Understanding Plantation and Natural Forests: A Handbook for Forestry Practