i=1}^{N} (Y_i - RX_i)^2$, and it is estimated by

$v(\hat{Y}_r) = N^2(1-n/N)(1/n)\, 1/(n-1) \sum_{i=1}^{n} (y_i - rx_i)^2$.

The ratio estimator of the population mean is $\overline{Y}_r = \hat{Y}_r/N = r\overline{X}$. and its MSE is

$MSE(\overline{Y}_r) \cong (1-n/N)(1/n)\, 1/(N-1) \sum_{i=1}^{N} (Y_i - RX_i)^2$, which is estimated by

$v(\overline{Y}_r) = (1-n/N)(1/n)\, 1/(n-1) \sum_{i=1}^{n} (y_i - rx_i)^2$.

3.6 Regression estimator.

If the values of an auxiliary variable are available but they do not correlate with the values of the object variable, estimators based on the sample mean are better than ratio estimators or regression estimators. The variance (and the bias) of the ratio estimator is small if the values (Y_i, X_i) in a scatter plot are close to a straight line passing through the origin. If the values (Y_i, X_i) in a scatter plot are close to a straight line which is not horizontal and which doesn't pass through the origin, a regression estimator is probably better than a ratio estimator and an estimator based on the sample mean.
The regression estimator of the population mean is

$\overline{Y}_l = \overline{y} + b(\overline{x} - \overline{X})$, where the regression coefficient $b = \dfrac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sum_{i=1}^{n}(x_i - \overline{x})^2}$.

The MSE and the variance of the regression estimator $\overline{Y}_l$ is approximately
$MSE(\overline{Y}_l) \cong (1-n/N)(1/n) S^2 (1-\rho)$, where S^2 is the variance of Y_i-values in a population and ρ is the correlation coefficient between the Y_i - and X_i-values.
An estimator of the $MSE(\overline{Y}_l)$ and the sampling variance is

$v(\overline{Y}_l).=.(1-n/N)(1/n)\, 1/(n-2) \sum_{i=1}^{n} (y_i - (\overline{y} + b(x_i - \overline{x})))^2$.

Regression estimator may be biased in small samples. The bias of $\overline{Y}_l$ is equal to $-cov(b, \overline{x})$ and it decreases as the sample size increases. The bias is also negligible if a straight line describes the dependence of the Y_i - values on the X_i - values.

4 Stratified sampling.

In stratified sampling the population is divided into groups (strata) and an independent simple random sample is drawn from each stratum. The independence means that when a sample is selected from a stratum, the selection result has no effect on which sample will be selected from another stratum. If the number of strata is L, the number of units in the population is N

= $N_1+N_2+N_3+...+N_L$, where N_i = the number of units in stratum i. The total sample size is n = $n_1+n_2+n_3+...+n_L$, where n_i = the sample size in stratum i. If all the L samples are selected using simple random sampling, the sampling method is called stratified random sampling.

Why to stratify?

-The study concerns also subpopulation parameters. For example, in an opinion poll we may want to study the attitudes of men and women both separately and combined. In stratified sampling the sample size of men and the sample size of women are decided before the study to ensure that the samples from both groups are large enough. If we take only one random sample from the whole population, either men or women may have too few representatives in the sample.

- Management reasons. The study may concern for example several regions and in each region the study is carried out by a regional organisation. In this case, each region forms a stratum.

- Stratification may lead to a more precise estimate for the population parameter. If the stratification is such that the variation within strata is small and the differences between strata are large, the estimators are more precise in stratified sampling than they are in simple random sampling.

Estimation.

Consider stratified random sampling when a simple random sample is selected from each stratum. $\overline{Y}_i$, the mean of the stratum i, is estimated by the sample mean of the same stratum $\overline{y}_i$. The stratum total Y_i is estimated by $\hat{Y}_i = N_i \overline{y}_i$.

The estimator of the population total Y is $\hat{Y}_{st} = \sum_{i=1}^{L} N_i \overline{y}_i$ and the estimator of the population mean $\overline{Y}$ is $\hat{\overline{Y}}_{st} = \sum_{i=1}^{L} (N_i/N)\overline{y}_i$.

As the samples from different strata are independent, the estimators of the different strata are not correlated and the variance of $\hat{Y}_{st}$ is

$V(\hat{Y}_{st}) = \sum_{i=1}^{L} N_i^2 V(\overline{y}_i)$, where $V(\overline{y}_i)$ is the variance of the sample mean $\overline{y}_i$ in simple random sampling. The variance of the estimator of the population mean is correspondingly

$V(\hat{\overline{Y}}_{st}) = \sum_{i=1}^{L} (N_i/N)^2 V(\overline{y}_i)$.

The estimators of the variances are obtained from these formulas by replacing the variances $V(\overline{y}_i)$ by their estimators. For example the estimator of the variance $V(\hat{Y}_{st})$ is

$v(\hat{Y}_{st}) = \sum_{i=1}^{L} N_i^2 (1-n_i/N_i)(1/n_i) s_i^2$, where $s_i^2 = 1/(n_i-1) \sum_{i=1}^{n_i} (y_{ij}-\overline{y}_i)^2$.

Allocation

In stratified sampling the sample sizes n_i in respective strata are chosen by the researcher. They may be chosen so that variance is minimised for a specified cost or the cost is minimised for a specified variance. Both principles give the same result. The cost function is usually $c = c0 + \sum_{i=1}^{L} c_i n_i$, where c_0 represents an overhead cost and c_i is the cost per unit in the stratum i. For this cost function the optimum sample sizes n_i are proportional $(N_i/N)S_i / \sqrt{c_i}$, where S_i is the square root of S_i^2, the variance of the stratum i. According to the result, the sample of the stratum i is large if the size N_i is large, the variance S_i^2 within the stratum is large and the unit cost c_i is small. If the unit cost is equal in all strata, the optimum sample size is $n_i = n \frac{N_i S_i}{\sum_i N_i S_i}$. This is called the optimum allocation or the Neuman allocation.

In proportional allocation the sample size is proportional to the stratum size and $n_i = n\, N_i/N$. This allocation is optimal if the variance and the unit costs are equal in all strata.

4.1 Post stratification.

Sometimes the stratification is made after the selection of the sample. Let us assume that in an opinion poll survey the answers depend on the respondent's education and we do not know the educational background before the study but ask it from the persons selected into the sample. If we know on the basis of official statistics the total number of people at each educational level, education levels can form strata. In post stratification estimates are computed the same way as in stratified sampling. In post stratification the sample sizes of the strata cannot be determined beforehand and the estimates are not as precise as in stratified sampling. This must be taken into account in the estimation of the sample size. In opinion polls post stratification is often used for the estimation of the effects of the nonresponse to the estimators.

5 Systematic sampling.

A systematic sample is selected from the sampling frame so that the starting point is random and between 1 and k, where k=N/n, and the distance between the selected units in the frame is equal to k. If N/n is not an integer, the sample size is not exactly n in all possible samples. If the order of the units in the frame is random, this selection method is the simple random sampling method. In systematic sampling we cannot assume that the order of the units is random. This sampling method divides the population into k groups and only one group is selected to the sample. In principle, this is a one stage cluster sampling when only one cluster is selected.

In systematic sampling the sample mean is an unbiased estimator of the population mean but its variance cannot be estimated unbiased from the sample. The variance depends on how the units in the frame are correlated. Several methods have been developed for the estimation of the correlation structure. Let $\bar{y}_{sys}$ be the sample mean in systematic sampling. One estimator of the variance of $\bar{y}_{sys}$ is

$$v(\bar{y}_{sys}) = (1-n/N)(1/n)\, 1/(n-2) \sum_{i=2}^{n} 1/2\, (y_i - y_{i-1})^2.$$

Since systematic sampling is often efficient and the sampling method is easily applicable, it is used quite often.

In systematic sampling the variance of the sample mean can be described by intra class correlation ω. In a population of finite size N, the total population variance σ^2 (=S^2(N-1)/N) is divided into between samples variance σ_B^2 , and within samples variance σ_W^2 ,
$\sigma^2 = \sigma_B^2 + \sigma_W^2$, and the intra class correlation is ω = 1 - n/(n-1)(σ_W^2 / σ^2). When σ_B^2 = 0, ω has its minimum value = -1/(n-1). This happens when the means of all the possible samples are equal. ω has its maximum value = 1, when all values within a sample are equal. The variance of the sample mean is
$V(\bar{y}_{sys}) = V(\bar{y}_{SRS})(1+(n-1)\,\omega)$, where $V(\bar{y}_{SRS})$ is the variance of the sample mean in simple random sampling. The variance $V(\bar{y}_{sys})$ = 0, when ω = 1/(n-1). If ω is close to one, systematic sampling is not a good sampling method.

6 PPS sampling.

The letters PPS stand for probability proportional to size. In PPS sampling the sampling probability of a unit is proportional to the value of an auxiliary variable that usually represents the size of a unit. For example, we want to estimate the total area of the sapling stands of the woodland estates. If the sizes of the estates are known and we can assume that the total area of the sapling stands of an estate is roughly proportional to the size of the estate, we can use PPS sampling and set the sampling probabilities in proportion to the sizes of the estates.
Horvitz-Thompson estimator (HT-estimator) for the population total Y is
$\hat{Y}_{HT} = \sum_{i=1}^{n} y_i/\pi_i$., where π_i is the probability that the unit i is selected in a sample. The variance of the HT-estimator is

$$V(\hat{Y}_{HT}) = \sum_{i=1}^{N} \frac{(1-\pi_i)}{\pi_i} y_i^2 + 2\sum_{i=1}^{N} \sum_{j>i}^{N} \frac{(\pi_{ij} - \pi_i\pi_j)}{\pi_i\pi_j} y_i y_j,$$

where π_{ij} is the selection probability of the unit pair ij. The probabilities π_{ij} depend on the selection method used when the PPS sample is drawn.
The variance can be estimated for example by using the formula

$$v(\hat{Y}_{HT}) = \sum_{i=1}^{n}\sum_{j>i} \frac{(\pi_{ij} - \pi_i\pi_j)}{\pi_i\pi_j}\left(\frac{y_i}{\pi_i} - \frac{y_j}{\pi_j}\right)^2 .$$

The HT-estimator is always unbiased. PPS - sampling together with an HT-estimator is efficient if the selection probabilities π_i are approximately proportional to the Y_i - values, i=1,2,3,...,N.

In the case sampling with replacement the probabilities $\pi_i = p_i{*}n$ and $\pi_{ij} = \pi_i{*}\pi_j$,
where p_i = probability that unit i is selected on one draw.
The estimator given above is called then Hansen-Hurwitz estimator

$$\hat{Y}_{HH} = 1/n \sum_{i=1}^{n} y_i/p_i.$$

and its variance is

$$V(\hat{Y}_{HH}) = 1/n \sum_{i=1}^{N} p_i \left(\frac{y_i}{p_i} - Y\right)^2 .$$

An unbiased estimator for the variance is

$$v(\hat{Y}_{HH}) = \frac{1}{n(n-1)} \sum_{i=1}^{n} \left(\frac{y_i}{p_i} - Y\right)^2.$$

7. Cluster sampling.

In cluster sampling the population is composed of unit groups, which are called clusters, or it is divided into clusters, and the sampling unit is a cluster. Only a sample of clusters are selected. In social studies, e.g., a person is population unit and clusters are families, villages, towns and so on. In forestry, a tree is population unit and sample plots are clusters. In stratified sampling the population is grouped into strata but every group is represented in the sample. If all the units of a cluster are selected in the sample when the cluster is selected in the sample, we talk about single-stage cluster sampling. Cluster sampling may also have two or more stages. In two stage sampling a sample of clusters are selected at the first stage. At the second stage an independent sample of units is drawn from each selected cluster.
As the units that belong to the same cluster are correlated, the variance of estimators are larger than, e.g., in SRS with the same sample size. Cluster sampling is often useful, however, because of lower measurement costs. If only a relatively small sample of the clusters are included in the sample, the travel costs may be essentially lower than in SRS or in stratified sampling; and the sample size can be larger in cluster sampling. If it is not possible to build the sampling frame of population units but we have a list of clusters, cluster sampling is the only possibility. We may want to interview people living in the villages of a province. If we have a list of villages but the register of people is not either available to us or it is out of date, we can select a sample of villages, generate a register of persons living in the sample villages, and interview all the persons or a sample of persons in these villages.

In cluster sampling the clusters can be selected by simple random sampling, systematic sampling, stratified sampling, or cluster sampling. In multi-stage sampling any sampling method can be used at all the stages. The more complicated the sampling method, the more complicated the estimation.

Consider the estimation of the mean in one stage cluster sampling when the clusters are selected by SRS. Let N be the number of clusters, M_i the number of units in the cluster i and n the number of clusters in a sample. The total number of units in the population is $M = \sum_{i=1}^{N} M_i$. If Y_i, the total of cluster i is proportional to the cluster size M_i, the population mean can be estimated by a ratio estimator

$$\hat{\bar{Y}}_r = \left(\sum_{i=1}^{n} Y_i\right) / \left(\sum_{i=1}^{n} M_i\right).$$

The variance of $\hat{\bar{Y}}_r$ is

$$V(\hat{\bar{Y}}_r) = (1-n/N)(1/n)(1/\bar{M}^2)\, 1/(N-1) \sum_{i=1}^{N} (Y_i - M_i \bar{Y})^2,$$

where $\bar{M} = M/N$ is the mean cluster size. An estimator of the variance of $\hat{\bar{Y}}_r$ is

$$v(\hat{\bar{Y}}_r) = (1-n/N)(1/n)(1/\bar{M}^2)\, 1/(n-1) \sum_{i=1}^{n} (y_i - M_i \hat{\bar{Y}}_r)^2.$$

If the variation between the cluster means is small, the variance of the estimator is also small.

The estimator of the population total is M times the estimator of the mean value and the variance of the estimator of the total is M^2 times the variance of the estimator of the mean.

8. Two phase sampling.

In the first phase of two phase sampling (double sampling) a large sample is selected from the population. Only the values of an auxiliary variable (or variables) are measured from all the units of the first phase sample. In the second phase a smaller sample is selected from the units of the first phase sample and the values of the target variable are measured from the smaller sample. For example, our purpose is to estimate the total volume of the trees in a forest. The first phase sample consists of all the trees in the sample plots in the forest and we measure the breast height diameters of all these trees. In the second phase we select a specified number of sample trees from the sample plots (the second phase sample) and measure the height of the sample trees. The first step of estimation is to estimate the volumes of the sample trees by using sample tree measurements and volume functions or volume tables. The second step is to estimate a regression model where the volume of a tree is the dependent variable and the breast height diameter is the independent variable. In the third step the regression model is applied to all the trees in the sample plots. This gives an estimate of the total volume of the trees in the sample plots. This estimate must be multiplied by the ratio A_S/A_F to get an estimate of the total volume of all the trees in the forest, where A_S is the sum of the areas of the sample plots and A_F is the area of the forest.
The error of the estimate includes the measurement error, the errors in the sample tree volumes, the error due to the sample tree selection and the error due to the sample plot selection. The size of each error component should be estimated before sampling. Otherwise it is not possible to decide how many sample plots and sample trees are needed.

9. Design effect.

The efficiency of complicate sampling can be assessed by comparing it with the SRS. Design effect Deff = Var_c / Var_{SRS}, where Var_{SRS} is the variance of the estimator in the SRS and Var_c is the variance of the same estimator in complicated design. The sample size is assumed to be the same in both designs. If Deff is less than 1, the design is more efficient than SRS. The case is usually such with stratified sampling. If Deff is more than 1, the sampling design is less efficient than SRS, e.g. cluster sampling usually. Design effect can be utilized in the estimation of the sample size and in data analysis. For example, when the means of two populations are compared by t-tests.

10. Sampling for a regression model.

If the purpose is to find the form of a regression model and estimate the regression coefficients of the model, it is thought that the population is hypothetical and consists all possible units that fulfill given criteria.

An example is a regression model that describes the bole volume of a tree as a function of the bole diameter at breast height (1.3 m) for a given tree species on given type of sites.

A model could be

$V = a0 \cdot D^2 + a1 \cdot D^3 + a2 \cdot D^4 + \varepsilon$,

where V = volume of a tree,
D = diameter and
ε = residual term of normal distribution and variance $\sigma^2 \cdot D^2$.

The selection probability of a tree may depend on the values of the independent variables but it is not allowed to depend on the value of the response variable.
A good approximation for the optimum allocation of sample trees to different size classes is analogous to that in stratified sampling. The sample size in a diameter class is then proportional to the standard deviation of volumes in the diameter class and the sample size n_i for a diameter class i is

$n_i = k \cdot \sigma_i = k \cdot D_i$, where constant k is chosen so that the total sample size is as wanted.

However, if certain size classes are more important in practice than others are, it may be wise to select larger samples from the more important size classes.

In practice we seldom can select a simple random sample. Instead, we have to select a multi stage sample.

For example, the first stage is a sample of sites, the second stage is a sample of plots on a site, and from each plot we select trees.

Total variance of volumes in a size class D_i is then $V_i = V_{site} + V_{plot} + V_{tree}$

where
V_{site} = variance of site-mean values of volumes in diameter class i,
V_{plot} = variance of plot-mean values within a site in diameter class i and
V_{tree} = variance of volume of trees within a plot in diameter class i.

Assume that
number of sites in the sample = n_{site},
cost of including one site in a sample = c_{site},
number of plots on a site = n_{plot},
cost of including one plot on a site = c_{plot},
number of sample trees on a plot = n_{tree} and
cost of including one tree on a plot = c_{tree}.

The total cost in a diameter class is then
$c_{tot} = n_{site} \cdot c_{site} + n_{site} \cdot n_{plot} \cdot c_{plot} + n_{site} \cdot n_{plot} \cdot c_{tree}$ and
the variance of the sample mean volume in a diameter class
$V_m = V_{site} / n_{site} + V_{plot} / n_{plot} + V_{tree} / n_{tree}$.

Optimum number of sites, plots and trees is obtained by minimizing the variance V_m given that
total cost c_{tot} is a given value (or minimizing cost c_{tot} given that the variance V_m is a given value).

In **spatial sampling** the selection of the units is based on their spatial coordinates.
Given the sample size, the variance is minimized if correlation between observations is as small as possible. The correlation between two trees is the stronger the smaller is the distance between trees.
If the measurement costs are not taken into account in spatial sampling, single tree plots far away from each other should be favored.
But the measurement costs of such samples are very high and
the same precision is obtained more cheaply by using multi stage sampling and selecting more sample trees. In two stage sampling described above the trees within plots are correlated and the plots within sites are correlated (intra class correlations) but the effect of correlations on variance can compensated by selecting more trees into the sample.

Literature:

Cochran,W.G.1977.Sampling Techniques.John Wiley&Sons.

This book is a classic in social sciences.

Lehtonen,R.,Pahkinen,E.J.1955.Practical Methods for Design and Analysis of Complex Surveys.

The applications of this book are also in social sciences. In addition to the subjects covered by the book of Cochran, this book contains examples of complex designs from the real world and shows how to analyse from complex surveys. The book also covers tests and model building.

S.K.Thompson.1992.Sampling.John Wiley&Sons,inc.

In addition to the classical methods described in the two books mentioned above, Thompson's book also covers sampling methods especially applied to the sciences, (such as spatial sampling, line-intersect sampling, detectability sampling, and adaptive sampling).

Timothy G.Gregoire,Harry T. Valentine.2008.Sampling strategies for natural resources and the environment.Chapman&Hall/CRC.

A new and thorough, but a bit laborious book to read. Describes sampling methods applicable in forestry and environmental sciences.

Statistical basis on experimental design and sampling -course 16.-27.7.2012
Jaakko Heinonen

Statistical Analysis

Contents

1 Introduction

About the topics of the course.

The main topics on this course are
- statistical data acquisition methods, which are
statistical theory of design of experiments and **statistical sampling theory** and
- **statistical analyses** based on **statical models.**

The models we'll talk about describe the variation of the values of a response variable (=dependent variable) by fixed explanatory variables (=independent variables) and random residuals (=error term).
We'll mainly talk about **linear models and linear mixed models.**

ANOVA, ANCOVA and linear regression with normal distributed uncorrelated residuals are special cases of linear models.
Models $y = a_0 + a_1x + a_2x^2 + \varepsilon$, where x is a continuos independent variable,and $y_{ij} = \mu + \alpha_i + \varepsilon_{ij}$, where α_i refers to level i of a cathegorical variable, are examples of linear models.
In both cases the random variation is described by residual terms ε, that are independent normal distributed variables (i.i.d $N(0,\sigma^2)$)

Linear model is a special case of linear mixed model, which allows correlated residuals. In both type of models the distribution of the random variation is a normal distribution.
Model $y_{ij} = \mu + \alpha_i + bl_j + \varepsilon_{ij}$,where bl_j refers to a random factor, is an

example of a linear mixed model. In this model the random variation is a sum of two normal distributed variables bl_j and ε_{ij}.
We'll talk also (briefly) about
- generalized linear models in which the distribution of the random variation is not normal but for example a Poisson distribution or a binomial distribution,
- nonlinear regression with normal distributed random variation and
- non parametric methods in which the distribution of the random part may be unspecified.
The statistical software packages like **SPSS**, **SAS** and **R** compute the estimates, confidence intervals and tests by applying statistical models and well established statistical methods and
the user of a software does not necessarily need to understand in detail the mathematics of these methods.
But she or he must know
- which model should be used,
- how to command the software to use correct model and to compute the analyses needed and

- how to check that the model describes correctly the variation of the values of the response variable.

The main steps in the analysis of data:

1. Use descriptive statistics and graphs to learn to know and describe the main features of the data set, and to identify possible recording mistakes and other irregularities.

2. Correct the possible errors in data.

3. Use statistical inference to draw conclusions about the population or process that the data is representing.

The main steps of statistical inference:

1. Statistical inference is based on a statistical model that describes the variation in the values of the response variable. Formulate the model.

2. In the analysis of experimental data the interesting things, e.g. main effects, interactions, marginal means and pairwise comparisons of treatment effects, are not the model parameters, but linear combinations and contrasts of the model parameters. Define the linear combinations and contrasts you want to estimate and test.

3. Estimates the parameters of the model, and compute the predicted values and the residuals of the measured response values.

4. Use scatterplots and Q-Q plots of residuals to check that the assumption about the distribution of residuals are satisfied (e.g.. normal distribution and homogenous variance of residuals).

5. If necessary, modify your model and go back to step 3.In the case of repeated measures you may need to try several alternative correlation structures (e.g.. compound symmetry, unstructured and ar1- structure) Use information criteria to decide which correlation structure is most suitable.

6. Compute the estimates, confidence intervals and P-values for the your contrasts.

7. Interpret the results.

2 Variables and distributions

2.1 Measurement scales

Empirical data come from measurements and consists of values of variables.

There are four different measurement scales.

Variables are classified according to the measurement scales.

2.1.1 Ratio scale

- Units are equal size. E.g. difference in height between a 16 m tree and a 15 m tree is 1 m and as big as the difference between the height of 2 m and 3 m.

- Value zero is the absolute minimum and no negative values exist. E.g. for the number of trees on a plot. The value zero means that there are no trees at all.

- The ratio of two values has a meaningful interpretation. For example a 14 m long tree is 2 times as long as a 7 m long tree.

2.1.2 Interval scale

- Units are equal size.

- There are values below zero, which means that negative values are allowed.

- The ratio of two values may be meaningless. For example temperature in Celsius (or Fahrenheit) is in interval scale and the ratio of temperatures. -10 C and +20 C is -1/2. It does not make sense to say that -10 C is -1/2 times as warm as +20C.

- But the ratio of differences make sense also in interval scale. For example the difference between +20 0 C and -10 0 C = 30 0 C and it is 2 times as big as difference between 10 0 C and -5 0 C = 15 0 C.

- Notice that date, for example 16th July 2012, is not expressed in interval scale, since years may have either 365 or 366 days and months may have 31, 30, 28 or 29 days.

  Julian day, instead, is an interval scale value. Julian day presents the interval of time in days and fractions of a day since January 1, 4713 BC Greenwich noon.

2.2 Ordinal scale

Ordinal scale measurements defines an order between the measured individuals, but it does not define the size of the differences between two values. For example healthy, damaged or dead seedling. Or biggest, second biggest, third biggest, fourth biggest and so on. Ordinal scale measurements do not tell how much bigger the second biggest tree is than the third biggest tree.

2.2.1 Nominal scale

Nominal scale measurement identify individuals or groups. For example the names tree species (pine, spruce, birch) or the numbers used as codes to tree species (1=pine, 2=spruce, 3=birch). In tree measurement data it is important to be able to identify each plot and tree. The usual identifiers are plot numbers and tree numbers and the identifiers are in nominal scale.Nominal scale variables

are also called categorical variables.

Ratio scale and interval scale responses can be analyzed by linear models, linear mixed models, generalized linear models etc.

Ordinal scale responses can be analyzed by generalized linear models. Also non-parametric methods, which use the ranks of observations and ignore the intervals, are available. For example rank correlation and the Mann-Whitney test of means.

Nominal scale responses can be analyzed by generalized linear models (e.g. logistic regression).

2.3 Continuous vs. discrete variable

- A continuous variable may have any value between its minimum and maximum value.

- A discrete variable may have only certain values within its range.

E.g. the height of a tree is continuous and the number of trees on a plot is discrete

The number of trees may be 0, 1, 2, 3, 4 and so on but not for example 3.21

- Ratio-, and interval scale variables may be continuous or discrete
- Ordinal scale values are usually numeric but discrete.
- Nominal scale values may be numeric or alphanumeric and they are always discrete

2.4 Frequency distributions

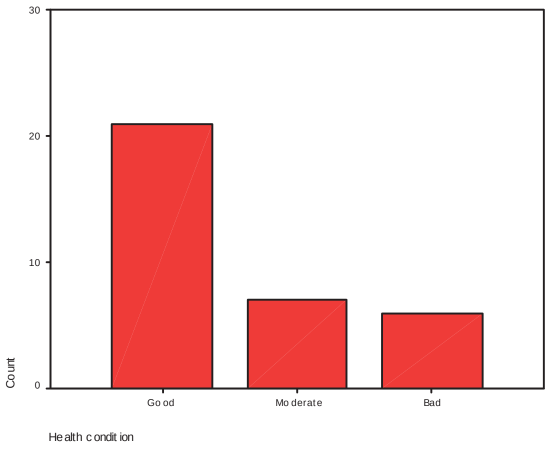
Large amount of observed values of a variable can be summarized by a frequency table and a graph showing the frequency distribution of values.

E.g. the frequency distribution of the health condition of trees

Table 1.

Health condition	Number of trees
Good	21
Moderate	17
Bad	6

Bar graph



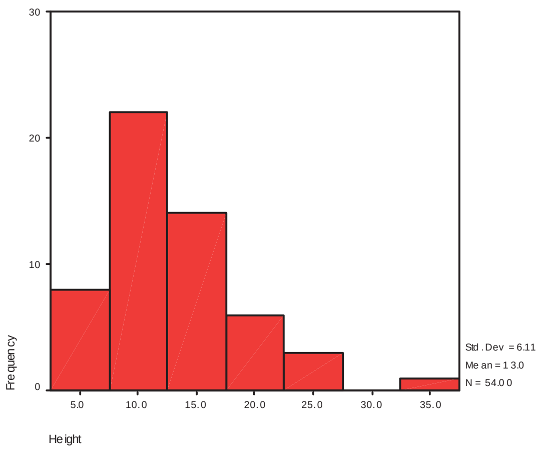
The frequency distribution and the histogram of a continuous variable shows the number of cases in each value group.

E.g. the distribution of trees in 5 m height classes.

Table 2.

Height class	Number of trees
2.6-7.5	8
7.6-12.5	22
12.6-17.5	14
17.6-22.5	6
22.6-27.5	3
27.6-32.5	0
32.6-37.5	1

Histogram



2.5 Measures of central tendency

Measures of central tendency describe the location of the distribution

2.5.1 Arithmetic mean

The arithmetic mean of n observations is

$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i = \frac{1}{n}(x_1 + x_2 + x_3 + ... + x_n)$ or

$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} n_i x_i$

$= \sum_{i=1}^{n} f_i x_i,$

where x_i is the midpoint of class i and n_i is the number of observations in the class i and $f_i = \frac{n_i}{n}$.

The mean is the value of m that minimizes the square of sums $SS = \sum_{i=1}^{n}(x_i - m)^2$ and hence the mean is sensitive to outliers.

2.5.2 Median

The values $x_1, x_2, x_3, ..., x_n$arranged in the order of magnitude are $x_{(1)}, x_{(2)}, x_{(3)}, ..., x_{(n)}$, where

$x_{(1)}$ is the smallest value and $x_{(n)}$ is the biggest value.

Median M is the middle value of $x_{(1)}, x_{(2)}, x_{(3)}, ..., x_{(n)}$.

If n is odd, $M = x_{(n+1)/2}$. If n is even, median is the mean of the two "middle most" values, $M = \frac{1}{2}\left(x_{(n/2)} + x_{(n/2+1)}\right)$.

E.g. the median of the values 5,7,9,10 and 11 is $M = 9$ and the median of the values 5,7,9,10,11 and 17 is $M = (9+10)/2 = 9.5$.

The median of a frequency distribution divides the distribution into two equal parts. If the median is within a class interval

$$M = (\text{the lower limit of the interval}) + \left(\frac{n/2-\text{ cumulative frequency on the lower limit}}{\text{number of observations in the interval}}\right)(\text{interval size}).$$

E.g. median of the height distribution given in the Table 2 is

$M = 7.6 + \left(\frac{0.5\times54\text{ - }8}{22}\right)\times5 = 12.2.$

Median does not take into account the size of the intervals of the measurement scale, only the order of values, and so it is not sensitive to possible outliers.

E.g. the median of the values 1,2 and 3 is $M = 2$, and the median of the values 1,2 and 101 is also $M = 2$.

The location of a distribution can also be described by other quantiles E.g. quartiles divide data into four equal parts. Median is the second quartile.

2.5.3 Geometric mean

The geometric mean is $\overline{x}_G = \sqrt[1/n]{x_1 x_2 x_3 ... x_n} = \sqrt[1/n]{\prod_{i=1}^n x_i} = \exp(\frac{1}{n}\sum_1^n \log(x_i))$

The geometric mean is occasionally used in averaging ratios.

2.5.4 Harmonic mean

The harmonic mean is $\overline{x}_H = \frac{1}{n}\sum_{i=1}^n \frac{1}{x_i}$.

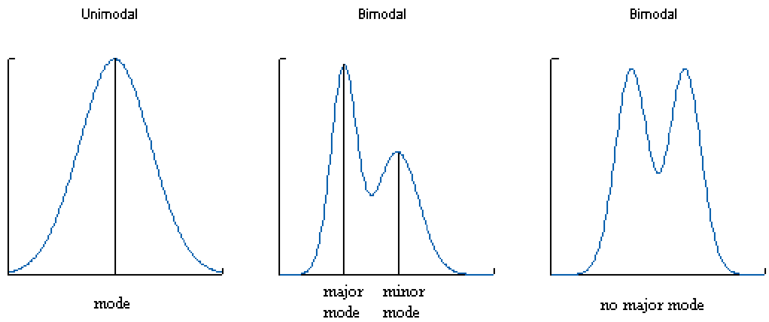
The harmonic mean is occasionally used in averaging rates.

The mean without any specifications refers usually to the arithmetic mean $\overline{x} = \frac{1}{n}\sum_{i=1}^n x_i$.

2.5.5 Mode

The mode is the most frequently occurred value.

A distribution may have more than one mode in which case the modes are called the major mode and the minor mode(s).



In a symmetric unimodal distribution mean = median = mode.

Scale of measurements and appropriate measures of location

Ratio scale: All measures.

Interval scale: All but geometric and harmonic means.

Ordinal scale: Median, other quantiles, mode.

Nominal scale: Mode.

2.6 Measures of dispersion and variability

The measures of dispersion and variability describe how clustered the values are around the center of the distribution.

2.6.1 Range

The range is equal to the biggest value minus the smallest value $= x_{(n)} - x_{(1)}$.

2.6.2 Mean deviation

The mean deviation is either $\frac{1}{n}\sum_{i=1}^{n}|x_i - M|$ or $\frac{1}{n}\sum_{i=1}^{n}|x_i - \overline{x}|$, where $|x_i - M|$ means the absolute value of the difference $x_i - M$.

2.6.3 Variance

The variance (mean square) is $\sigma^2 = \frac{1}{n}\sum_{i=1}^{n}(x_i - \overline{x})^2 = \sum_{i=1}^{n} f_i (x_i - \overline{x})^2$, where $f_i = n_i/n$ is the relative frequency of the values x_i.

2.6.4 Standard deviation

The standard deviation (root mean square) is $\sigma = \sqrt{\sigma^2}$.

2.6.5 Coefficient of variation

The coefficient of variation is $cv = \sigma/\overline{x}$.

2.7 Other moments about the mean

Variance is also called the second moment about the mean.

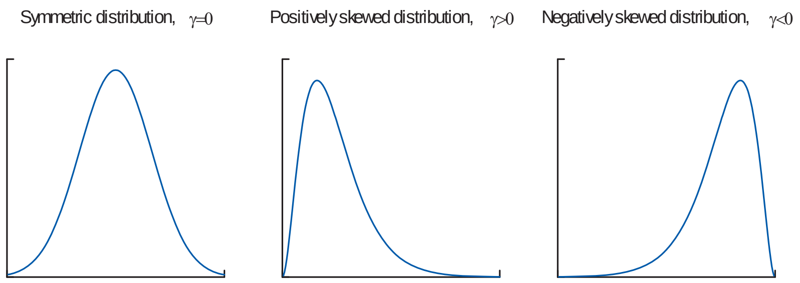
The third and the fourth moments about the mean are used to describe the form of the distribution.

2.7.1 Skewness

The skewness is

$$\gamma_1 = \frac{\sigma^3}{(\sqrt{\sigma})^3},$$

where $\sigma^3 = \frac{1}{n}\sum_{i=1}^{n}(x_i - \overline{x})^3$.



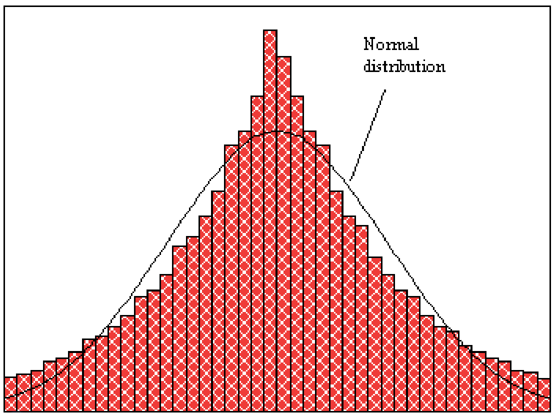
2.7.2 Kurtosis

The kurtosis is

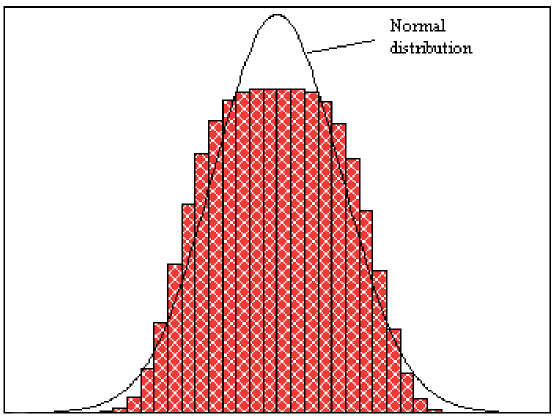
$$\gamma_2 = \frac{\sigma^4}{\left(\sigma^2\right)^2} - 3,$$

where $\sigma^4 = \frac{1}{n} \sum_{i=1}^{n} \left(x_i - \overline{x}\right)^4$.

The kurtosis of the normal distribution is $= 0$. If the kurtosis of a distribution is positive, the distribution has heavier tails than the normal distribution. If the kurtosis is negative, the distribution is more peaked than the normal distribution.



$\gamma_2 > 0$



$\gamma_2 < 0$

In the above pictures the normal distribution has the same variance as the distribution compared to the normal distribution.

2.8

2.9 Random variable and its distribution

A random variable is a variable the values of which are determined by a random phenomenon. When phenomenon is repeated more and more times (= the size of the sample from the distribution is increased), the distribution of the observed values approaches to the distribution of the random variable (=distribution in the population).

The distribution of a random variable is expressed by the probabilities of the possible values.

In mathematics a capital letter (e.g. X) refers to a random variable and the corresponding small letter (x) refers to a value of the variable.

The cumulative distribution function $F(x)$ of a random variable X expresses the probability that the value of X is smaller than or equal to x, where x is any real number. $F(x) = P(X \leq x)$.

The probability function $f(x)$ of a discrete random variable X expresses the probability that the value of X is equal to x. $f(x) = P(X = x)$.

If X is continuous, we talk about the density function instead of the probability function, because the probability of any single value of a continuous variable $= 0$. When the possible values of a continuous variable are grouped into the classes of the width l, the distribution of the classified values can be expressed by a histogram of relative frequencies. If the class width l is decreased gradually towards zero, the histogram approaches a smooth function which is called the density function of the distribution.

The expectation of a random variable is the mean value of its distribution in the population (the mean value in a sample is different in different samples).

E.g.1 Consider 4 numbered cards.

- The number on one card is 1 and the number on each of the three other cards is 5.
  - One card is selected at random.
  - Variable X gets the value = the number on the selected card.

Then X is a random variable. The value of X is either 1 or 5. The probability of the value 1 is $P(X = 1) = 1/4$, and probability of the value 5 is $P(X = 5) = 3/4$.

The expectation of X is $E(X) = P(X = 1)\cdot 1 + P(X = 5)\cdot 5 = 1/4\cdot 1 + 3/4\cdot 5 = 4$ and

the variance of X is $V(X) = P(X = 1)\cdot(1-4)^2 + P(X = 5)\cdot(5-4)^2 = 3$.

E.g.2 A population consists of type A units and type B units.

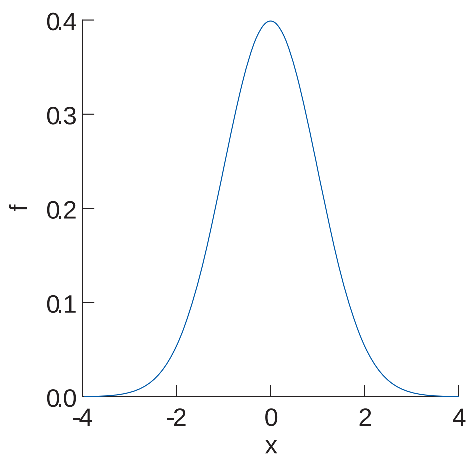
The proportion of type A units is p and the proportion of type B units is $1-p$. One unit is selected at random from the population and then returned. This is repeated n times. Let X be the number of times that the type A unit was selected. Then X is a random variable and its distribution is a binomial distribution. The probability function of the binomial distribution is

$P(X = k) = \binom{n}{k} p^k (1-p)^{n-k}$, if $0 \leq k \leq n$, and
$P(X = k) = 0$, if $k < 0$ or $k > n$.

The distribution of a continuous variable can be expressed by the density function. For example the density function of the normal distribution is

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{-1}{2}\left(\frac{x-\mu}{\sigma}\right)^2},$$

where μ is the expectation (mean value) and σ^2 is the variance of the distribution.



$N(0,1)$ - distribution

The normal distribution (= Gaussian distribution), $N(\mu, \sigma^2)$ for short, is symmetric about the mean and its shape is the bell shape.

3 Population, sample and sampling distribution

Let us assume that the objective of the study is to estimate the total volume of the growing trees on a forest area. The population of the study is then the growing trees on that area.

A random sample of trees is selected from the population and only the selected trees are measured.

The measured volumes comprise a random sample from the distribution of volumes in the population.

Estimate of the total volume is computed from the sample.

If we repeat sampling more and more times, we get different estimates from each sample.

The distribution of the estimates is called the sampling distribution of the estimate

Let us next assume that the purpose of a field trial is to get an estimate for the size of a treatment effect on the height growth of a certain tree species on a certain type of sites in.

Treated sites and untreated sites comprise two hypothetical populations.

The population averages of the height growth are two fixed, unknown values.

Treatment effect is the difference of the two averages and it is the fixed unknown value which we want to estimate.

Treated plots and untreated plots comprise two random samples, one sample from each population.

If we repeat the experiment on a new place, we get different estimates for the treatment effect because trees and plots are different and also the weather and other conditions may differ.

The estimate of the effect is a random sample from the sampling distribution of the estimates of the effect.

In both cases described above, the values of the response variable are attached to units of the population and

the statistical inference concerns one or more parameters of the distribution of values in the population (e.g. the total volume and the mean height growth).

A sample is the subgroup of the units of the population actually examined in order to estimate the parameter(s).

Note. Here the population parameters are regarded to have fixed unknown values. In Bayesian analysis the population parameters are regarded as random variables which have some known (prior) distribution.

4 Estimate, confidence interval and test

4.1 The point estimate of a population parameter

The distribution of values in the population is characterized by one or more parameters and the purpose is to estimate the value of these parameters using a sample.

The mathematical formula used in the calculation of the estimate is called an estimator. It is a random variable and its distribution (=sampling distribution) is defined by the formula itself, by the distribution of the values in the population and by sampling method.

E.g. The population distribution is the normal distribution with the mean μ and the variance σ^2, $N(\mu, \sigma^2)$, for short. The distribution of the mean of the random sample is $N(\mu, \sigma^2/n)$, the normal distribution with the expectation μ and the variance σ^2/n.

Because the expectation of the sample mean is equal to the parameter μ, we say that the sample mean is an <u>unbiased estimator</u> of μ.

The standard deviation of the estimate is also called the standard error of the estimate.

4.2 The confidence interval for a parameter.

The confidence interval is one way to describe how precise our estimate of the parameter is.

E.g.. The population mean μ is estimated by the sample mean $\overline{x}$. The unbiased estimate of the population variance σ^2 is $s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \overline{x})^2$.

The distribution of the statistic

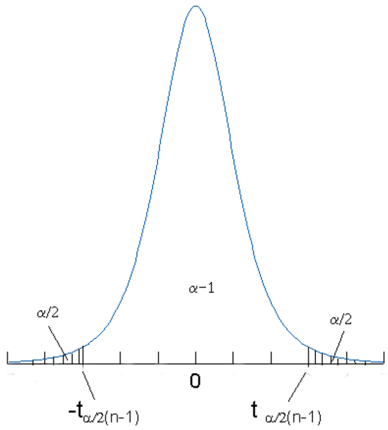
$$t = \frac{(\overline{x} - \mu)}{s}$$

is t-distribution with $n-1$ degrees of freedom, $t_{(n-1)}$ for short.

Hence we get the probability

$$P(-t_{\alpha/2(n-1)} \leq \frac{\overline{x} - \mu}{s} \leq t_{\alpha/2(n-1)}) = 1 - \alpha, \tag{1}$$

where $t_{\alpha/2(n-1)})$ is such a percentage point of the $t_{(n-1)}$ - distribution that the sum of the sizes of the two tail areas of the distribution $= \alpha$.



$t-$ distribution

The equation (1) can be written in the form

$$P(\overline{x} - s \cdot t_{\alpha/2(n-1)} \leq \mu \leq \overline{x} + s \cdot t_{\alpha/2(n-1)}) = 1 - \alpha,$$

The interval $\overline{x} \pm s \cdot t_{\alpha/2(n-1)}$ is called the confidence interval for mean μ at confidence level $1 - \alpha$. Probability $1 - \alpha$ is called the coverage probability since $1 - \alpha$ is the probability that the confidence interval covers the parameter. If, for example, $1 - \alpha = 0.95$, we can also talk about 95% confidence interval.

4.3 Tests

The test of a null hypothesis H0 is the decision rule weather the hypothesis should be rejected or not.

E.g. H0: The population mean $\mu = \mu_0$ against the alternative hypothesis H1: $\mu \neq \mu_0$.

If H0 is true, the distribution of the statistic t,

$$t = \frac{(\overline{x} - \mu_0)}{s}$$

is a t-distribution with $n - 1$ degrees of freedom and we get the probability

$$P(-t_{\alpha/2(n-1)} \leq \frac{\overline{x} - \mu_0}{s} \leq t_{\alpha/2(n-1)}) = 1 - \alpha.$$

If the absolute value of t is bigger than or equal to $t_{\alpha/2(n-1)}$, that is

$$\left| \frac{\overline{x} - \mu_0}{s} \right| \geq t_{\alpha/2(n-1)},$$

we conclude that the hypothesis H0 is rejected at the significance level α The percentage point $t_{\alpha/2(n-1)}$ is called the critical value of the test statistic. This test is called two-sided test because both the positive and negative values of the test statistic can lead to the rejection of the null hypothesis.

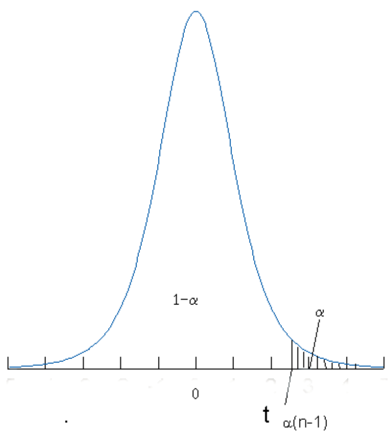
The P-value of a test = the observed significance level of the test = the probability that the test statistic gets the observed value or more extreme value when H0 is true. If the P-value is smaller than a fixed value, for example 0.05, the hypothesis H0 is rejected at that significance level.

The confidence interval for μ gives also the test result because $1 - \alpha$ level confidence interval covers the hypothetical value μ if H0 is not rejected at the significance level α, and conversely, the confidence interval doesn't cover the the hypothetical value if H0 is rejected.

If the alternative hypothesis is H1: $\mu > \mu_0$, one-sided test should be used instead of the two-sided test. In the one-sided test the critical value is $t_{\alpha(n-1)}$. If H0 is true,

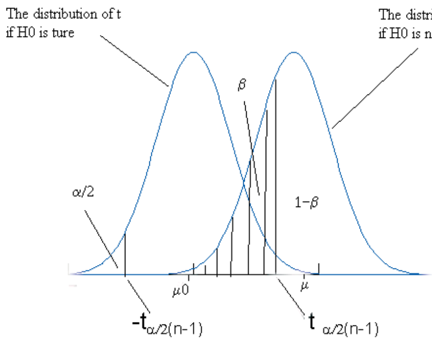
$$P(\frac{\overline{x} - \mu_0}{s} \geq t_{\alpha(n-1)}) = 1 - \alpha,$$

and H0 is rejected if $t = \frac{\overline{x}-\mu_0}{s} \leq t_{\alpha(n-1)}$.



4.3.1 The power of the test.

The test result may be wrong in two cases. If we reject H0 when it is true, we make type I error. The probability of type I error is α. If we don't reject H0 when it is false, we make type II error. If the probability of type II error is β, the power of the test is $1-\beta =$ the probability that H0 is rejected when it is false. The power of the test depends on the difference $\mu - \mu_0$, the significance level of the test and the sample size.



If the true mean value μ is far from the hypothetical value μ_0, it is more probable that the value of t is bigger than the critical value $t_{\alpha/2(n-1)}$, than in the case the difference $|\mu - \mu_0|$ is small.

4.4 The sample size

Consider we want to estimate the population mean. Assume that we have somehow got an estimate of the population variance, let it be s^2, and we want that the probability is α that the error of the estimate of the mean is at most $= d$. Then the sample size n should be

$$n = \frac{s^2 t^2_{a/2(n-1)}}{d^2}.$$

The value $t_{\alpha/2(n-1)}$ is not known when n is not known and the sample size is computed by using iterative trial and error method (Zar, pp 107-108). If n is large, the percentage point $t_{\alpha/2}$ can be taken from the normal distribution and no iteration is needed.

The sample size can also be based on the significance level and the power of the test. Assume we wish to perform a two-sided t-test using the significance level α. We want also that H0 is rejected with the probability of at least 1-β if the difference between the true mean μ and the hypothetical value μ_0 is at least δ. The formula for the sample size is then

$$n = \frac{s^2}{\delta^2} \left(t_{\alpha/2(n-1)} + t_{\beta(n-1)}\right)^2 .$$

4.5 Some other tests and the role of the normal distribution.

A tests and a confidence interval can be computed if the distributions of the estimator and the test statistic are known.

In parametric tests it is assumed that the distribution of the estimate is a normal distribution and, in the case of several estimates, a multivariate normal distribution or

it is assumed that the distribution is asymptotically a normal distribution, which means that the distribution can be approximated by a normal distribution if the sample size is large enough.

t-test can be used also in small samples. It assumes normal distribution for observations and that the estimate of the parameter and the estimate for standard error are independent (this is not true always).

If the sample size is large enough, the distribution of a statistic $w = est/sd(est)$ is $N(0, 1)$ and the distribution of w^2 is , χ^2 distribution with one degrees of freedom..Here est is estimate for a parameter and $sd(est)$ is its standard error

χ^2_k - distribution with k degrees of freedom is generated by the sum of k squared independent $N(0, 1)$ distributed variables.

The statistic of **Wald test** is $(est/sd(est))^2$. In a test of one parameter, its value is compared to the χ^2_1.

In the simultaneous test of k parameters, the distribution of corresponding Wald test statistic is the χ^2_k - distribution.

The F-distribution of a **F-test** statistic is generated by the ratio of two independent χ^2 - distributed variables. The the distribution of t^2-statistic is $F_{1,n}$- distribution, where the distribution of t is t-distribution with n degrees of freedom.

The **likelihood** of the values of a set parameters, given the observed data, is equal to the probability of the observed data given those values of parameters.

Maximum likelihood estimate for the parameters are those values of parameters which maximize the probability of observed data values.

The distribution of a maximum likelihood estimate is normal or asymptotically normal.

Loglikelihood is the (natural) logarithm of likelihood. In practice the likelihood estimates are obtained by maximizing the loglikelihood of the parameters.

Likelihood ratio test for k parameters is obtained as follows:

Estimate the model. Let the loglikelhood of the model be l_1.

Remove the effects corresponding the k parameters from the model and estimate the new model. Let the loglikelihood be now l_0.

The distribution of $-2 \times (l_0 - l_1)$ is (asymptotically) χ^2_k-distribution and the P-value of the test is obtained from this distribution.

If the distribution of the residuals is normal, the distribution of the estimates of the parameters of linear models is normal also in small samples.

If the distribution of the residuals is not normal, it may be possible to make a (monotonic) transformation to the observations (for example logarithmic transformation) so that the transformed observations have normal residuals

In that case the analysis are made using transformed observations

The computed P-values for tests are correct also for the untransformed observations

It is often useful to transform the computed predicted values, sizes of treatment effects, and the confidence intervals back to the original scale using the inverse transformation.

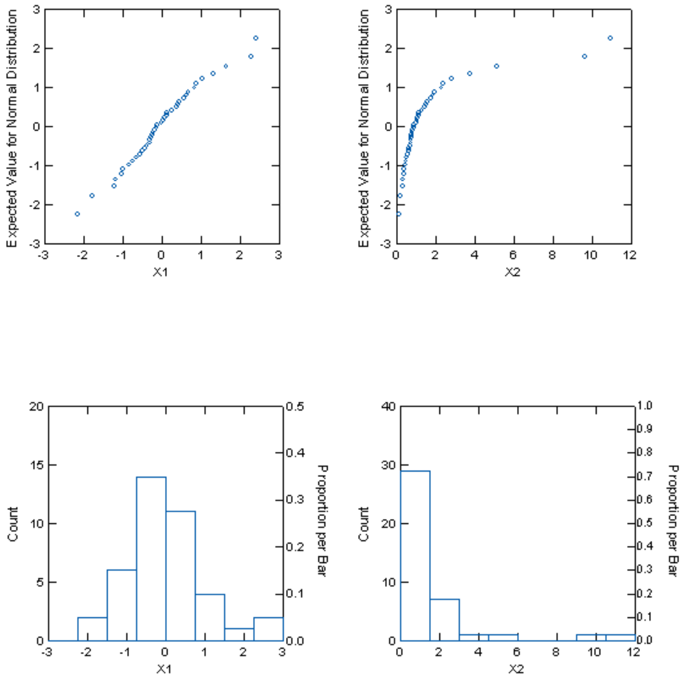
If the distribution of the response variable is not normal, the normal distribution based confidence intervals and tests may are valid if the sample size is large enough.

In generalized linear models the distribution of the response variable may be Poisson or Binomial etc., and the distributions of the estimates are asymptotically normal if the distribution of observations is described correctly in the model..

Non-parametric methods and so called exact tests do not require normal distribution.

Q-Q plots and normal probability plots.

An empirical distribution can be compared graphically to a theoretical distribution by Q-Q plots, that is by plotting the quantiles of the observed distribution against the quantiles of the theoretical distribution. If the points in the plot form approximately a straight line, the observed distribution is approximately same as the theoretical distribution. If the theoretical distribution is a normal distribution, this plot is called a normal probability plot or a normal quantile plot.



Above on the left normal quantile plot the empirical distribution is approximately normal and on the right the distribution is skewed. The lower chart is the histogram of the distribution and the upper plot is the corresponding probability plot.

4.6 Information criteria

Lets assume that we have a model candidate

$y = \alpha_0 + \alpha_1 x + \alpha_2 x^2 + \varepsilon$, where $\alpha_0, \alpha_1,$ *and* α_2 are regression coefficients, and

we want to test hypothesis $\mathrm{H}_0 : \alpha_2 = 0$.to decide if the second degree term is needed or not.

If we don't reject the hypothesis, we decide that a straight line $y = \alpha_0 + \alpha_1 x + \varepsilon$ describes the dependence of y on x as well as a parabola = the second degree polynomial .

Test can be used because the two models are hierarchical in the sense that the straight line model $y = \alpha_0 + \alpha_1 x + \varepsilon$ is a special case of the the second degree polynomial model $y = \alpha_0 + \alpha_1 x + \alpha_2 x^2 + \varepsilon$

Tests described previously can not be used if the two models are not hierarchical.

For instance if measure same experiment in several time points and the residuals are correlated.

We are considering two alternative models for the correlation structure. The models are

a compound symmetry model. Then $y_{ij} = \alpha_0 + \alpha_1 x_{ij} + plot_i + \varepsilon_{ij}$, where plot is a random plot-effect and the residuals of the same plot are not correlated.

The other model is an AR(1) model. Then $y_{ij} = \alpha_0 + \alpha_1 x_{ij} + \varepsilon_{ij}$, where the residuals of a plot are correlated according to an autoregressive (1) - model, but there is no plot effect.

In AR(1) structure there is one more parameter than in compound symmetry structure (see Linear mixed models for more details), but compound symmetry is not a special case of AR(1) model.

Because the models are not hierarchical, we use **information criteria** to decide between the alternative models

Akaike's information criterion AIC, is the loglikelihood adjusted for the number of parameters.

Likelihood (and loglikelihood) of a model tends to be the better the more parameters there are in the model and this tendency is eliminated in information criteria.

AICc is a version of AIC that takes into account the sample size. This is not needed if we compare models in the same data.

The values of information criteria are (usually) given in such a form that the smaller the value, the better is the agreement between the model and the data.

Most often the model for correlation structure is needed only because the tests and the confidence intervals of the interesting parameters are biased, if the correlations between the residuals are not taken into account.

In this case no tests for the differences between the alternative correlation models are needed and

we simply select the model that results the smallest information criteria.

There are also other information criteria than AIC, for instance Bayesian based BIC and deviance information criteria.

5 Correlation.

Correlation is a measure of association between the values of two random variables or between the ranks of their values.

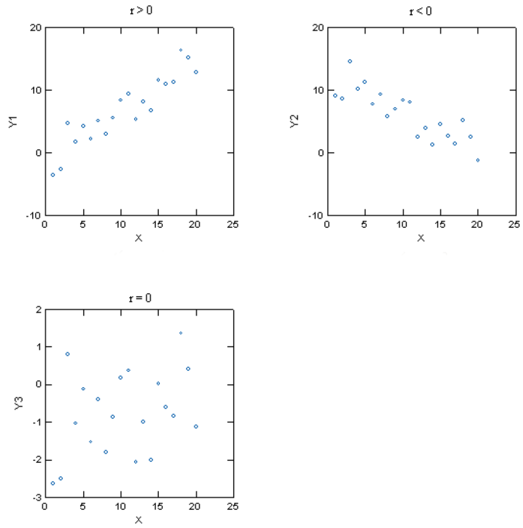
5.1 Correlation coefficient

Correlation coefficient of two variables is a measure of linear association (= Pearson coefficient of correlation). If the association is not linear, correlation coefficient is a misleading measure of association. Correlation coefficient of variables y and x (both variables must be ratio or interval scale variables) is $\rho = \frac{cov(x,y)}{\sigma_x \sigma_y}$ and it is estimated by

$$r = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \overline{y})^2}} = \frac{s_{xy}}{s_x s_y},$$

where $cov(x,y)$ is the covariance of x and y (= the expectation (mean) of the cross product $(x-\overline{x})(y-\overline{y})$), $s_{xy} = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})$ is the estimate of $cov(x,y)$, $s_x = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \overline{x})^2}$ is the estimate of σ_x, the standard deviation of x, and $s_y = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(y_i - \overline{y})^2}$ is the estimate of σ_y, the standard deviation of y.

The absolute value of both ρ and r is at most 1 ($-1 \leq r \leq 1$ and $-1 \leq \rho \leq 1$).



The standard error of r is estimated by

$$s_r = \sqrt{\frac{1 - r^2}{n - 2}}.$$

Hypothesis H0: $\rho = 0$ can be tested by using t - distribution. H0 is rejected if

$$\left| \frac{r}{s_r} \right| \geq t_{\alpha/2(n-2)}.$$

Formula for the confidence interval for ρ is given in Zar p 377.

Two coefficients of correlation can be compared by the method given in Zar pp 380-381.

Assumption: For tests and confidence intervals (x,y)-pairs must be a random sample from bivariate normal distribution (the distribution of the pairs (x, y) is bivariate normal if both x and y have normal distribution and the association is linear).

5.1.1 Independence

Random variables x and y are **independent,** if their joint cumulative distribution function is the product of their marginal distribution functions That is $F_{xy}(x, y) = F_x(x)F_y(y)$.

If random variables x and y are **independent**, correlation $\rho(x, y) = 0$ If their distribution is a bivariate normal distribution and $\rho(x, y) = 0$, they are also independent. For other distributions they may be dependent even if the correlation =0.

5.2 Rank correlation.

If the distribution of (x,y)-observations is far from the bivariate normal distribution or the measurement scale is ordinal scale, we can use rank correlation which is based on the ranks of the observations. The rank of x_i is the ordinal of x_i when all the x-values are in the order of magnitude.

Spearman rank correlation coefficient is the correlation coefficient of ranks. It can be computed using formula

$$r_s = \frac{6\sum_{i=1}^{n} d_i^2}{n^3 - n},$$

where d_i is the difference between the ranks of x_i and y_i.

Kendal rank correlation coefficient τ is another measure of rank correlation. The performance of both coefficients are very similar. Spearman coefficient is used more often.

5.3 Intra class correlation.

When the observation come from several groups, for example tree height measurements from several sites, the average height of trees are (more or less) different on different sites. The variance of the heights of all the trees is the sum within sites variance + between sites variance. Within site variance refers to variation around site mean values and between site variance refers to variance of the site mean values.

Formally $\sigma^2 = \sigma_w^2 + \sigma_b^2$, where σ^2 is the total variance, σ_w^2 is the within group (site) variance and σ_b^2 is the between group variance.

Intra class correlation between the units that belong to the same group is $\omega = \sigma_b^2/\sigma^2$ = 1-σ_w^2/σ^2. When the variation within groups is small, that is the values of the same group are close to each other, the within group variance σ_w^2 is small and the intra class correlation is strong, close to one. And when the average values of different groups are close to each other, the between groups variance σ_b^2 is small, and the intra class correlation is close to zero. Intra class correlation ω is never negative.

Intra class correlation between units that belong to different groups is = 0.

6 Regression

A regression function describes how the mean value of the dependent variable (= response variable) depends on the values of one ore more independent variables (= explanatory variables).

Linear regression is a special case of linear models, in which the distribution of the residuals is a normal distribution and explanatory variables are continuos.

6.1 Simple linear regression

Simple means here that only one independent variable is included in the model.

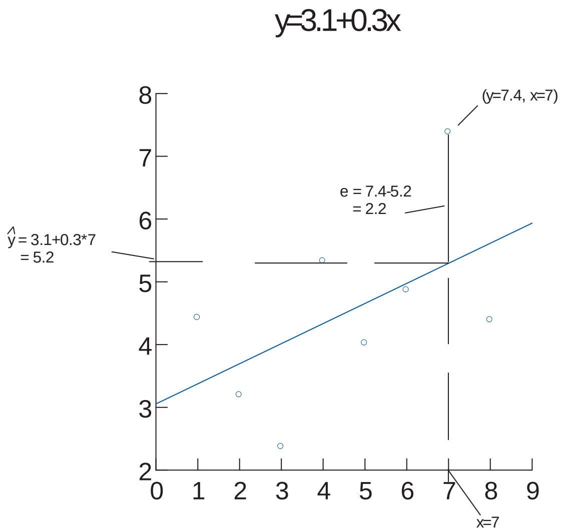
The regression model is

$$y = \alpha + \beta x + \varepsilon,$$

where y is the dependent variable (or response variable), x is the independent variable, α and β are parameters (α is the intercept and β is the slope), and ε is the error term. The errors are assumed to be independent and the distribution of the errors are assumed to be normal with the mean $= 0$ and the same (unknown) variance.

The estimator of β is $\widehat{\beta} = \frac{\sum_{i=1}^{n}(x_i-\overline{x})(y_i-\overline{y})}{\sum_{i=1}^{n}(x_i-\overline{x})^2}$ and the estimator of α is $\widehat{\alpha} = \overline{y} - \widehat{\beta}\overline{x}$.

Residual $e_i = y_i - \widehat{y}_i$, where $\widehat{y}_i = \widehat{\alpha} + \widehat{\beta}x_i$ is the estimate of y_i.



Coefficient of determination

The variation of the dependent variable y can be described by the total sum of squares (SS_{Total}) which has two components: Regression sum of squares ($SS_{Regression}$) and residual sum of squares ($SS_{Residual}$).

$$SS_{Total} = \sum_i (y_i - \bar{y})^2 \ ,$$
$$SS_{Regression} = \sum_i (\hat{y}_i - \bar{y})^2 \text{ and}$$
$$SS_{Residual} = \sum_i (y_i - \hat{y}_i)^2 \ .$$

Mean squares MS are sum of squares divided by the degrees of freedom.

E.g. $MS_{Residual} = SS_{Residual}/(n-p)$, where p = the number of parameters of the model. In the case of the simple linear regression model p=2.

Standard error of the estimate is $\sqrt{MS_{Residual}}$.

Coefficient of determination is $R^2 = \frac{SS_{Regression}}{SS_{Total}}$.

$R = \sqrt{R^2}$ is the correlation coefficient of y_i and $\hat{y}_i, i = 1, 2, 3, ..., n$.

Test and confidence interval for the coefficient β.

Statistic $t = \frac{\hat{b}}{s_{\hat{b}}}$ has distribution $t_{(n-2)}$, where $s_{\hat{b}}$ is the estimate of the standard error of $\hat{b}$.

Hypothesis H0: $\beta = 0$ is rejected at the significance level α if the absolute value of t is bigger than $t_{\alpha/2(n-2)}$, the $\alpha/2$ -percentage point of the $t_{(n-2)}$ -distribution

The confidence interval for β is $\widehat{\beta} \pm s_{\hat{b}} \cdot t_{\alpha/2(n-2)}$.

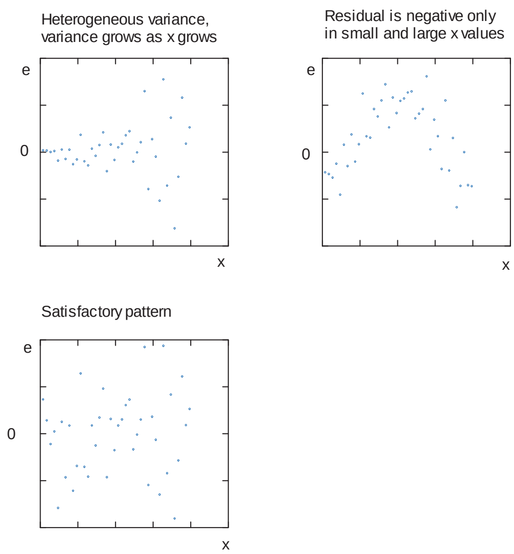
The confidence band for the regression line can also be computed.

6.2 Regression analysis. One independent variable. Model building and diagnostics.

- - Start the analysis by plotting the dependent variable y against the independent variable x. This helps you to find the first model candidate and to identify possible outliers and typing mistakes. Outliers are observations that come from different population than the rest of the observations and are far from the other observations in the scatterplot.

If outliers are included in the analysis, the estimates may be biased. If observations that are not outliers are excluded, the estimates may be biased. If observations are excluded from the analysis, it should be told in the report. You should also mention how many and why they have been excluded.

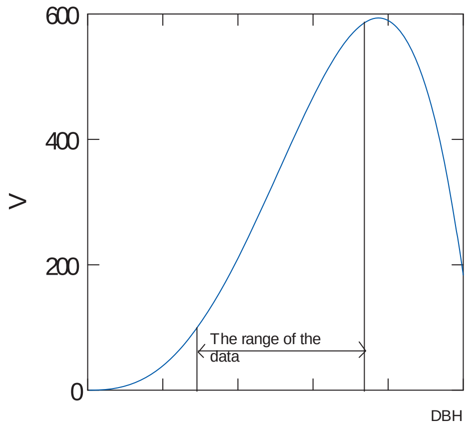
- - Estimate the model candidate.
- - Examine the coefficients and their P-values. If the P-value of a parameter is big (e.g. >0.05), the term is not needed in the model.
- - Examine the residuals by plotting them against the independent variable (or its transformation).



- - If the residual plot indicates heteroscedasticity (= heterogeneous variance), transform y-variable and modify the model respectively, or use the weighted least squares estimation method.
- - If the plot indicates lack of fit (= feature that can be described by some transformation(s) of x-variable, add a new term to the model or try some other type of function of x. E.g. if the plot looks like the right hand side plot above, try to add the term x^2 into the model.
- - Estimate the new model candidate.

- - When you think that the model is good enough, make sure that the form of the model is satisfactory by plotting estimates against x-values. If the model should be applied outside the range of data, is the function such that the extrapolation can be made ? Polynomials may be unsatisfactory in this respect.

E.g. the polynomial volume function Vol = a1·DBH^2 + a2·DBH^3 + a3·DBH^4, where Vol is the volume of the bole of the tree and DBH is the breast height diameter, may be a good model for interpolation but very poor for extrapolation.



An example of the polynomial volume function.

6.3 Transformations of the dependent variable.

The purpose of the transformation is to write the regression model in such a form that the residuals of the model of the transformed variable have approximately normal distribution and homogenous variance. The purpose is to satisfy the assumptions of the regression analysis. If the variance of the residuals is heterogeneous, we should use the weighted least squares estimation method instead of the unweighted least squares method, which is the default method in statistical computer packages. In tests and confidence intervals we assume the normal distribution of the residuals.

- If y is count, y ' = $\sqrt{y+0.5}$ is more suitable for tests than y. However, if the mean value of count is small (<5) and the sample size is not very small, it may be better to apply generalized linear models instead of linear models.

- If the variance of the residuals grows when the value of x grows, and y is positive, y ' $= log(y)$ or y ' $= log(y+1)$ may have homogeneous variance and and the distribution of the residuals may be close to the normal distribution.

- The general form of the power transformation is $y' = y^k$, where k is either positive or negative and is k selected so that the variance of y' is homogeneous. The transformation $log(y)$.corresponds the value $k = 0$. The power transformation is possible if all the y - values are positive.

- If y is percentages or proportions, the standard transformation is y ' = arcsin $\sqrt{y}$.

- If the variance of the residuals grows when the values of x grow, $y' = \frac{y}{x^k}$ may have homogenous variance. You may try e.g. k=0.5, k=1 and k=2 to find the best form. The distribution of residuals is normal if it is normal before the transformation. This transformation doesn't help if the distribution is skewed. Logarithmic transformation and square root transformation help if the distribution is skewed to the right. If $\frac{y}{x^k}$ has homogeneous variance, you may estimate and test your model using the original y as the dependent variable but you should use the weighted least squares estimation method with the weights $w = \frac{1}{x^{2k}}$.

- If the dependent variable is transformed, the alternative models are estimated and the effects of the independent variables are tested using the transformed dependent variable. If the developed model will be used for estimation (e.g. volume function to estimate the volume of trees) the form of the final model should be checked also in the original scale. E.g. if $y' = log(y) = a + bx + cx^2$, then the model for y is $y = e^{a+bx+cx^2}$, where log is the natural logarithm and e is the base of the natural logarithm. It is important that the model for y is logical and unbiased. Sometimes you have to use transformation correction to reduce the bias in the original scale. The usual correction for the logarithmic transformation is the coefficient $c = e^{s^2/2}$, where s^2 is the variance of the residuals in the logarithmic scale. The corrected model is then $y = e^{s^2/2+a+bx+cx^2}$.

The influence of observations.

The observations with the biggest x-values and the observations with the smallest x-values have more influence on the estimates of the parameters than the observations in the middle of the range of the x-values. Some observations may be too influential and the estimates may change essentially if they are excluded from the analysis.

Leverage value and Cook's distance measure the influence of the observations. The leverage value of an observation takes into account the values of the independent variables but it doesn't take into account the y-value and so it measures only the potential influence. Cook's distance of an observation measures how much the estimates change if the observation is excluded from the analysis. You may use these measures to identify observations that are too influential.

Sometimes influential observations are needed. E.g. the biggest trees of a sample may have large leverage value but they are needed in the estimation of the volume model so that the need for extrapolation can be avoided.

6.4 Multiple regression.

In multiple regression there is one dependent variable and two or more independent variables. Some of the independent variables may be functions of the other independent variables.

The purpose is to select the best subset of variables into the model and estimate the parameters. In multiple regression the square root of the coefficient of determination is called multiple correlation coefficient. Multiple correlation coefficient is the maximal correlation between one variable and any linear combination of the other variables.

If there are only a few independent variables, the variables can easily by selected by using scatterplots and tests. Scatterplots of the dependent variable vs independent variables hint which variables could be the most important ones. Often two or more independent variables are correlated and maybe only one of them is needed in the model.

Partial residual plots and added variable plots show how the dependent variable is related to the dependent variable after the effect of other independent variables is removed.

If there are many independent variables, stepwise selection procedures can be used for variable selection.

In backwards selection at first all the variables are in the model and then the least significant variables are removed one by one until all the variables in the model are significant.

In forward selection the most significant variable is at first alone in the model and then a new variable, which is best from the remaining variables, is included in the model. New variables are added one by one until no new significant variable can be found.

In the stepwise method one variable is either added to or removed from the model one by one until the model can not be improved by using this method. Note: If a new variable is added to or removed from the model, the P-values (significance) of the other variables in the model change.

6.4.1 Correlated dependent variables and multicollinearity

If two or more independent variables are correlated, the contribution of a variable on the variance of the rensponse can not assessed uniquely. Only the joint contribution of the correlated variables can be assessed uniquely.

If the correlation between two independent variables or if the multiple correlation between one independent variable and the other independent variables is very close to one, it is called ill conditioning and it causes problems in the numerical accuracy of the computation. Tolerance parameter in statistical computer packages define how strong linear relationship is allowed. In the case of ill conditioning one or more of the correlated variables has to be removed from the model. Ill conditioning happens if we add the same variable twice in the model, for example one variable in the model is the height in metres and another variable is the height in centimeters. Ill conditioning may happen also if we include very many transformations of the variables in the model.

6.5 Explanatory model vs predictive model

The relationship of the independent variables to the dependent variable may be a causal relationship or it may be statistical relationship. Regression analysis doesn't reveal weather the relationship is only statistical or weather it reflects causal dependency. The statistical relationship doesn't necessarily describe the biological relationship but the models based on merely statistical relationship may function as good predictive models.

6.6 Heterogenous variance and correlated residuals

In regression analysis it is assumed that the residuals are independent, identically distributed and have a normal distribution, and the estimation method is the method of least squares.

If the variance of the residuals is **heterogeneous** and proportional to the values of a variable v, this can be taken into account by using the weighted least squares estimation method with the **regression weights** w=1/v.

In the case of **correlated** residuals apply **linear mixed models** instead of linear models.

6.7 Nonlinear regression

A regression model is linear if it is of the form $y = a_1x_1 + a_2x_2 + a_3x_3 + ... + a_kx_k + \varepsilon$,

where $a_1, a_2, a_3, ..., a_k$ are parameters and $x_1, x_2, x_3, ..., x_k$ are independent variables.

For example

$y = a_0 + a_1x + \varepsilon$,
$y = a_0 + a_1x + a_2x^2 + \varepsilon$, and

$y = a0 + a_1/x_1 + \varepsilon$ are linear models.

The model $y = a_0 e^{a_1/x} \cdot \varepsilon$ is an example of the nonlinear models that can be linearized. If we take logarithm from both sides of the equal sign we get the model

$ln(y) = ln(a_0) + a_1/x + ln(\varepsilon)$, which is a linear model.

If the model is estimated in the form $z = b_1 + b_2 \frac{1}{x} + \eta$, where $z = log(y)$ and η is the error term, the model for y is

$$\widehat{y} = e^{\widehat{b}_1 + \widehat{b}_2/x},$$

where $\widehat{b}_1$ and $\widehat{b}_2$ are the estimates of the parameters.

The model $y = a_0 e^{a_1/x_1} + a_2 x_2 + \varepsilon$ is an example of the nonlinear models that cannot be transformed to a linear model.

If a nonlinear model can not be transformed to the linear form, nonlinear regression analysis can be used. In nonlinear regression analysis the estimation method is usually the least squares or the weighted least squares method but the estimates must be computed by using iterative methods. The tests and confidence intervals are exact only in large samples but usually good enough for practical purposes also in small samples.

Heterogenous variance of residuals can be taken into account by **regression weights**.

The **correlation of residuals** can be taken into account in **nonlinear mixed models**

7 Comparison of means

7.1 t-test

7.1.1 Two sample t-test

In the two sample t-test we compare the means of two populations and we have an independent sample from each population.

The test statistic of the hypothesis H0: $\mu_1 = \mu_2$ is $t = \frac{\bar{x}_1 - \bar{x}_2}{s_{\bar{x}_1 - \bar{x}_2}}$, where μ_1 and μ_2 are the population means and $\bar{x}_1$ and $\bar{x}_2$ are the sample means.

The distribution of the test statistic t is a t-distribution and H0 is rejected if $|t| \geq t_{\alpha/2,\nu}$, where ν is the degrees of freedom of $s_{\bar{x}_1 - \bar{x}_2}$.

If the population variances are equal,

$\widehat{\sigma}_p^2 = \frac{\sum_{j=1}^{n_1} (x_{1j} - \bar{x}_1)^2 + \sum_{j=1}^{n_2} (x_{2j} - \bar{x}_2)^2}{n_1 + n_2 - 2}$, $s_{\bar{x}_1 - \bar{x}_2} = \hat{\sigma}_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$, and $\nu = n_1 - n_2 - 2$, where n_1 and n_2 are the sample sizes.

If the population variances are not equal

$s_1^2 = \frac{1}{n_1-1}\sum_{j=1}^{n_1}(x_{1j}-\bar{x}_1)^2$, $s_2^2 = \frac{1}{n_2-1}\sum_{j=1}^{n_2}(x_{2j}-\bar{x}_2)^2$, $s_{\bar{x}_1-\bar{x}_2} = \sqrt{s_1^2+s_2^2}$

and $\nu = \frac{\left(\frac{s_1^2}{n_1}+\frac{s_2^2}{n_2}\right)^2}{\frac{\left(\frac{s_1^2}{n_1}\right)}{n_1-1} - \frac{\left(\frac{s_2^2}{n_2}\right)}{n_2-1}}$.

7.1.2 Paired sample t-test

Consider an experiment with n blocks. On each block there are two plots. One plot has been treated and the other is the control plot. If population 1 is the treated population and population 2 is the control population, the treatment effect μ_1 - μ_2 is estimated by $\bar{d} = \bar{x}_1$ - $\bar{x}_2 = \frac{1}{n}\sum_{i=1}^{n} d_i$, where $d_i = x_{1i} - x_{2i}$.

The test of the hypothesis H0: "there is no treatment effect" against H1: "the treatment effect is either positive or negative" is

$t_{\alpha/2(n-1)}$, where $s_d^2 = \frac{1}{n-1}\sum_{i=1}^{n}(d_i-\bar{d})^2$.

In this example the values x_{1i} and x_{2i} are correlated because the block means vary, and the two sample test can not be applied.

Note: The comparison based on the paired samples is more powerful than the comparison based on two independent samples.

Note. All t-tests described above are special cases of linear models and linear mixed models, and the same results can be computed by applying these models.

7.2 Non-parametric tests for the mean

Non-parametric tests of the location of the distribution are based on the ranks of the observations and test the population median. If the distribution of observations is symmetric, the median is equal to the mean and non-parametric tests can be used to test the means. Non-parametric tests are used when the distribution(s) is (are) not the normal distribution(s).

7.2.1 Test and confidence interval for the median

The confidence interval for the median is $x_{(i)} \leq$ median $\leq x_{(j)}$, where $i = C_{\alpha(2),n+1}$ and $j = n$ - $C_{\alpha(2),n}$.

$C_{\alpha(2),n}$ and $C_{\alpha(2),n+1}$ are critical values of the two-sided test at the significance level α . The critical values are given in Table B.27 in the book of Zar.

The test H0: median $= m_0$ against H1: median $\neq m_0$ is rejected at the significance level α if the confidence interval doesn't cover m_0.

7.2.2 Two-sample rank test

We have an independent sample from each of the two populations and we want to test the hypothesis H_0: $m_1 = m_2$, the population medians are equal, against H1: $m_1 \neq m_2$. The Mann-Whitney test is suitable for this.

In the Mann-Whitney test the two samples are combined and ordered according to the magnitude. The biggest value in either of the two samples gets the rank = 1 and the smallest value gets the rank $n_1 + n_2$, where n_1 and n_2 are sample sizes. The test statistic $U = n_1 n_2 + \frac{n_1(n_1-1)}{2} - R_1$, where R_1 = the sum of ranks in the sample 1. The test statistic $U' = n_1 n_2 - U$. In the two-sided test the bigger of the values U and U' is compared to the tabulated critical value $U_{\alpha(2),n_1 n_2}$.

This is also a test for the mean values if the population distributions are symmetric.

7.2.3 Wilcoxon paired-sample test

The Wilcoxon paired-sample test can be used for the test of the difference between the median of two populations. It can also be used for the test of the mean values if the population distributions are symmetric.

The hypothesis are again $H_0 : \mu_1 = \mu_2$ against $H_1 : \mu_1 \neq \mu_2$.

To compute the test statistic the differences of the pairwise observations $d_i = x_{1i} - x_{2i}, i = 1, 2, ..., n$, are ordered according to the magnitude. The ranks of the positive differences get the plus sign and the ranks of the negative differences get the minus sign. The hypothesis H_0 is rejected if either T_+ or T_- is smaller than the tabulated critical value, where T_+ is the sum of the positive ranks and T_- is the sum of the negative ranks (e.g. Zar, Table B.12).

8 Kolmogorov-Smirnov test of the distributions

Consider we have measured the diameters of the sample trees in two sites and we want to test if the diameter distributions are equal. For this we can use the nonparametric Kolmogorov-Smirnov test.

The test statistic is based on the biggest difference between the two cumulative distributions. The critical values of the test statistic have been tabulated (e.g. Zar, Table B.10).

Note: If the diameter data has been grouped to diameter classes and is given in the form of the number of trees in the diameter classes, then the larger is the class width the smaller is the power of the test.

9 The chi-square test for the independency

Two diameter distributions given by the number of trees in each diameter class can be arranged in a 2 by m contingency table where each diameter distribution is on one row and the m diameter classes form the m columns.

E.g.

Diam. class	3	6	9	12	15	18	Total
Site 1	11	17	15	13	12	10	78
Site 2	15	13	20	25	11	12	96

The χ^2 (chi-square) test statistic of independency of the columns and the rows is

$$\chi^2 = \sum_{i=1}^{2}\sum_{j=1}^{m} \frac{\left(f_{ij} - \widehat{f}_{ij}\right)^2}{\widehat{f}_{ij}}$$

where

f_{ij} = the number of trees in the cell ij and

$\widehat{f}_{ij}$ = the expected value of f_{ij} if H_0 is true.

The distribution of χ^2 is χ^2_ν, where ν, the degrees of freedom is $(c-1)\cdot(r-1)$, where r = the number of rows and c = the number of columns. In our example ν = (2-1)$\cdot(6-1) = 5$.

The Chi-square test is biased if the number of small values of $\widehat{f}_{ij}$ is too big. One rule of thumb says that the test should not be used if any of $\widehat{f}_{ij}$ is smaller than 1 or if more than 20 % of $\widehat{f}_{ij}$ values are smaller than 5.

10 The comparison of more than two means

E.g. The equality of 4 means should be tested. The null hypothesis is $H_0 : \mu_1 = \mu_2 = \mu_3 = \mu_4$, and an independent sample has been taken from each of the 4 populations.

The hypothesis is true if three hypothesis $H_{01} : \mu_1 = \mu_2$, $H_{02} : \mu_2 = \mu_3$, and $H_{03} : \mu_3 = \mu_4$ are all true at the same time. This cannot be be tested by three t-tests because the more tests there are, the bigger is the probability that at least one null hypothesis is rejected even if all the hypothesis are true. This probability depends on the number of mean values that are compared as follows.

The number of mean values	The rejection probability
2	0.05
3	0.13
4	0.22
10	0.65
20	0.90

If we test two mean values at the 5 % significance level, the rejection probability of the null hypothesis is 0.05 if the hypothesis is true. If we compare 20 mean values, we have to make 19 tests, and the probability that at least one null hypothesis is rejected when all the null hypothesis are true, is 0.90.

For this reason, if we want to compare several mean values, we use analysis of variance instead of several t-tests.

10.1 The principle of the analysis of variance

Consider we have an independent sample from k populations (completely randomized design).

Notations:

y_{ij} = the value of the observation j of the treatment i,

n = the number of replicates,

k = the number of treatments,

$\overline{y}_{i.}$ = the mean of the observations of the treatment i,

$\overline{y}$ = the mean of all the observations.

Each observation can be written as

$y_{ij} = \overline{y} + (\overline{y}_{i.} - \overline{y}) + (y_{ij} - \overline{y}_{i.})$, and further
$(y_{ij} - \overline{y}) = (\overline{y}_{i.} - \overline{y}) + (y_{ij} - \overline{y}_{i.})$. From this
$(y_{ij} - \overline{y})^2 = ((\overline{y}_{i.} - \overline{y}) + (y_{ij} - \overline{y}_{i.}))^2$, and
$\sum_{i=1}^{k}\sum_{j=1}^{n}(y_{ij} - \overline{y})^2 = \sum_{i=1}^{k}\sum_{j=1}^{n}(\overline{y}_{i.} - \overline{y})^2 + \sum_{i=1}^{k}\sum_{j=1}^{n}(y_{ij} - \overline{y}_{i.})^2$.

These sums of squares (SS) are are called

Total sum of squares = Treatment sum of squares + Error sum of squares or

$SS_{Total} = SS_{Treatment} + SS_{Error}$.

The mean squares (MS) are the sum of squares divided by their degrees of freedom.

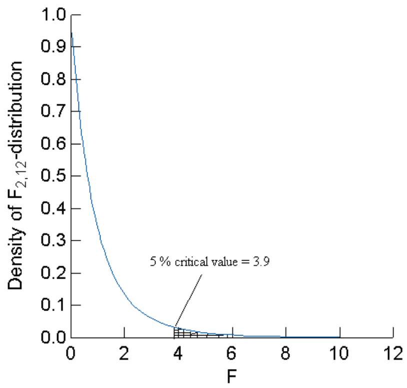
$$MS_{Total} = \frac{SS_{Total}}{nk-1}, \quad MS_{Treatment} = \frac{SS_{Treatment}}{k-1}, \quad MS_{Error} = \frac{SS_{Error}}{k(n-1)}.$$

The test statistic F of the hypothesis $\text{H}_0 : \mu_1 = \mu_2 = ... = \mu_k$ is the ratio of the treatment mean square and the error mean square (= residual mean square), $F = \frac{MS_{Treatment}}{MS_{error}}$. The distribution of F is the F_{ν_1,ν_2}- distribution with ν_1 and ν_2 degrees of freedom (df), where ν_1 =.the degrees of freedom of $MS_{Tretament}$ and ν_2 = the degrees of freedom of MS_{Error}.

The big values of F (small P-values of F) lead to the rejection of H_0. The P-value (= significance) of F is the probability that the F gets the observed value or bigger than that when H_0 is true.

E.g. Data from an experiment about the effect of pot type on the height of seedlings is as follows. The number of treatments is 3, the number of replicates is 5 and the design is the completely randomized design.

Plot	Replicate					Mean
type	1	2	3	4	5	height
Type 1	47	53	49	50	46	49
Type 2	55	54	58	61	52	56
Type 3	54	50	51	51	49	51



10.2 The analysis of variance table

Source of variation	df	SS	MS	F	Significance
Total	14	224	16.0		
Treatment	2	130	65.0	8.30	0.00
Error	12	94	7.83		

$F = \frac{130/2}{94/12} = \frac{65}{7.83} = 8.3$

The distribution of the statistic F is the F-distribution with 2 and 12 degrees of freedom.

Different design lead to different set of sum of squares.

E.g.1. The analysis of variance table for a completely randomized 2×3 factorial design. Factors A and B, 3 replicates:

Source of variation	df	SS	Ms	F	Significance
Total	17	SS_{Total}			
A	1	SS_A	MS_A	MS_A/MS_{Error}	
B	2	SS_B	MS_B	MS_B/MS_{Error}	
AB	2	SS_{AB}	MS_{AB}	MS_{AB}/MS_{Error}	
Error	12	SS_{Error}	MS_{Error}		

E.g.2. The analysis of variance table for a randomized blocks design. 4 treatments and 3 blocks:

Source of variation	df	SS	Ms	F	Significance
Total	11	SS_{Total}			
Block	2	SS_{Bl}	MS_{Bl}	MS_{Bl}/MS_{Error}	
Treatment	3	SS_{Tr}	MS_{Tr}	MS_{Tr}/MS_{Error}	
Error	6	SS_{Error}	MS_{Error}		

E.g.3. The analysis of variance table for a randomized block 2×3 factorial design. Factors A and B, 3 blocks:

Source of variation	df	SS	Ms	F	Significance
Total	17	SS_{Total}			
Block	2	SS_{Bl}	MS_{Bl}	MS_{Bl}/MS_{Error}	
A	1	SS_A	MS_A	MS_A/MS_{Error}	
B	2	SS_B	MS_B	MS_B/MS_{Error}	
AB	2	SS_{AB}	MS_{AB}	MS_{AB}/MS_{Error}	
Error	10	SS_{Error}	MS_{Error}		

10.3 Linear model approach to ANOVA and ANCOVA

In linear model approach

- the values of the response variable are described by a linear model,
- estimates for the model parameters and for the variances and covariances of these estimates are computed and
- estimates, confidence intervals and tests for the main effect-, interaction effect- , and other contrasts of the model parameters are computed.

Treatment levels are represented in the model by indicator variables and the regression coefficients of the indicator variables are estimates for the treatmen means.

In data each factor is presented by a categorical variable. For example **univariate** and **mixed** procedures in SPSS create automatically indicator variables for the levels of the factors.

Continuous explanatory variables (=covariates) are additional independent variables in the model.

Different treatment structures and experimental designs lead to different models.

Traditionally, if the model includes continuos covariate(s), we talk about the analysis of covariance or covariance analysis (ANCOVA). If the model doesn't include any covariate, we talk about the analysis of variance (ANOVA).

Nowadays we talk simply about linear models and linear mixed models etc. and the models used in the analysis are usually reported in the Statistical methods - chapter.

It used to be important to report the ANOVA tables as described above, including the sum of squares, F-values, their degrees of freedom and the P-values (significances).

In most journals the sum of squares, F-values and their degrees of freedom are not reported any more.

Instead the estimates for the treatment effects and their confidence intervals and/or P-values are reported.

For example the linear model for a completely randomized design with 3 treatments is
$y_{ij} = \mu + \alpha_i + \varepsilon_{ij},$

where

μ = the overall mean,

α_i = the effect of treatment $i,\ i = 1, 2, 3$, and

ε_{ij} = the error, $i = 1, 2, 3,\ j = 1, 2, 3, ..., n$. It is assumed that the errors are independent and their distribution is identical normal distribution with the mean = 0 and unknown variance.

The treatment mean $\mu_i = \mu + \alpha_i,\ i = 1, 2, 3$, and there is no treatment effect if the null hypothesis $H_0 : a_1 = \alpha_2 = \alpha_3 = 0$ is true.

This can be expressed using two contrast. For example contrast set 1:
contrast 1: $1 \times a_1 - 1 \times \alpha_3$ and
contrast 2: $1 \times \alpha_2 - 1 \times \alpha_3$.

If the value of both contrasts is = 0, H_0 is true. For each contrast this can be tested separately using t-test. F-test is used to tes if the values of both contrasts are = 0.

There are several possibilities to write contrasts for the H_0 hypothesis, but all possibilities result the same P-value in F-test. For example contrast set 2 could be:
contrast 1: $1 \times a_1 - 1 \times \alpha 2$ and
contrast 2: $1 \times \alpha_2 - 1 \times \alpha_3$

Contrast set 1 and contrasts set 2 result the same P-value of the F-test of the hypothesis H_0

Statistical procedures like unianova and mixed in spss generate automatically contrasts for the main effects and interactions and so called simple contrasts. Other contrasts user have to formulate.

To be able to compute an analysis, the information a computer software needs includes at least:

- which variable in the data is the dependent variable,

- which variables are independent variables,

- which independent variables are categorical and which are continuous and

- which interactions are included in the model.

10.4 About the parametrization of the model

Model

$y_{ij} = \mu + \alpha_i + \varepsilon_{ij}$,

has four parameters but the constant μ is such that the sum $\alpha_1+\alpha_2+\alpha_3 = 0$.

For this reason one of the effects can be computed using from the two other parameters, for example $\alpha_1 = -\alpha_2 - \alpha_3$ and this form of the model is overparametrized .

This means that the estimates are not unique, there are many possible estimates.

For this reason the computer procedures set the constant μ value=0, one treatment mean a reference value and the other levels are compared to that.

If we set level 3 as the reference level, the corresponding model is
$y_{ij} = \alpha_3 + \beta_i + \varepsilon_{ij}$,
where $\beta_1 = \alpha_1 - \alpha_3$, $\beta_2 = \alpha_2 - \alpha_3$,and $\beta_3 = 0$.
Treatment means are now $\alpha_1 = \alpha_3 + \beta_1$, $\alpha_2 = \alpha_3 + \beta_2$ and α_3.
If we set level 1 as a reference level, the model is
$y_{ij} = \alpha_1 + \beta_i + \varepsilon_{ij}$,
where $\beta_2 = \alpha_2 - \alpha_1$ and $\beta_3 = \alpha_3 - \alpha_1$, and $\beta_1 = 0$.

In reports the model in usually given in the form $y_{ij} = \mu + \alpha_i + \varepsilon_{ij}$,

but the many computer baggages report the parameters for the model $y_{ij} = \alpha_3 + \beta_i + \varepsilon_{ij}$.

The syntax for the contrasts may be different for different parametrization and different computer software, but they all give the same estimates, confidence intervals and test results for treatment effects and their contrasts.

Linear models for the basic designs.

1. Completely randomized design,
one-way (= non factorial) treatment structure.

$$y_{ij} = \mu + \alpha_i + \varepsilon_{ij}$$

where
y_{ij} = response of treatment i in replicate j,
μ = overall mean,

α_i = the effect of treatment i,
ε_{ij} = the error ij, $i = 1, 2, 3, ..., t,\ j = 1, 2, 3, ..., n_i$,
where t = the number of treatments and
n_i = the number of replicates of the treatment i.

2. Randomized blocks design,
one-way treatment structure.

$$y_{ij} = \mu + \alpha_i + bl_j + \varepsilon_{ij}$$

where
y_{ij} = response of treatment i , block (=replicate) j
μ = overall mean,
α_i = the effect of treatment i,
bl_j= the (random or fixed) effect of block j,
ε_{ij} = the error ij, $i = 1, 2, 3, ..., t,\ j = 1, 2, 3, ..., n$,
where t = the number of treatments and n = the number of blocks.

3. Completely randomized design,
two-way treatment structure, factors A and B.

$$y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}$$

where
y_{ijk} = response of treatment A_iB_j replicate k,
μ = overall mean,
α_i = the effect of treatment A_i,
β_j = the effect of treatment B_j,
$(\alpha\beta)_{ij}$ = the interaction effect of treatment A_iB_j,
ε_{ijk} = error ijk, $i = 1, 2, 3, ..., t_A,\ j = 1, 2, 3, ..., t_B,\ k = 1, 2, 3, ..., n_{ij}$,
where
t_A = the number of levels of the factor A,
t_B = the number of levels of the factor B, and
n_{ij} = the number of replicates of the treatment A_iB_j .

4. Randomized blocks design,
two-way treatment structure, factors A and B.

$$y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + bl_k + \varepsilon_{ijk}$$

where
y_{ijk} = response of treatment A_iB_j in block k,
μ = overall mean,
α_i = the effect of treatment A_i,

β_j = the effect of treatment B_j,
$(\alpha\beta)_{ij}$ = the interaction of treatment A_iB_j,
bl_k = the (random or fixed) effect of block k,
ε_{ijk} = error ijk, $i = 1, 2, 3, ..., t_A,\ j = 1, 2, 3, ..., t_B,\ k = 1, 2, 3, ..., n$,where
t_A = the number of levels of the factor A,
t_B = the number of levels of the factor B, and
n = the number of blocks.

In randomized block designs the block effect may be treated either as a random or as a fixed effect. In balanced designs the test results are the same in both cases.
In unbalanced designs it is better to treat blocks as random effects

5. Latin square, one-way treatment structure.

$$y_{ijk} = \mu + \alpha_i + r_j + c_k + \varepsilon_{ijk}$$

where
y_{ijk} = response of treatment i on row j, column k,
μ = overall mean,
α_i = the effect of the treatment A_i,
r_j = the (random or fixed) effect of the row j,
c_k = the (random or fixed) effect of the column j,
ε_{ijk} = error ijk, $i = 1, 2, 3, ..., t,\ j = 1, 2, 3, ..., n,\ k = 1, 2, 3, ..., n$,where
t = the number of treatments and
n = the number rows = the number of columns.

In the models 1 - 5 above it is assumed that the error are independent, identically distributed random variables and their distribution is the normal distribution.

6. Randomized blocks, split-plot design.
The whole plot factor is A and the sub-plot factor is B.
Randomized block split-plot design

$$y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + bl_k + (bl\alpha)_{ij} + \varepsilon_{ijk}$$

where
y_{ijk} = response of treatment A_iB_j on block k
μ = overall mean,
α_i = the effect of treatment A_j,
β_j = the effect of treatment B_k,
$(\alpha\beta)_{ij}$ = the interaction of treatment A_jB_k,
bl_k = the (random or fixed) effect of block k,

$(bl\alpha)_{ik}$ = the random interaction of block k and treatment A_i
= the whole-plot error,
ε_{ijk} = the split-plot error ijk, $i = 1, 2, 3, ..., n_A,\ j = 1, 2, 3, ..., t_A$, $k = 1, 2, 3, ..., t_B$, where
n_A = the number of blocks,
t_A = the number of levels of the factor A and
t_B = the number of levels of the factor B.

In split-plot model it is assumed that (i) the whole-plot errors are independent and identically distributed and they have the normal distribution, (ii) the sub-plot errors are independent and identically distributed and they have the normal distribution, and (iii) the whole-plot errors are independent from the sub-plot errors.

The whole-plot error is the error term of the tests and confidence intervals for the whole-plot treatment effects.

The sub-plot error is the error term of the tests and confidence intervals for the sub-plot treatment effects and for the whole-plot and the sub-plot treatments interaction.

If the residuals are correlated (there are more than one error term), as is the case for example in split-plot models, the user of a traditional ANOVA software has to point to the software the error terms for each test.

The modern approach is the **linear mixed model** approach, which allows correlated residuals and software solves automatically the error terms on the basis of the model and data.

10.5 More about contrasts

Contrast is a mathematical way of expressing differences between the mean values of two or more populations for estimation and testing.

Consider a treatment T with t levels. If the population mean values at the t levels are $\mu_1,\ \mu_2,\ \mu_3, ...,\ \mu_t$, a contrast in the T-effects is any linear combination $\sum_{i=1}^{t} c_i\mu_i = c_1\mu_1 + c_2\mu_2 + c_3\mu_3 + ... + c_t\mu_t$ such that $c_1 + c_2 + c_3 + ... + c_t = 0$.

For example

$\mu_1 - \mu_2$,

$\mu_2 - \mu_t$, and

$\mu_1 + \mu_2 + \mu_3 - 3\mu_4$ are contrasts.

The estimate of the contrast $\mu_1 - \mu_2$ is the estimate of the difference between the effects of the treatments T_1 and T_2. The confidence interval for the contrast is the confidence interval for the difference between the effects. The test of the hypothesis H0: $\mu_1 - \mu_2 = 0$ (the value of the contrast is = 0) is also a test of the hypothesis $H_0 : \mu_1 = \mu_2$ (there is no difference between the treatment effects).

10.5.1 Main effect and interaction

Consider a factorial field trial where three weeding methods are tested using seedlings of two provenances and the response variable is the height of the seedlings.

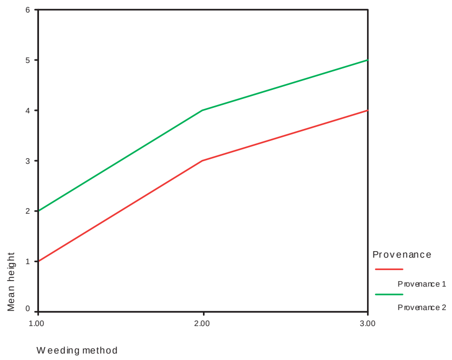
In analysis of variance the differences between the effects of the six different treatment combinations (3 weeding methods * 2 provenances) are grouped to main effects and interaction. The difference between the mean height of the provenances, averaged over all weeding methods, is represented by the main effect of the provenance factor.

The difference between the mean height of any two weeding methods, averaged over both provenances, is a component of the main effect of the weeding method factor. There are three pairs of weeding methods (if the methods are 1,2 and 3, the pairs are 1-2, 1-3 and 2-3) and the comparison of each pair is a main effect component. If the differences of any two pairs of weeding methods are known, the third difference can be computed from the known differences, which means that the main effect of the weeding method has two independent components. The degrees of freedom of a main effect (or an interaction) is equal to the number of independent components in it. If a factor has k levels, its degrees of freedom is k-1. Thus the degrees of freedom of the main effect of the weeding method is two. The main effect of the provenance has one component and one degree of freedom.

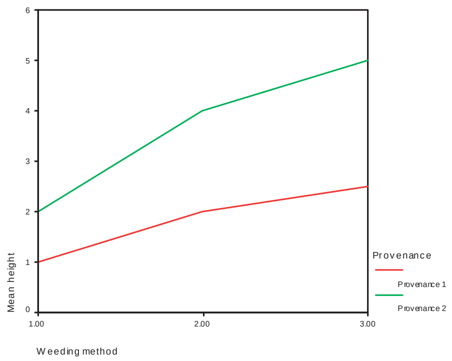
The components of the (two-way) interaction are the differences of differences. One interaction component of the provenance and the weeding method is the difference between the mean height of the provenances on one weeding method compared to the difference between the mean height of the provenance on some other weeding method. There are three this kind of comparisons of provenances. Also the difference between the mean height of any two weeding methods for one provenance compared to the same difference for the other provenance is an interaction component. The number of this kind of comparisons of the weeding effects is three. The interaction of the provenance and the weeding method has, however, only two independent components (= comparisons) and its degrees of freedom is two. The degrees of freedom of the interaction of two factors is the product of the degrees of freedom of the factors.

In the treatments structure of three factors the comparisons of treatment effects are grouped to 3 main effects, 3 two-way interactions and 1 three-way interaction. The components of a two-way interaction are now average two-way interactions averaged over the levels of the third factor. Analogously, components of the three-way interaction compare two-way interactions on different levels of the third factor.

No interaction. The lines connecting the means are parallel.



Interaction. The difference between the provenances is larger in the method 1 than in the method 3.



Let the treatment combination means be $\mu_{11}, \mu_{12}, \mu_{21}, \mu_{22}, \mu_{31}$ and μ_{32}, where the first index refers to provenance and the second index refers to weeding method.

Provenance mean values over the weeding methods are then $\mu_{1.} = (\mu_{11} + \mu_{12})/2$, $\mu_{2.} = (\mu_{21} + \mu_{22})/2$ and $\mu_{3.} = (\mu_{31} + \mu_{32})/2$.

Contrasts for the F-test of the main effects of provenance are for instance
$\mu_{1.} - \mu_{3.} = (\mu_{11} + \mu_{12} - \mu_{31} - \mu_{32})/2$ and
$\mu_{2.} - \mu_{3.} = (\mu_{21} + \mu_{22} - \mu_{31} - \mu_{32})/2$

The main effect contrast for the weeding method is
$\mu_{.1} - \mu_{.2} = (\mu_{11} + \mu_{21} + \mu_{31} - \mu_{12} - \mu_{22} - \mu_{32})/3$

The interaction contrasts are for instance
$(\mu_{11} - \mu_{12}) - (\mu_{31} - \mu_{32}) = \mu_{11} - \mu_{12} - \mu_{31} + \mu_{32}$ and
$(\mu_{21} - \mu_{22}) - (\mu_{31} - \mu_{32}) = \mu_{21} - \mu_{22} - \mu_{31} + \mu_{32}$.

10.6 Simple contrasts.

We can estimate and test effects of one factor on one level of the other factor. These comparisons are called simple contrasts. SPSS software the estimates are called estimated marginal means and in SAS their are least square means.

For example corresponding contrasts for the weeding effect on each of the provinces are
$\mu_{11} - \mu_{21}$
$\mu_{12} - \mu_{22}$ and
$\mu_{13} - \mu_{23}$
When the treatments are expressed as combinations of different factors, the computer software generates and tests main-effect and interaction effect contrasts automatically and reports their F-test results.

The same result is obtained if the treatment combinations are analyzed as one way analysis and the main effect and interaction contrasts are defined by the user of the software.

10.7 Type I, II, III and IV hypothesis

We can test the significance of a term in the model in more than one way.

The Type I hypothesis takes into account only those terms which are already in the model and test how significant the new term is if it is added to the model. The significance of a term depends on in which order the terms are added to the model.

In the type II hypothesis the significance of a main effect is tested assuming that all the other main effects are already in the model. The significance of a two way interaction is tested assuming that all the main effects and all the other two-way interactions are already in the model, etc.

In the type III hypothesis the significance of a term is tested assuming all the other terms are already in the model.

If no treatment is missing, type IV hypothesis is the same as the type III hypothesis. If there are missing treatments, this is taken into account in type IV hypothesis.

E.g. factors A and B, factor A has two levels and factor B has three levels and the treatment means are $m_{ij}, i = 1, 2,\ j = 1, 2, 3$.

	B1	B2	B3
A1	m_{11}	m_{12}	m_{13}
A2	m_{21}	-	m_{23}

Above the treatment A2B2 is missing.

The type III hypothesis of the main effect of A is $(m_{11} + m_{12} + m_{13})/3 = (m_{21} + m_{23})/2$

and the type IV hypothesis is $(m_{11} + m_{13})/2 = (m_{21} + m_{23})/2$.

Type III hypothesis can be used always except if there are missing treatments. In that case effects should be tested using type IV hypothesis.

In most statistical computer programs the default is type III hypothesis.

10.8 Multiple comparisons

In the analysis of variance we test the treatment effects. If we reject the hypothesis that there are no differences, we have to find out which treatment effects differ from each other. This can be done by using multiple comparison methods.

When we compare several treatments with each other, we make several tests, which is taken into account in the multiple comparison methods. The experimentwise error rate is the probability of rejecting at least one null hypothesis when all the null hypothesis are true. By using multiple comparison methods we can fix the experimentwise error rate at some level, e.g. 0.05. For example in the t-test we fix the comparisonwise error rate at some level but we don't take into account the other tests we are computing.

In each comparison the power of the t-test at a fixed significance level is usually bigger than the power of the multiple comparison test at the same significance level. However, if several hypothesis are tested in a single experiment, the experimentwise error rate must be controlled. In LSD-method the experimentwise error is controlled by a F-test and if it indicates significant differences, P-values of individual comparisons are not adjusted.

- If the F-test in the analysis of variance is significant, make all the planned comparisons using LSD-method.
- For other pairwise comparisons use LSD-method, Bonferroni or stepwise Bonferroni adjustment or use Tukeys HSD method.
- If all the other treatments are compared to one treatment (e.g. control), use LSD-method, Bonferroni or stepwise Bonferroni adjustment or Dunnett's method.

11 Linear mixed models

If units are grouped, for example plots within blocks and split-plots within whole plots, there is intra class correlations between units.

If the same subject (=unit) is measured more than once, the responses of the subject may be correlated (=within subject correlations).

Linear mixed models are a generalization of linear models in the sense that it allows correlated residuals.

The fixed part of a linear mixed model is similar to that of linear models but the variation of the **error term** is described by means of **random effect**(s) and/or **within subject correlations**.

Intra class correlations are taken into account by random effects that correspond the grouping of subjects.

Variances of random effects are called variance components and they are between subject variances within groups.

Subjects within the smallest groups are assumed to be uncorrelated, but the residuals of the same subject may be correlated.

Fixed factors and random factors

- A fixed factor is such that its levels are known and there is no randomness involved with the levels. For example the treatments in an experiment are set by the researcher who planned the experiment.

If we repeat the experiment in some other place of the same population, we get the same treatment effects. However, the estimated of the treatment effects are more or less different because of the random residual variation.

- A random factor is such that its levels are a random sample from some distribution. For example blocks in an experiment are thought to be a random sample from all possible blocks

If we repeat the experiment in some other place, the new blocks and their effects are a new sample and they are not the same as in the first experiment.

Note. In statistical analyses we sometimes may treat random effects as fixed effects. In that case the analysis is called a conditional analysis. Condition is that the random effects are those that have generated the data.

Examples of linear mixed models

The linear mixed model for a randomized block design is

$y_{ij} = \mu + \alpha_i + bl_j + \varepsilon_{ij}$

where α_i is a fixed treatment effect and bl_j is a random block effect. Variable bl defines which subjects belong to the same group.

There is only one measurement from each plot, so the residuals ε_{ij} from the same block are not correlated.

If we measure the same experiment at t different times, the model is

$y_{ijk} = \mu + \alpha_i + T_k + (\alpha T)_{ik} + bl_j + \varepsilon_{ijk}$,
where T_k is the fixed time effect, $k,\ k = 1, 2, ..., t$.
Residuals ε_{ijk} within each plot ij, $(\varepsilon_{ij1}, \varepsilon_{ij2}, ..., \varepsilon_{ijt})$ may be correlated (time correlation in this case).

Typical models for the time correlation are compound symmetry, Ar(1) - structure and unstructured.

Compound symmetry is a split-plot structure. In other words time point are split plots within subjects which means that the residuals ε_{ijk} within a plot ij, $(\varepsilon_{ij1}, \varepsilon_{ij2}, ..., \varepsilon_{ijt})$ are not correlated
In split-plot structure only one additional parameter (variance between time points) need to be estimated.

AR(1) is autoregressive one structure for which two additional parameters need to be estimated. They are variance between time points and correlation between two consecutive time points (or between time point one unit apart from each other)
Correlations between any pair of consecutive time points are equal.

Unstructured model means that variances of each time point and correlations between each pair of time points are estimated. This means that (t+1)×t/2 additional parameters need to be estimated.

In homogenous version of the compound structure and AR(1) structure, it is assumed that variance of different time points do not differ and only one (pooled) estimate is needed for the between subjects variance.
In heterogenous version between subjects variance is estimated separately for each time point, which means that t additional parameters need to be estimated.

The correlation structure that is most consistent with the data is found by running the analysis several times and using different structure on different runs
The structure that results the smallest information criteria value is selected.

If we take soil samples from three different depths and there is one result for each depth of each plot in data, the model is again
$y_{ijk} = \mu + \alpha_i + D_k + (\alpha D)_{ik} + bl_j + \varepsilon_{ijk}$,
where D_k = depth effect, $k = 1, 2, 3$, and residuals of plot ij may be correlated.
In this case the unstructured alternative for the within subject correlations is probably the best choice.

If randomized block split-plot design described above (model $y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + bl_k + (bl\alpha)_{ij} + \varepsilon_{ijk}$) is measured in t time points, the new model is

$y_{ijkl} = \mu + \alpha_i + \beta_j + T_l + (\alpha\beta)_{ij} + (\alpha T)_{il} + (\beta T)_{jl} + (\alpha\beta T)_{ijl} + bl_k + (bl\alpha)_{ij} + \varepsilon_{ijkl,}$

where the residuals of each subplot ijk may be correlated.

Note There are probably interactions between blocks and time, between whole plots and time, between subplots and time and so on. Interaction is random, if any of its effect is random. All the random interactions that are not explicitly expressed in the model are confounded with the error term. This means that the correlation structure in the model is to some extend simplified model for the real structure, but this is acceptable. Most important thing is that the variance structure is correct and that the main features of the correlation structure are correct. Fine tuning of the correlation structure does not help.if the sample size is not large This is because we don't know the real correlations and variances, only their estimates and the more complex the structure of the random part, the larger sample is needed to obtain reasonable estimates for the parameters of the structure.

Estimation.

Estimation method for linear mixed models is either maximum likelihood (ML) or restricted maximum likelihood (REML) method.

ML method search such values for the model parameters that maximize the likelihood of the observations. ML-estimates for the variance components are biased.

REML maximizes the likelihood of observation with restriction that the estimates of the variance components are unbiased.

REML is usually the default method.

Estimates must be computed using iterative methods. In some special cases procedure does not find solution. In that case it mays help that the values of parameters that are controlling iteration are changed.

In some cases model must be simplified because the data doe not support so complicated model.

Tests.

Tests for the fixed parameters and their contrasts are exact or approximated F-tests, (asymptotic), WALD tests or (asymptotic) likelihood ratio tests.

Because of the complex correlation structure of residuals, the distribution of the F-statistic is not necessarily exactly F-ditribution

In this case distribution is approximated by a F-distribution so that the suitable degrees of freedom for the error term is computed by some algorithm.

SPSS computes error degrees of freedom using Satterthweite method.

Note 1: Opposite to the case of exact F-distribution, approximated degrees of freedom of the error term do not approximate the number of replicates.

Note 2: Mixed procedure in SPSS (and in SAS) analyses linear mixed models and it can be also used for the analyses of.linear models with uncorrelated residuals.

Note 3: The two traditional approaches to the analyses of repeated measures (=longitudinal data) are **MANOVA** and **split-plot model**.

ANOVA tests differences between groups with respect of one response variable. **MANOVA** tests differences between groups taking into account several response variables at the same time.

The assumptions of MANOVA are: a) different units are independent and b) the distribution of the residuals of the same unit is a multivariate normal distribution.

Wilk's lambda test, Pillai's lambda test and Hotelling's trace test are manova tests.

In MANOVA approach to the analyses of longitudinal data the measurements at different time points are treated as different variables measured from the same units

In split-plot approach time is a sub-plot treatment. Each unit is a whole plot, and different time points are the sub plots within a whole plot.

Because residuals of the same unit at different time point may be correlated, the F-test must be adjusted. Two most popular adjustments were Greenhouse-Geisser test and Huynh-Feldt test.E.g. SPSS GLM/repeated procedure provides these tests.

The modern approach to the analysis of longitudinal data is the **linear mixed model** approach.

12 Generalized linear model

In linear model $y = \alpha + \beta x + \epsilon$ the distribution of the residual is $N(0, \sigma^2)$.

The expected value of y (the mean value of the distribution in the population) is $\mu = \alpha + \beta x$

The distribution of y can also be written in the form $y \sim N(\mu, \sigma^2)$, where $\mu = \alpha + \beta x$ .and

the distribution of y can be expressed by two equations

$\mu = \alpha + \beta x$,

$y \sim N(\mu, \sigma^2)$

The distribution of counts, for example the number of seedlings on a plot, is often a **Poisson distribution**, $Pois(\lambda)$, where λ is the mean value. The variance of the Poisson distribution =the mean value of the distribution.

If $\lambda = \alpha + \beta x$, the distribution of y can be expressed by equations

$\lambda = \alpha + \beta x$,

$y \sim Pois(\lambda)$.

Link function.

For Poisson variable a better model is usually

$\log(\lambda) = \alpha + \beta x$,

$y \sim Pois(\lambda)$.

where log is natural logarithm.

In this model the observations are not transformed, but the expected values are.

The function that is used to transfer the expected value is called a link function.

In generalized linear models

the transformed mean values are explained by a linear model and

the random variation around the mean value is described by some known distribution like Poisson or binomial. distribution.

Estimates for mean value is obtained in original scale by computing the inverse of link function

E.g. inverse of log-transformation is exp-function and the Poisson model above is in original scale

$\lambda = exp(\alpha + \beta x)$,

$y \sim Pois(\lambda)$.

If there are n seedlings planted on a plot and variable y stands for the the number of seedlings that are alive after one year, the distribution of y is a **binomial distribution**,

$y \sim Bin(n, p)$, where $n =$ the number of planted seedlings and $p =$ the probability that a seedling is alive after one year $(0 \leq p \leq 1)$.

The expected value of y is $E(y) = np$ and the variance is $\sigma^2 = np(1-p)$.

For binomial distribution the standard link function is

$\log it(p) = \log(p/(1-p))$.

If the model for $logit(p) = \alpha + \beta x$

the model for y is

$logit(p) = \alpha + \beta x$

$y \sim Bin(n, p)$.

The inverse of logit transformation gives $p = \frac{\exp(\alpha+\beta x)}{1+\exp(\alpha+\beta x)}$.

In the case of normal distribution we had

$\mu = \alpha + \beta x$,

$y \sim N(\mu, \sigma^2)$

and the mean values were not transformed. In this case the link function is called identity link.

These models are called **generalized linear models** because the random variation does not need to follow normal distribution and because the

model for the link-function transformed mean value is a linear model.

In the estimation and test of a generalized linear model the information given to the statistical software is:

- which distribution is used,
- which link function is used,
- which explanatory variables are included in the linear model and
- should the scale parameter be estimated from data.

If normal distribution and identical link function is chosen, the result is the usual linear model and its analysis.

In most software the distributions available for generalized linear models belong to so called exponential family of distributions for which the variance is a function of the mean value,

and the default link function is a distribution specific so called canonical link function.

The canonical link function results some favorable statistical properties for the parameter estimates, and it should be used if it results correct model for the mean value.

In practice the variance may be larger or smaller, which lead to biased tests and confidence intervals.

This is taken into account by estimating so called scale parameter. The user of the software decides if the analysis is computed using theoretical variance or variance estimated from data.

13 Literature

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Agrarian Research Institute of Mozambique
Faculty of Agronomy and Forest Engineering in Eduardo Mondlane University (FAEF-UEM)
In cooperation with the Forecas Project
METLA
The 9th Conference on Dendrochronology
13-17 January 2014 | Melbourne, Australia
O01. Tropical dendrochronology

Esperanca Chamba[1], Alberto Manhica[1], Jacob Bila[1], Elias Secretario[1], Paulo Valeriano Timoteo[2], Martinho Bonomar[2], Eunice Catarina Sitoe[2], Mauri Timonen[3] & Hannu Herva[3]

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The Potential Of Dendrochronology For Tree Growth And Yield Studies In Mozambique

Mozambique is a country endowed with vast forest resources, a source of livelihood of 80% of the population living in rural areas. About 54 millions of the country is covered by forests and other vegetation types from which 51% are classified as forests. The predominant ecoregions are Miombo and Mopane (Fig. 1.) proving the majority of wood species for domestic use and export. The sustainable management of this resource base for the economy and livelihood of Mozambique population is becoming increasingly important with the growing demand on forest products and services.

Climatic variability poses an additional pressure into forest resources since it affects their growth and productivity. Thus, scientific information regarding growth, yields and dynamic of forests are crucial. In the last 10 years, growth and yield studies through the establishment of permanent sampling plots (PSP) are conducted. These are long term studies and the monitoring of extreme climatic events and variability on the forest is not easy.

Dendrochronology is a useful complement to PSP since it gives faster and reliable results. There are some potential Mozambique tree-species for climate reconstruction, e.g. Millettia Stuhlmannii or Panga-panga (Fig. 2.) correlates positively with monthly and seasonal precipitation: rainfall during December and February explains about 43% of the chronology variation (Remane 2013).

Some initial studies on dendrochronology with the new equipment (Fig 3.) were done with encouraging results. This research aims at study the growth and yield patterns of three species used for timber and one for fuel wood in the south of Mozambique. Destructive and non-destructive methods are used for sampling. (Fig. 4). It is expected that the results will contribute to design sound polices that leads to a sustainable management of forest ecosystems in Mozambique.

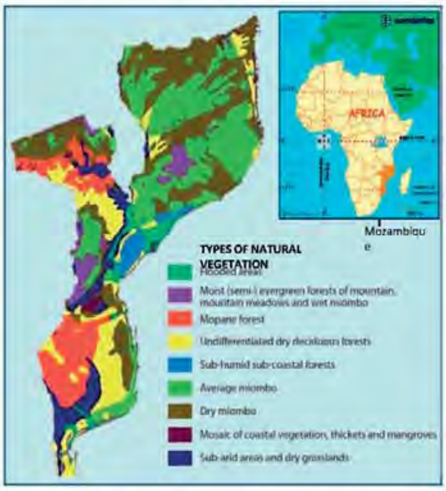


Fig. 1. Map of the different types of natural vegetation

Fig. 2. Panga panga forest in Maputo

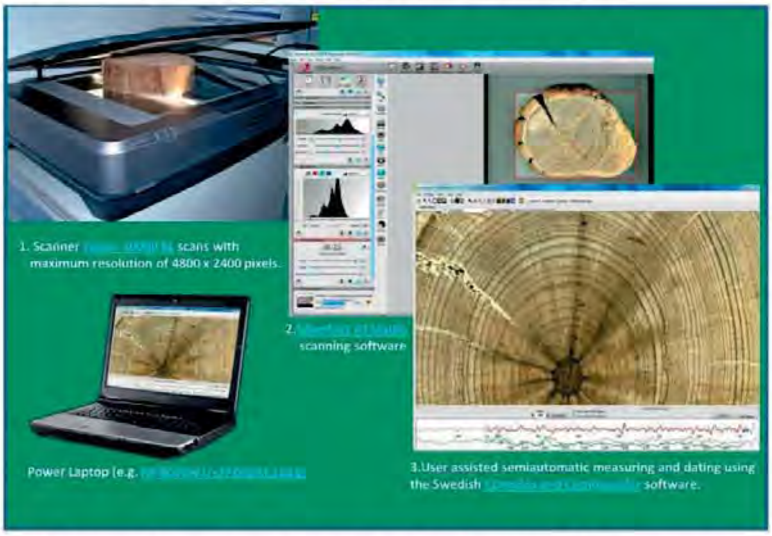


Fig. 3. Our tree-ring laboratory in Maputo uses high-resolution disk images and the Swedish Cdendro software. See closer description here.

Fig. 4. Panga panga forest in Maputo

Annex 6

SAMPLING FOR TECHNOLOGICAL PROPERTIES OF LESSER KNOWN SPECIES (LKS)

SELECTION OF SPECIES

„LKS are those that are of *minor importance in terms of consumption, production and utilization, and are not exploited to contribute to the regional/national economy*“

Ghana government (2007)

Annex 6

SELECTION OF SPECIES

The use of LKS allows:

- Wider range of silvicultural options available and supports natural regeneration
- Decrease waste of energy and resources
- Diversification of species and products
- Commercialization?

SELECTION OF SPECIES

- Utilization as raw material especially in small sized industry in the countryside and village communities of Mozambique?
- Possibilities to develop wood products industry in the countryside?
  - Business and job opportunities

Annex 6

SELECTION OF SPECIES

- Total volume
- Frequency
- Growth rate
- Log size
- Regeneration
- Availability
- …

OBJECTIVES

- Describe and analyse physical and mechanical properties of wood of selected tree species
- Launching the utilization of lesser known tree species based on their identified product options
- Regional economic development

Annex 6

OBJECTIVES

- What kind of production could be developed based on lesser known tree species?
  - Sawn timber production?
  - Drying of sawn timber for furniture or parquet products? Solar drying?
  - Heat treatment for value added wood products?
  - Peeling or slicing of veneers?
  - Other?

METLA

MATERIALS AND METHODS

Statistical prerequisites:

- Stratum (Soil types)
- Different growing sites (Miombo, Mopane,…)
- Age classes
- Crown layer
- Minimum number of samples from each combination of variation
- Sampling method

METLA

Annex 6

MATERIALS AND METHODS

Selection of sample trees

- Random sampling: after selecting the first sample tree, the selection of next ones is based on random numbers (from the list printed beforehand), numbers may be restricted to 1-7, for example

or

- Systematic sampling: every n tree is selected

METLA

MATERIALS AND METHODS

Cutting of wood samples

- Within tree variation:
  - Radial variation
  - Longitudinal variation
- Number of radial locations depends on the diameter
- Longitudinal locations from selected relative heights (Minumum top diameter)

METLA

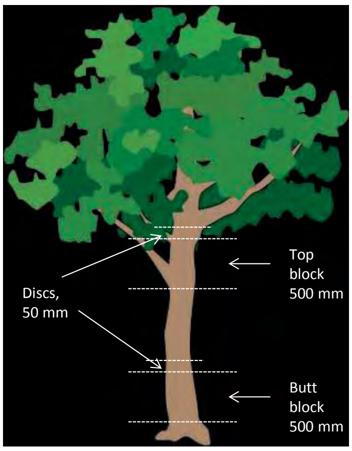
MATERIALS AND METHODS

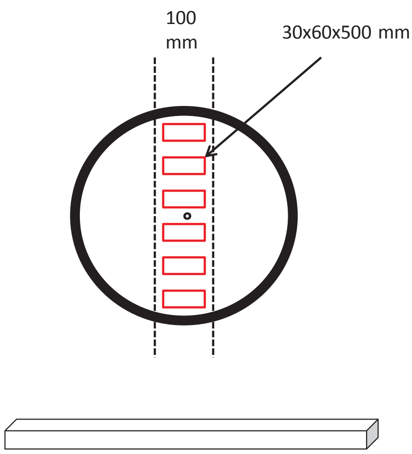
Cutting of wood samples

- Cut a block length of 500 mm from the butt and another block from the top of the usable part of trunk. Cut also a disc length of 50 mm right next to the location where you cut the blocks.

- Saw pieces with dimensions of 30 x 60 x 500 (or 30 x 30 x 750) from different radial locations of the blocks. Number of pieces to be sawn is related to the diameter of the block. Probably you can get 6 pieces from the butt block and 4 pieces from the top log (see the figure in the next page). If the size of the trees of the selected species is smaller you will get fewer specimens. Pay attention to get defect free wood for the tests, at least 200 mm in each piece free from knots and other mechanical defects. Moreover, the grain direction should be as even and as parallel to the longitudinal direction of the pieces as possible.

MATERIALS AND METHODS





 Annex 6

MATERIALS AND METHODS

Encoding the samples

- Sampling form is used to bookkeeping and collecting the data
- Each sample is encoded with permanent mark comparable with the bookkeeping

MATERIALS AND METHODS

Encoding the samples

- Write down the background data: tree measurements (diameter, lenght, …), place of the growing site (locality, coordinates etc.), site fertility, soil type and dryness/wetness, and other description related to the place (forest type etc.)

 Annex 6

MATERIALS AND METHODS

Encoding the samples

Encode the pieces (sticks) as follows:

- Location – plot number
- Tree species: A or B,
- number of the tree: from 1 to 10
- location of the block: L = lower part (butt), T = top
- radial location of the piece: 1a or 1b = near the pith, 2a or 2b = between the pith and bark, 3a or 3b = near the bark

- example: Mopane1-B-4-L-2a

MATERIALS AND METHODS

- Encode the discs as follows
  - Location – plot number
  - Tree species: A or B,
  - number of the tree: from 1 to 10
  - location of the disc: L = lower part (butt), T = top
- example Mopane1-B-4-L

- (Weigh the pieces and discs and write down the weight reading.)
-
- Dry (preferably air-drying) the pieces and discs outside (or indoors) to the moisture content of 20% or less in an airy pile using dry sticks between the pieces and discs. Shelter the samples from direct sun light and rain during the drying period. When the moisture content has decreased below 20% (preferably below 15%), the samples can be processed further.

Annex 6

MATERIALS AND METHODS

Cutting of wood samples

- Size of wood sample billets depends on the analyses the samples are collected for (dimensions of test specimens at 12% MC)
  - Bending tests (MOE, MOR) (20x20x340 mm)
  - Compressive strength (20x20x60 mm)
  - Tensile strength, (20x20x350 mm)
  - Shrinkage
  - Density
- Other
  - Torsion
  - Hardness
  - Shear …

MATERIALS AND METHODS

- Later, during the on-job-training period in Finland, samples for modulus of elacticy, bending strength, tensile strength, compression strength, hardness, density, moisture content and growth ring analysis will be prepared from the pieces and discs.

Forest Research Capacity Strengthening in Mozambique

(FORECAS)

Wood science course in Maputo 17.-28.11.2014

Measuring techniques, instruments and standards in wood science

Manual for the wood laboratory instruments

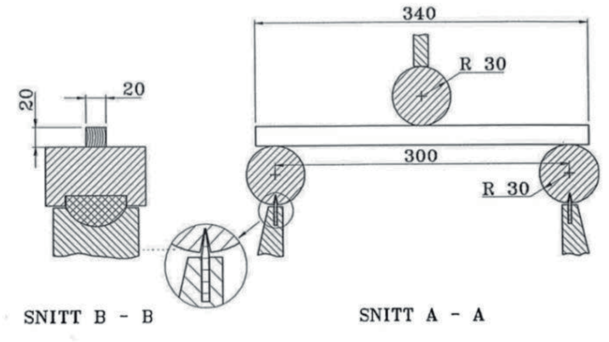
Veikko Möttönen & Tuula Jyske

METLA

UNIVERSAL MATERIAL TESTING MACHINE - TESTOMETRIC

ISO 3133 - Determination of ultimate strength in static bending (MOR)

- Determination of the maximum load in bending required to cause rupture 1.5 ± 0.5 min.
- Estimation of stress at the load of rupture.
- The radius of curvature of the supports and a loading shoe shall be 30 mm.
- Check the span (distance between supports): 300 mm (different from MOE test!)
- Testometric program named:



$$E_w = \frac{F \cdot l^3}{36 \cdot b \cdot h^3 \cdot f}$$

MAKE LONGER SPECIMENS!

To enable the use of same specimens in MOE and MOR tests, I recommend to increase the length of specimens to 360 mm.

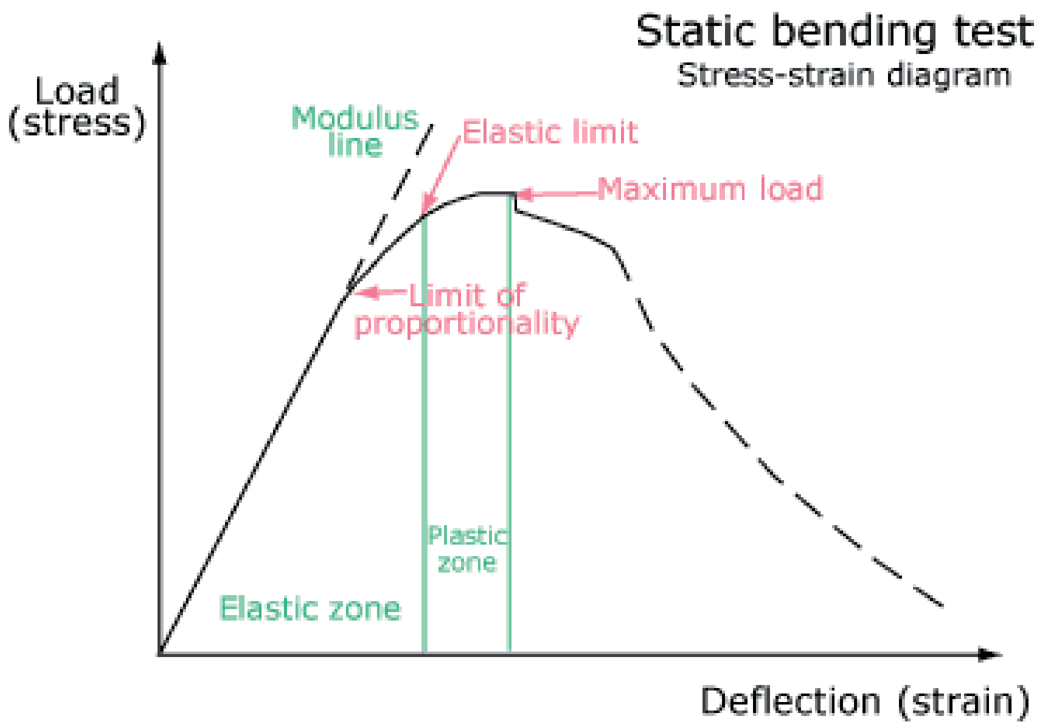
Span is different from that in MOE test.

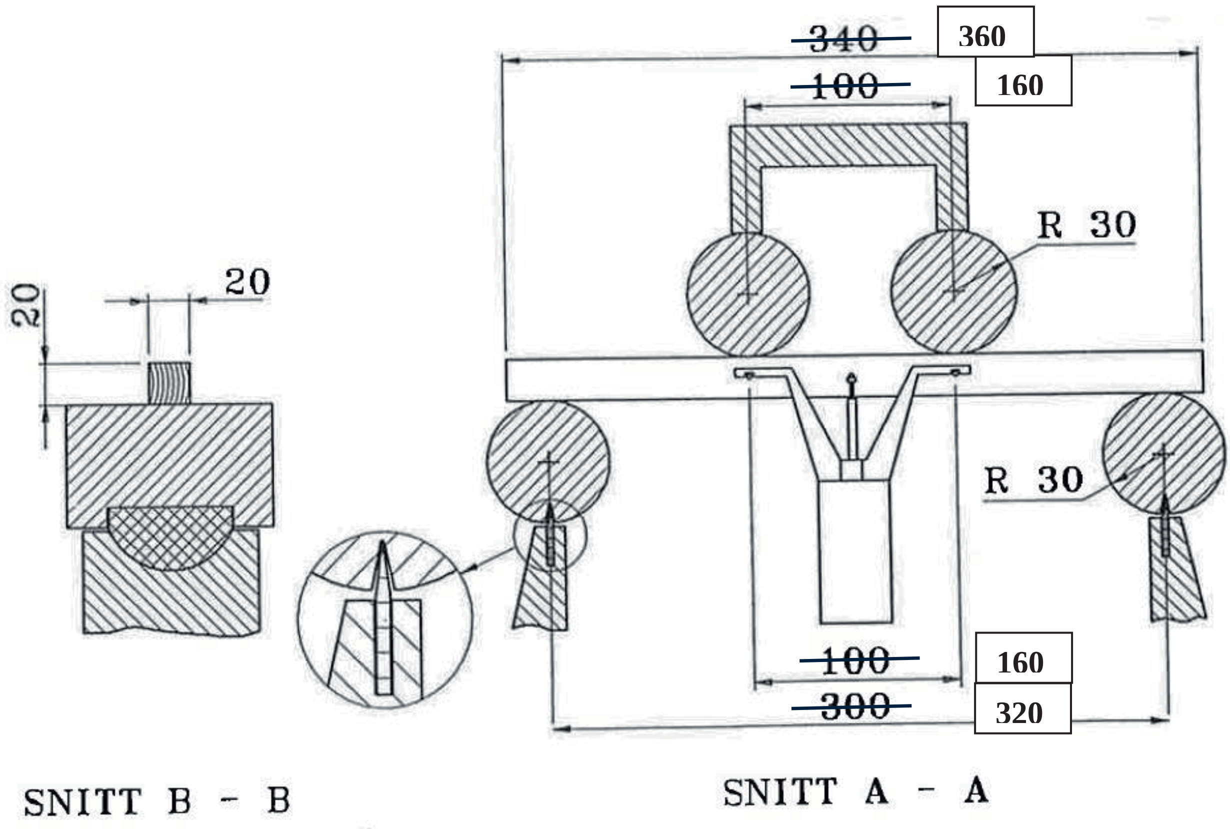
$\alpha = 0.04$

$E_{12} = E_w \times [1+\alpha\times(w - 12)]$

ISO 3349 - Determination of modulus of elasticity in static bending (MOE)

- By measuring the deflection in the net bending area
- Gradually increasing load within the region of proportionality of the load and deflection





- Measure the cross sectional dimensions (width and thickness) to an accuracy of 0.1 mm
- Bending force directed perpendicular the radial surface (tangential bending)
- Test at constant rate of loading or constant speed of movement
- Check the span (distance between supports): 320 mm (different from MOR test!)
- Testometric program named: ISO3349 Modulus of elasticity

The duration of the four test loadings should be no more than 10 sec.
The upper load level (18 MPa) should correspond to 25% of the bending strength of the test piece.
The lower load level (7 MPa) should correspond to 10% of the bending strength of the test piece.
The pre-load level (5 MPa) should correspond to ca. 70% of the lower load level (7 MPa).
Determine the moisture content (w) of the test pieces after test.

Calculation of modulus of elasticity Ew at the moisture content w

$$E_W = \frac{3\,Pl^3}{64\,bh^3 f}$$

P is the load difference between the upper and lower limit of loading, N.

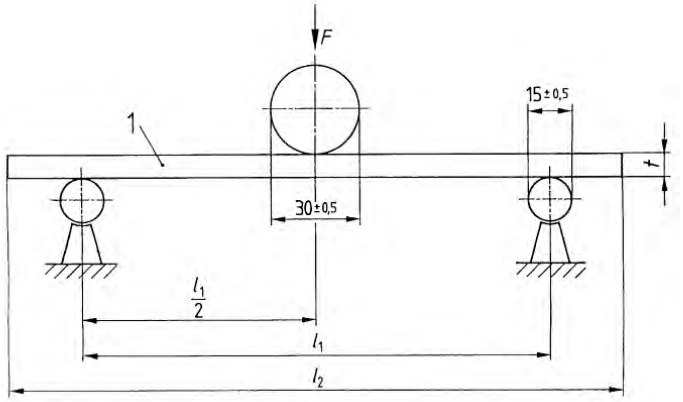
And adjusted to moisture content of 12%

$$E_{12} = \frac{E_W}{1 - \alpha\,(W - 12)}$$

$\alpha = 0.02$

EN 310 - Wood-based panels — Determination of modulus of elasticity in bending and of bending strength

- Modulus of elasticity in flatwise bending and bending strength of wood-based panels of nominal thickness equal to or greater than 3 mm



1 = test piece
F = load
t = thickness of the test piece
l_1 = 20 t
l_2 = l_1 + 50
Dimensions in millimetres.

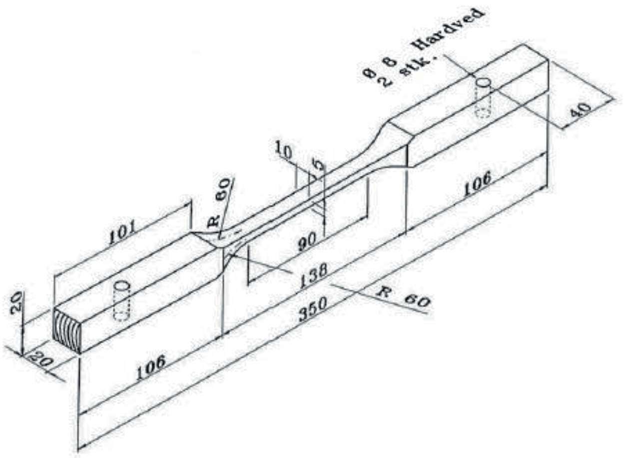
Figure 1 — Arrangement of the bending apparatus

- The test pieces shall be conditioned to constant mass in an atmosphere with a relative humidity of (65 ± 5) % and a temperature of (20 ± 2) °C.
- Measure the width and thickness of each test piece
- Adjust the distance between the centres of the supports, to within 1 mm of 20 times the nominal thickness of the panel
- Testometric program named:
- Maximum load is reached within (60 ± 30) s
- Modulus of elasticity is calculated by using the slope of the linear region of the load-deflection curve
- Bending strength of each test piece is calculated by determining the ratio of the bending moment M, at the maximum load Fmax, to the moment of its full cross section
- The test pieces shall be rectangular, and of the following dimensions:
- The width b shall be (50 ± 1) mm
- The length l2 shall be 20 times the nominal thickness plus 50 mm, with a maximum length of 1 050 mm and a minimum length of 150 mm.

$$E_m = \frac{l_1^3 (F_2 - F_1)}{4\, b t^3 (a_2 - a_1)} \qquad f_m = \frac{3\, F_{max}\, l_1}{2\, b t^2}$$

- F1 shall be approximately 10 % and F2 shall be approximately 40 % of the maximum load

ISO 3345 - Determination of ultimate tensile stress parallel to grain

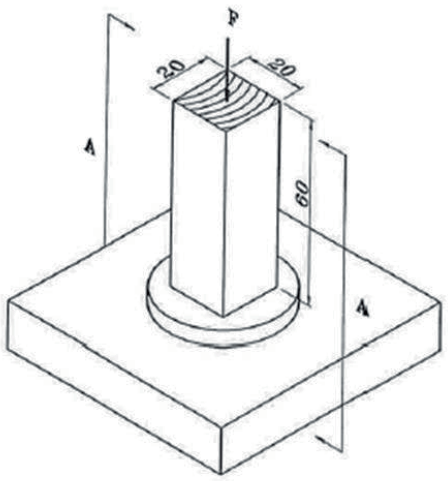


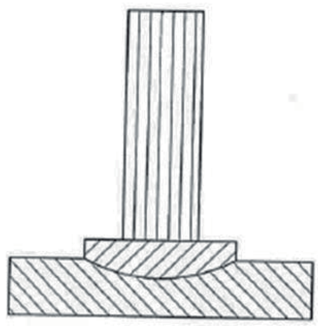
ATTENTION!

At the ends of the test piece between the grips the cross-section could be the maximum 25 x 25 mm (the maximum opening of the grips). You can increase also the dimensions of the cross-section of the gauge portion, for example to 15 mm in the radial direction and to 10 mm in the tangential direction. Using these dimensions the manufacturing of the test pieces may be easier.

- Determination of the ultimate tensile stress parallel to grain by application of a gradually increasing load to a test piece.
- The gauge portion of test pieces shall have a rectangular cross-section with dimensions from 10 to 20 mm in the radial direction and from 5 to 10 mm in the tangential direction.
- The gauge length of the test piece shall be from 50 to 100 mm.
- Clamp the ends of the test piece between the grips of the testing machine at a distance of 20 to 25 mm from the gauge portion.
- Clamp the upper grip first and zero the load reading
- Clamp also the lower grip but do not zero the load reading
- Testometric program named:
- Load the test piece at constant rate such that the test piece is broken in 1.52 minutes.
- Take the gauge portion of the test piece as the sample for determination of moisture content.
- $\sigma_w = \frac{\mathbf{F}_{max}}{\mathbf{b} \cdot \mathbf{h}}$
-
- Adjustment for moisture content is not needed if MC varies between 9 and 15%.

ISO 3787 - Determination of ultimate stress in compression parallel to grain





Snitt A-A

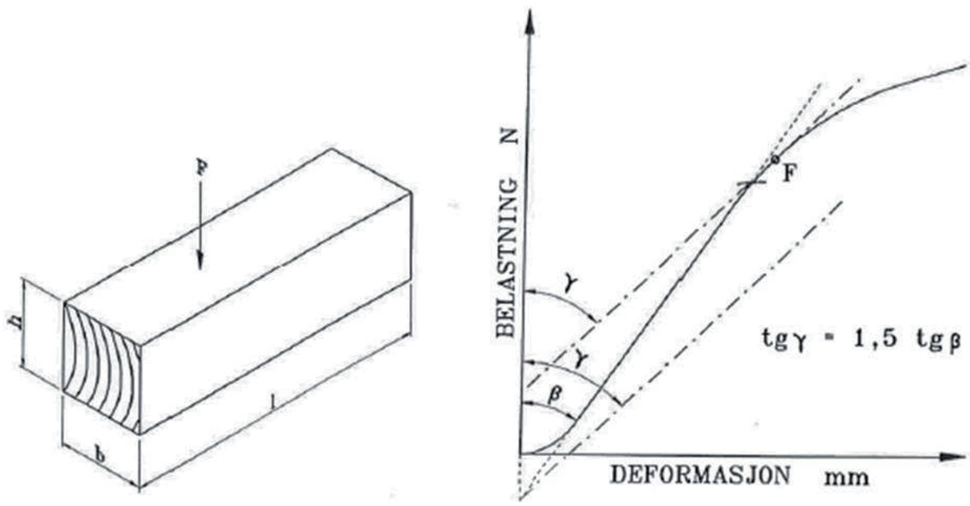
- Measure the cross-cut dimensions (b=radial, h=tangential) and length, length is needed for the calculation of density
- Testometric program named:
- Determination of the maximum load required to cause rupture 1.5 - 2 min

- Determine the moisture content (w) of the test pieces after test.

$$\sigma_w = \frac{F_{max}}{b \cdot h} \qquad \sigma_{12} = \sigma_w \cdot [1 + \alpha \cdot (w - 12)]$$

α = 0.05

ISO 3132 - Testing in compression perpendicular to grain

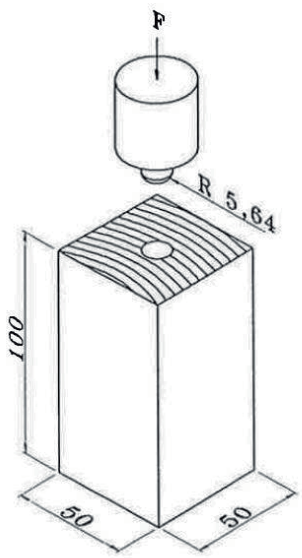


- Measure the cross-cut dimensions and length, length is needed for the calculation of density
- Testometric program named:
- F is the load at the proportional limit which is determined with tangent β and tangent γ: tangent γ = 1.5 × tangent β
- Determine the moisture content (w) of the test pieces after the test.

$$\sigma_{yw} = \frac{F}{b \cdot l} \qquad \sigma_{y12} = \sigma_{yw} \cdot [1 + \alpha \cdot (w - 12)]$$

α = 0.035

ISO 3350 - Determination of static hardness (Janka)



- Janka hardness can be determined in tangential, radial or longitudinal direction
- The ball is loaded at constant speed of 3 – 4 mm/min to the depth of 5.64 mm (to the depth of 2.82 mm with easily splitting wood species)
- Determine the moisture content (w) of the test pieces after the test.
- K = 1 if depth is 5.64
- K = 4/3 if depth is 2.82

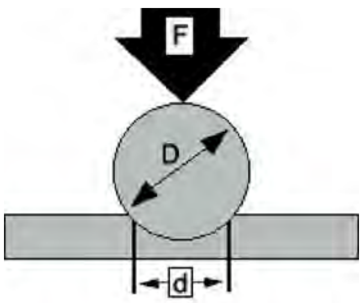
$$\mathbf{H_w = K \cdot F_{max}} \qquad \mathbf{H_{12} = H_w} \cdot [1+\alpha \cdot (\mathbf{w}-12)]$$

α = 0.025, for tangential and radial direction

α = 0.04, for longitudinal direction

EN 1534 - Wood and parquet flooring. Determination of resistance to indentation (Brinell). Test method

- A loaded indenter (a hardened steel ball with a diameter of 10 ± 0.01 mm) is applied to the face of the test specimen.
- The diameter of the residual indentation is used to evaluate the resistance to indentation of the specimen.
- Test specimens may be elements or pieces cut from the elements
- The minimum distance from the center of indentation to any edge or to a knot is 20 mm.
- Load is applied at such rate that the nominal value of 1 kN is reached in 15±3 seconds and maintained for 25±5 seconds.
- After 3 min, measure the residual indentation along the grain (d1) and across the grain (d2)



$$HB = \frac{2F}{\pi D\left(D - \sqrt{D^2 - d^2}\right)} \qquad d = \frac{d_1 + d_2}{2}$$

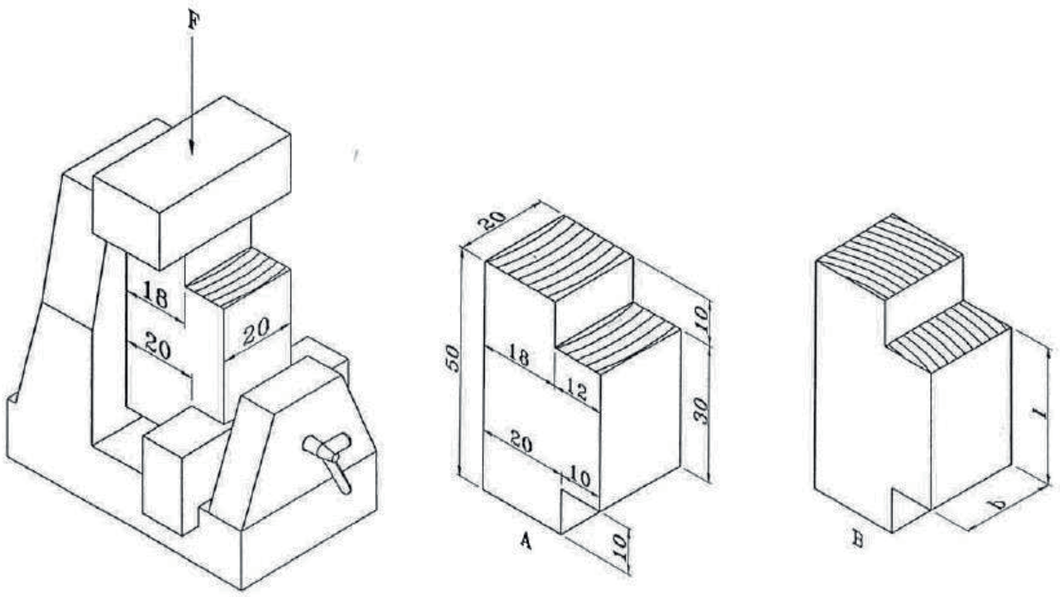
[MPa]

d can be determined computationally as follows (NOT INCLUDED IN THE STANDARD):

$d \cong 2\sqrt{10h\ 0\ h^2}$, where h is the depth of the indentation

ISO 3347 - Determination of ultimate shearing stress parallel to grain

- Determination of the maximum load required to cause rupture 1.5 - 2 min



$\tau_w = \frac{F_{max}}{b \cdot l}$ $\tau_{12} = \tau_w \cdot [1 + \alpha \cdot (w - 12)]$ $\alpha = 0.03$

CIELAB – COLOUR MEASUREMENT

Presentation of colour in numerical form

- Reflectance spectra in the visible range 400 – 700 nm at 10 nm steps
- L*a*b* -colour scale, Lab –values can be calculated from the reflectance spectra
- L*C*h° -colour scale, calculated from the L*a*b* -values
- ΔE, the difference in colour

$$\Gamma E \cong \sqrt{\Gamma L^2\ .\ \Gamma a^2\ .\ \Gamma b^2}$$

Measuring conditions to be reported:

1. Calibrated to WHITE (always with Lab –values)
2. Selected illumination: D65 (6500 K, day light) most common
3. Observer (angle) 2° or 10°, 2° is normally used with wood
4. Filter if used, usually no filter

Metsä Tieto Osaaminen Hyvinvointi METLA

Wood Science Course

17 – 28 November 2014

Color measurements

- What is color?
- Principals of color determination
- Spectrophotometer
- Carrying color measurements by spectrophotometer

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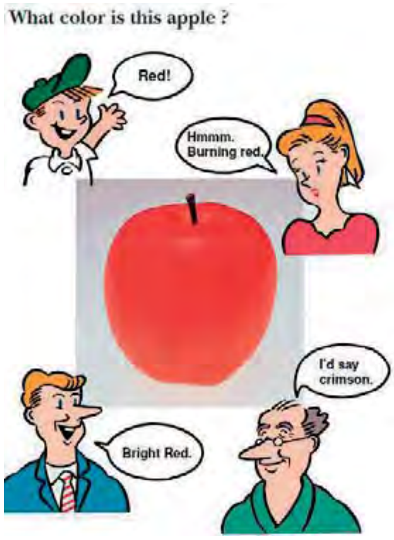
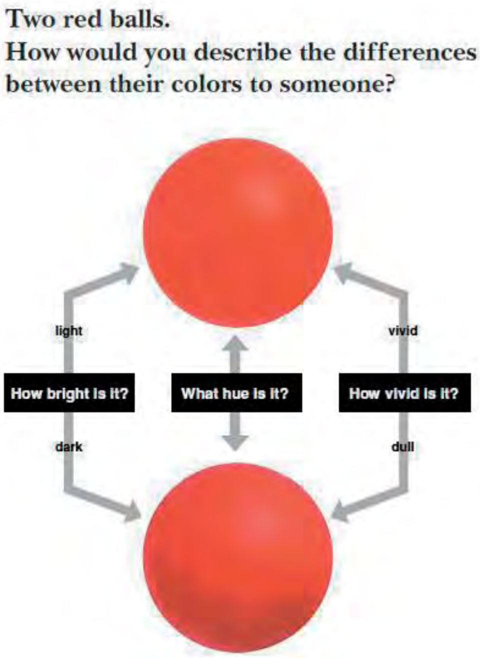
What is color?

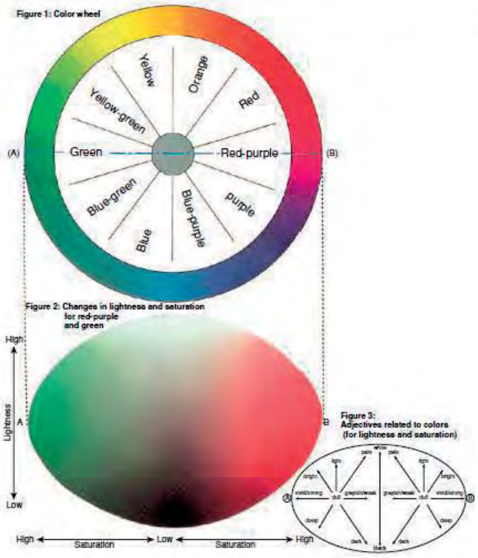
- Color is difficult to accurately express in words – subjective interpretation
- Several things affect how color looks:
  - Light-source
  - Observer
  - Size of the object
  - Background
  - Directional differences

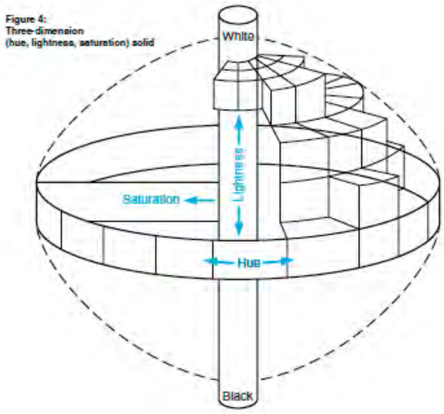


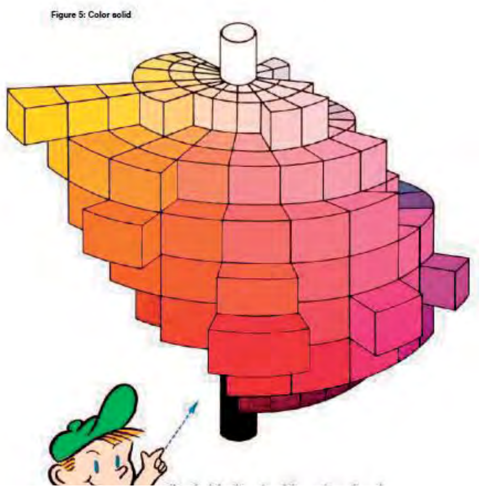


- Hue – color (red, yellow, green, blue)
- Lightness (bright and dark colors)
- Saturation (vivid colors, dull colors)

Hue. Lightness. Saturation. The world of color is a mixture of these three attributes.



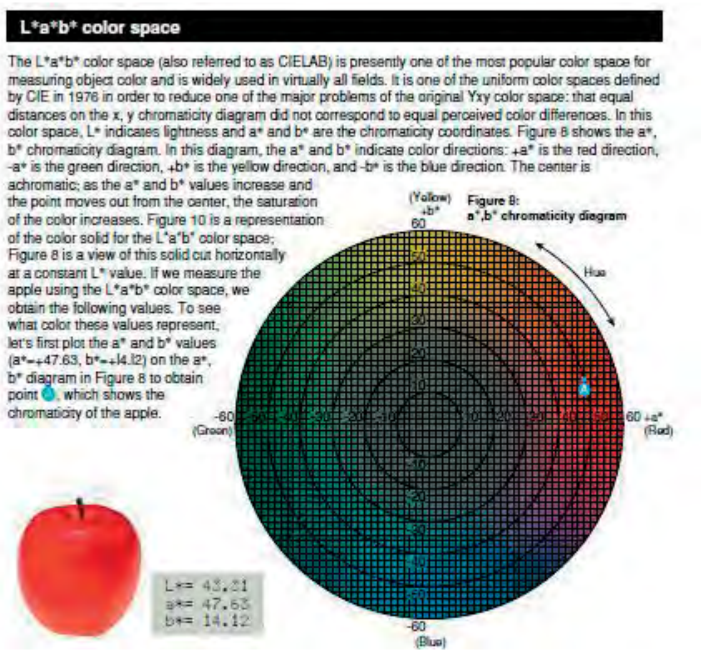




When we create scales for hue, lightness and saturation, we can measure color numerically.

Color space

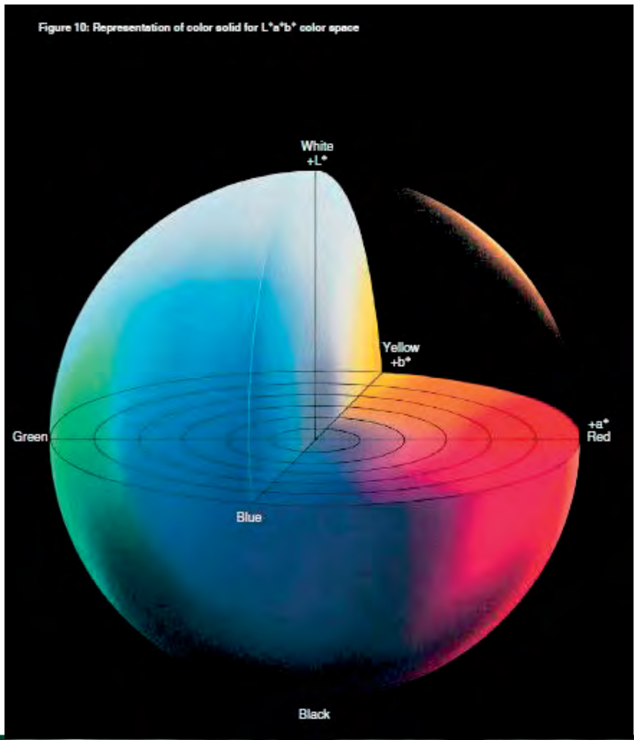
- A method for expressing the color of an object of a light source using some kind of notation, such as numbers.
  - Yxy color space, based on tristimulus values (XYZ; eye has receptors for red, green, blue)
  - L*a*b color space
  - L*C*h
  - Hunter Lab
  - …



L*a*b* color space

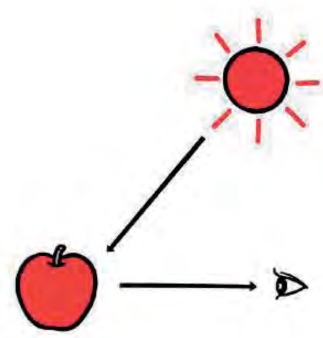
The L*a*b* color space (also referred to as CIELAB) is presently one of the most popular color space for measuring object color and is widely used in virtually all fields. It is one of the uniform color spaces defined by CIE in 1976 in order to reduce one of the major problems of the original Yxy color space: that equal distances on the x, y chromaticity diagram did not correspond to equal perceived color differences. In this color space, L* indicates lightness and a* and b* are the chromaticity coordinates. Figure 8 shows the a*, b* chromaticity diagram. In this diagram, the a* and b* indicate color directions: +a* is the red direction, -a* is the green direction, +b* is the yellow direction, and -b* is the blue direction. The center is achromatic; as the a* and b* values increase and the point moves out from the center, the saturation of the color increases. Figure 10 is a representation of the color solid for the L*a*b* color space; Figure 8 is a view of this solid cut horizontally at a constant L* value. If we measure the apple using the L*a*b* color space, we obtain the following values. To see what color these values represent, let's first plot the a* and b* values (a*=+47.63, b*=+14.12) on the a*, b* diagram in Figure 8 to obtain point A, which shows the chromaticity of the apple.

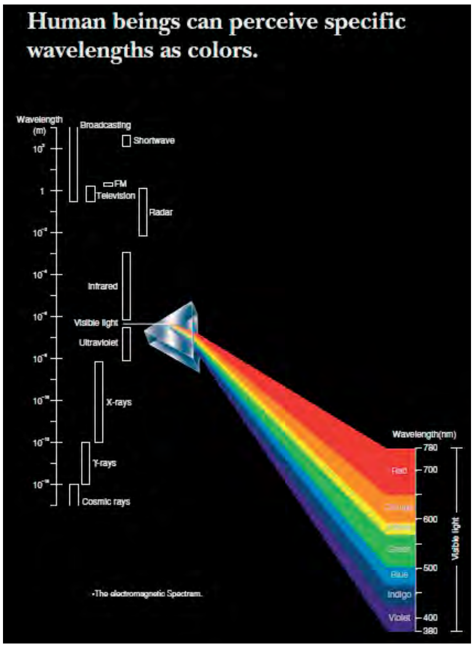
Figure 8:
a*,b* chromaticity diagram



- Vision
- Object
- Light

->color perceiving

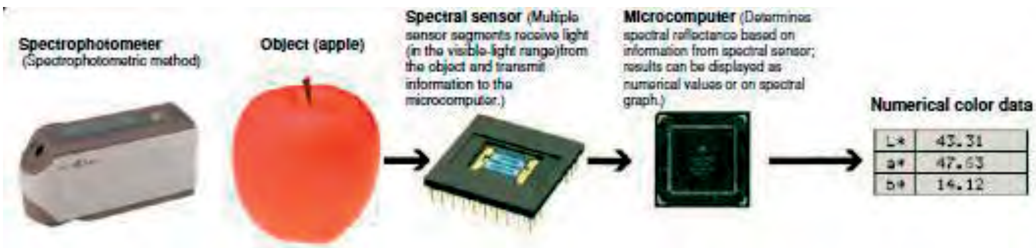


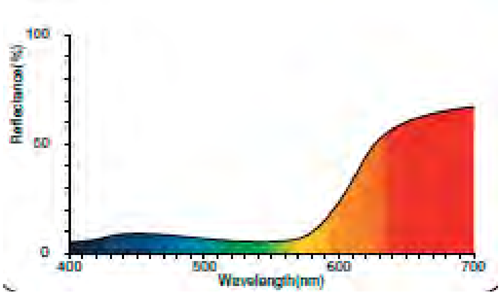


- When light is separated into its different wavelengths, we create a spectrum
- Colors are created by mixing the separated wavelengths

Spectrophotometer

- Spectrophotometers measures the light reflected from the object at each wavelength or in each wavelength region





- Data can be displayed by on a graph to provide detailed information on the color

Apple

L*	43.31
a*	47.63
b*	14.12

If we measure an apple, we obtain the spectral graph shown in Figure 17a. If we look at this graph, we see that in the red wavelength region the reflectance (the amount of reflected light) is high, but in other wavelength regions the reflectance (the amount of reflected light) is low. Figure 17b shows that the apple reflects light in the orange and red wavelength regions and absorbs light in the green, blue, indigo, and violet wavelength regions. In this way, by taking a measurement with a spectrophotometer and displaying the results on a spectral graph, we can see the nature of the apple's color.
Each of the multiple sensors (40 in the Konica Minolta Spectrophotometer CM-2002) of a spectrophotometer measures light in a strictly defined wavelength region of the visible-light wavelength range. Because of this, the spectrophotometer can measure differences in the elements of color which are not noticeable to the human eye.

Figure 17a:
Spectral reflectance graph for an apple

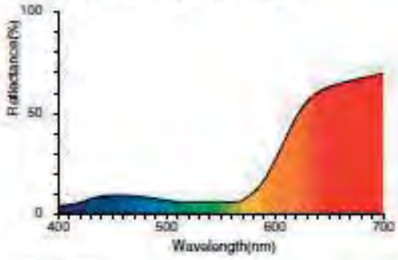
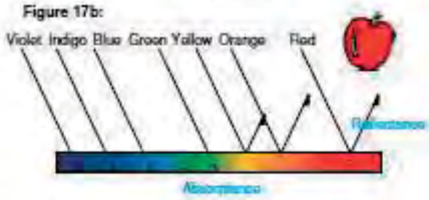


Figure 17b:



L*	75.34
a*	4.11
b*	68.54

Lemon

If we measure a lemon, we obtain the spectral graph shown in Figure 18a. If we look at this graph, we see that in the red and yellow wavelength regions the reflectance (the amount of reflected light) is high, but in the indigo and violet wavelength regions the reflectance (the amount of reflected light) is low. Figure 18b shows that the lemon reflects light in the green, yellow, and red wavelength regions and absorbs light in the indigo and violet wavelength regions. This is the nature of the lemon's color. Such high accuracy is not possible with the human eye or even with the colorimeters discussed in Part 1 ; it is only possible with a spectrophotometer.

Figure 18a:
Spectral reflectance graph for a lemon

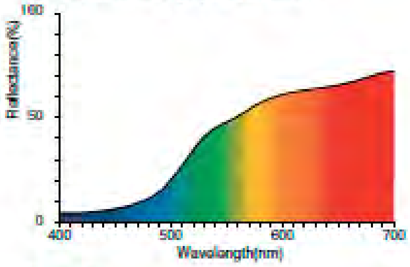
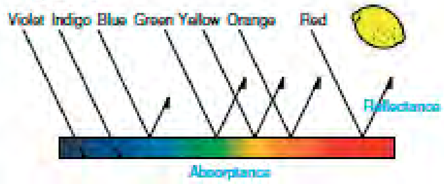


Figure 18b



Features of spectrophotometers

Spectrophotometers offer a wide range of features and superior accuracy.

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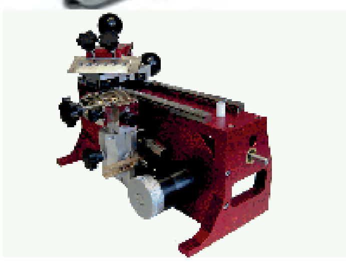
Sectioning with sliding microtome

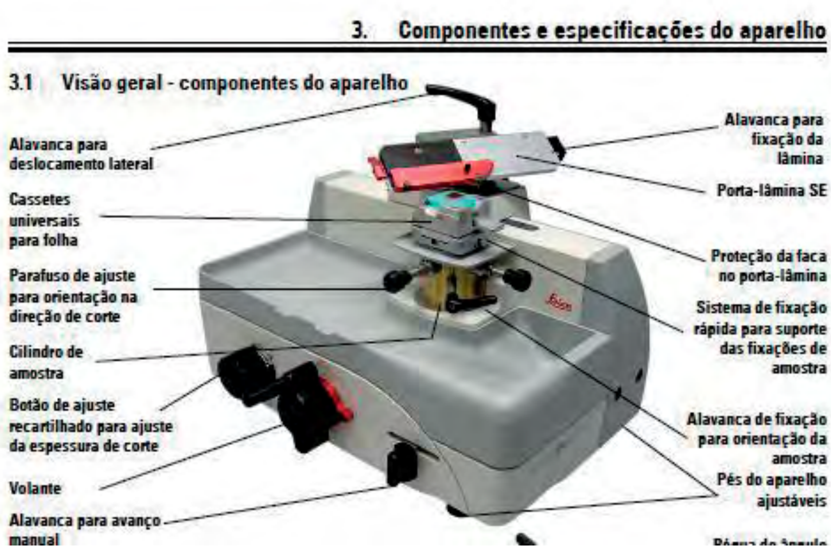
Tips

Sliding microtomes

- Sliding or sledge microtome
- Serial sections of large and hard samples
- Tissue fixed in place and blade moves
- Rigid samples of wood and stems, 12-50 µm



Leica SM2010 R



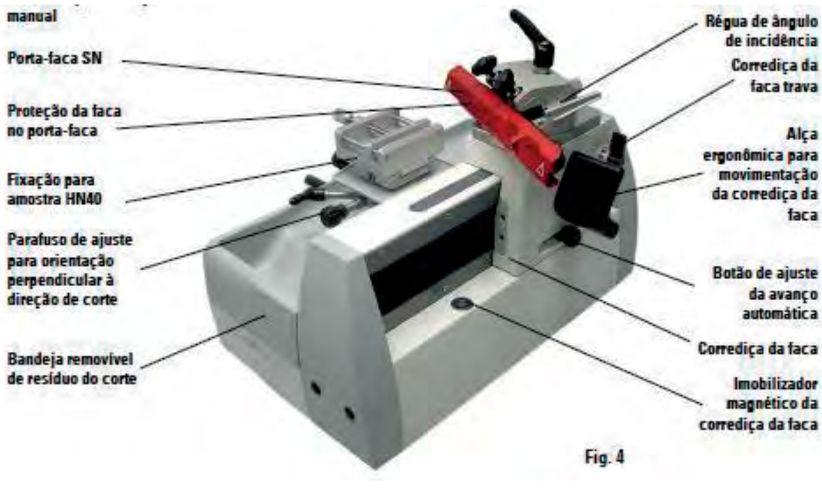
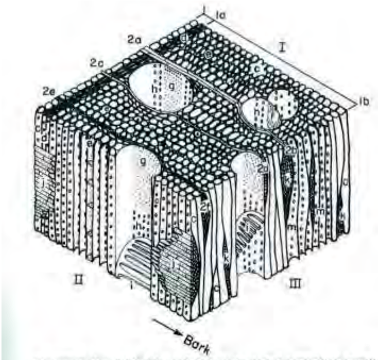


Fig. 4

Microstuctural details of hardwoods

- Please use a microscope and sketch the following aspects of your hardwood specimens the cross-sections and tangential longitudinal sections :
  - Fibers, vessels, perforation plates, rays
  - Longitudinal parenchyma grouping (from cross-section)



Transverse view. I. *I-Ia*, latewood; *Ia-Ib*, earlywood of succeeding growth ring; *c*, earlywood fiber; *d*, latewood fiber; *e*, longitudinal parenchyma; *f*, vessel-to-vessel pitting; *g*, vessel-to-ray parenchyma pitting; *h*, vessel-to-fiber pitting; *2a-2b*, *2c-2d*, *2e-2f*, rays.

Radial view. II. *c*, earlywood fiber; *d*, latewood fiber; *e*, longitudinal parenchyma; *g*, vessel-to-ray parenchyma pitting; *h*, vessel-to-fiber pitting; *i*, perforation plate between vessel elements; *j*, ray composed of procumbent ray parenchyma.

Tangential view. III. *c*, fibers; *i*, perforation plate between vessel elements; *k*, rays in end view; *m*, fiber-to-fiber pitting (bordered).

Birch (*Betula* spp.)

FIGURE 3.19. Three-dimensional representation of diffuse-porous hardwood.

Boyer et al. (eds). 2007

Microstuctural details of softwoods

- Please use a microscope and sketch the following aspects of your softwood specimens from the cross-sections and tangential longitudinal sections
  - Resin canals
  - Epithelial cells
  - Uniseriate ray
  - Fusiform ray (with resin canal)
  - Cross-field pitting (from radial longitudinal sections)

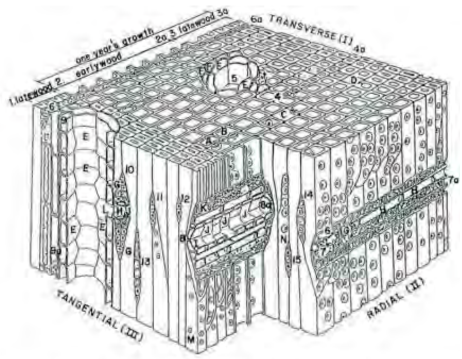


FIGURE 4.12. Three-dimensional representation of distinct-ring softwood.

Boyer et al. (eds). 2007

Transverse Surface (I)

Examination of the transverse surface of Figure 4.12 reveals numerous longitudinal tracheids in cross section. Portions of two growth rings are shown. Latewood tracheids of one annual growth layer lie to the left (1); these are followed to the immediate right by earlywood (2–2a) and latewood (3–3a) of the succeeding annual ring. Transition in zone 3–3a is relatively abrupt. A row of tracheids visible at 4–4a is traceable to an anticlinal division of a fusiform initial that occurred when the position indicated by 4 marked the outer extremity of the xylem and the position of the tangentially oriented cambium. Bordered pits that have been sectioned transversely are pictured at A, B, C, and D.

A resin canal, pictured at 5, is surrounded by short, thin-walled epithelial cells (E). Thin-walled longitudinal parenchyma (F) lie to the outside of the epithelial cells. A transversely sectioned row of ray tracheids can be seen at 6–6a.

Tangential Surface (III)

To the extreme left of the tangential surface a septated longitudinal parenchyma cell is visible (9–9a). This is adjacent to a large longitudinal resin canal, which is surrounded by epithelium (E). An opening can be seen connecting transverse and longitudinal resin canals (L).

A fusiform ray at 10 exhibits ray tracheids (G), ray parenchyma (H), ray epithelium (J), and a large-diameter transverse resin canal (I). Uniseriate heterogeneous rays are shown at 11, 13, 14, and 15. A homogeneous type ray, composed of ray tracheids, is seen at 12.

Longitudinal tracheids appear sharply tapered tangentially rather than rounded as in radial view. Pitting is sparse but can be seen in occasional tracheids at M (latewood) and N (earlywood).

Radial Surface (II)

Numerous conically shaped bordered pits dot the radial surface of longitudinal tracheids, marking locations of matching pits in adjacent rows of tracheids. Earlywood tracheids are bluntly tapered in this view, whereas end walls of the narrower latewood are more angular.

A longitudinally sectioned uniseriate and heterogeneous ray composed of both ray tracheids (G) and ray parenchyma (H) is shown at 7–7a. A sectioned fusiform ray is at 8–8a. This ray is built around a resin canal (I) and contains short, bricklike epithelial cells (J), ray parenchyma, and ray tracheids. An unsectioned ray tracheid is at (K).

Boyer et al. (eds). 2007

Specimen collection and preparation

- Wooden blocks collected in the forest and placed in a solution of e.g., ethanol-glycerin (1:1), or stored frozen in a freezer
- Block of about 1.5 x 1.5 x 1.5 cm
- Softened in a boiling solution of water (and glycerin (9:1)) for a reasonable time (->half a day)

Cutting

- Set up the microtome, select a correct blade type (steelknife or disposable)
- Set-up of microtome
  - Knife orientation and angle (e.g., 10-30º)
  - Sample orientation
  - Solution to easier the cuttings: ethanol:glycerin 1:1
  - Brushes, forceps, objective glasses, petri dishes, hot plate, stains, mounting medium, cover glasses

METLA

- The first corner of the sample sections must be collected by the brush, slide the section with the brus on the blade and then collect it to the objective glass
- Several sections collected on objective glasses
- Place on hot plate under pressure
- Staining

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Staining the sections

- Correct use of stains will make the identification much easier since it gives contrast between different components of the tissues and allow examination by light microscopy. Staining also tells you something about the chemical composition of the objects. Select one of the four choices:
- 1) -Stain sections with 1% Alcian blue (aqueous) for 1-2 min -> affinity to carbohydrates
  -Rinse with water
  -Stain sections with 1% Safranin (in 50% ethanol) for 1-2 min -> affinity to lignin
  -Rinse with water
- 2) double staining: mix 1 portion of safranin and 2 portions of Alcian blue, stain sections for 2-3 min, rinse with water
- 3) stain with 1% safranin only, for 1-2 min, rinse with water
- 4) stain with 1% Toluidine blue (aqueous) for 1-2 min, rinse with water

Tissue element	Color created by Toluidine blue
Tracheary elements (lignified walls)	Green or bluish green
Lignified sclerenchyma	Blue-green, but occasionally green
Collenchyma	Reddish purple
Parenchyma	Reddish purple
Sieve tubes and companion cells	Red
Callose, starch	Unstained

Mounting the sections

- For preservation purposes and subsequent optimal microscopy, the (stained) sections normally mounted using a suitable mounting medium, and covered with a cover glass. One of the most important parameters of mounting mediums is the refractive index (nD) which should be around 1.5, the refractive index of glass.
- Mount the sections to make them permanent/semi-permanent, using e.g.
  - Permanent, organic-solvent based medium like Canada balsam:
    - Dehydrate the specimens in an increasing ethanol series: 50%, 70%, 94% and 2x100%
    - Clear the specimens by inserting a drop of xylene (hazardous: do not breathe the vapours, always work in a fume hood) on specimen
    - Add a drop of Canada balsam
    - Place a cover glass gently, starting from one edge and then slowly lowering it to avoid formation of air bubbles
    - Place to dry in the oven (about 34-40°), use small weights to straighten the sections
  - Semi-permanent, water-soluble agent like Kaiser's glyserin-gelatin (hazardous, includes phenol, needs to be warmed up in water bath), or Aquatex
    - Cover-slipping directly from water, be careful with the air bubbles!

Olympus BX-60 microscope

Setting Up Köhler Illumination

1. Focus on the specimen.
2. Close the field diaphragm (no. 1 in Figure 1) to its most closed state so that you can see the edges of the diaphragm (may be blurry) in the field of view.
3. Use the condenser focus knob (2 in Fig. 1) to bring the edges of the field diaphragm into the best focus possible. The best focus is achieved, when the colour at the edges changes from red to blue and vice verse.
4. Use the condenser-centring screws (3 and 4 in Fig. 2) to centre the image of the closed field diaphragm in the field of view. The centre should be in the middle of the field of view.
5. Open the field diaphragm just enough so that its edges are just beyond the field of view.
6. Adjust the condenser diaphragm (5 in Fig. 2) to introduce the proper amount of contrast into your sample. The amount of contrast added will depend on the sample, however too much contrast can introduce artefacts into your images. Check the proper contrast value from here:

Magnification in objective	Value for condenser diaphragm
1X	No condenser diaphragm
2X – 4X	Condenser diaphragm open, adjust the contrast by the field diaphragm
10X	0.20
20X	0.30
40X	0.45
60X	0.56

7. Adjust the light intensity as necessary (6 in Fig. 3).
To adjust light intensity it is best to use a neutral density filters (7, 8, and 9 in Fig. 4) rather than increasing or reducing the supply of power to the light source. Neutral density filters block all wavelengths of light equally, while changing the power to the light source will alter the balance in the spectrum of incident light giving a yellow/brown appearance to the image.

Figure 1

Figure 2

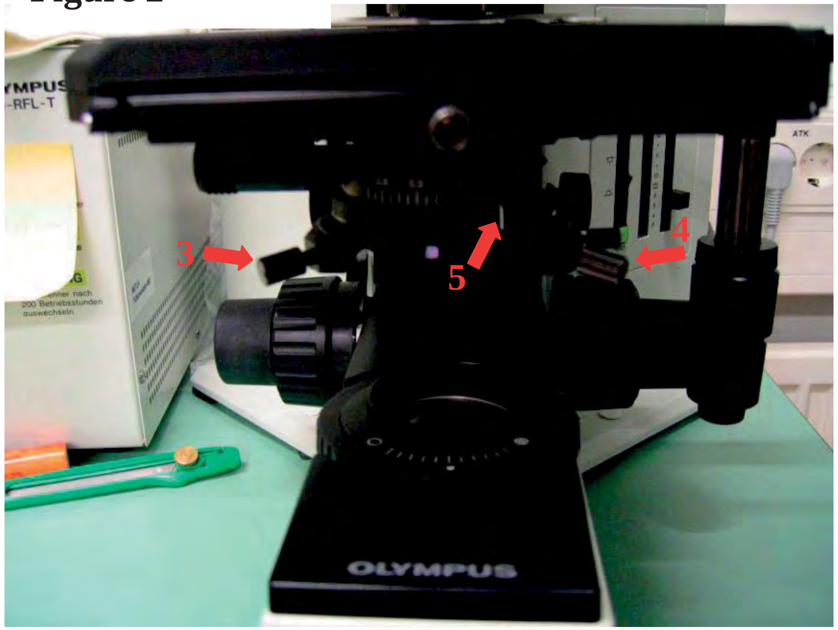


Figure 3

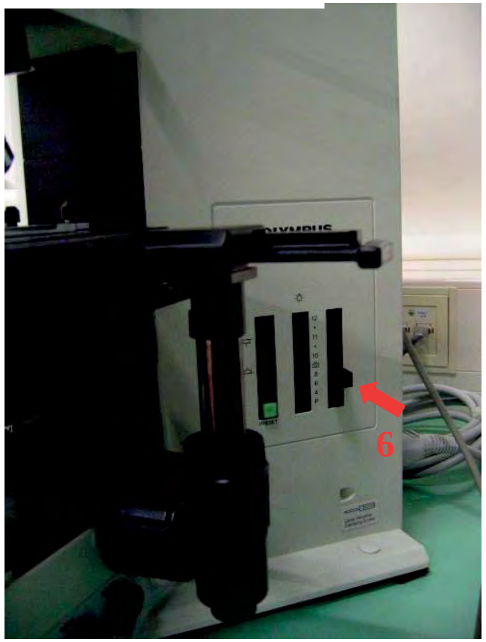
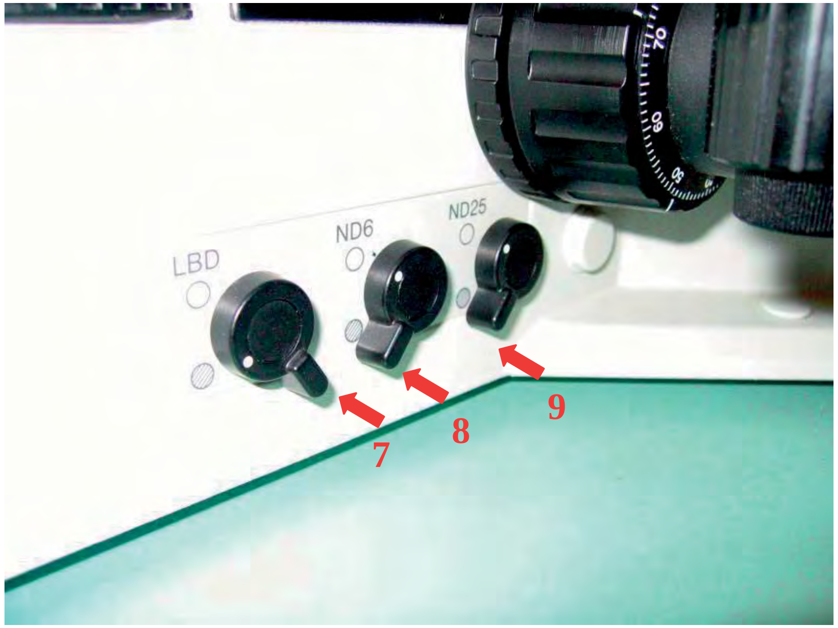


Figure 4



Forecas - List of wood laboratory equipment to be purchased

Nr	Equipment	Estimated price
1	Universal wood testing machine	43372
2	Microscopy with camera + image analysis software	8000
3	Microtome of sliding	12600
4	Consumables and chemicals (microscope slides, coverglasses, trial tubes, petri dishes/plates, pipets, safranin, lactophenol blue, ethanol, peroxides, glycerol, canada balsam)	3000
5	Universal woodworking machine for sample preparation	20377
6	Kiln drier	6000
7	Fridge/refrigerator	2000
8	Spectrophotometer	9000
9	Digital scale	1500
10	Registador de temperatura e humidade relativa do ar (Hygrometer)- temperature range -20 to 150o C	500
11	Lupa de mesa (Table magnifier lamp – 5x/20x/100x)	200
12	Placas aquecedores de um prato (Lab hob heater diffuser plate)	400
13	Paquímetro digital (digital lab calliper)	300
14	Escala graduada Stanley (Régua graduada) (Stanley graduated ruler)	50
15	Cronómetro digital (Digital chronometer)	100
16	Medidor de humidade (Handheld wood moisture meter)	300
17	Thermometer (Termómetro)	86
18	Motosserra (portable chainsaw)	1200
19	Afiador de navalha automático (Automatic Knife Sharpener)	400
20	Elevador de laboratório (Lab Jack)	425
21	Sistemas de ar condicionados (Air conditioned system)	3000
22	Relógio comparador digital	2000
23	Devices and material for acclimatization chamber for wood samples	20000
24	Stress Wave Timer – Emissor de Ondas Acústicas	8500

luke.fi

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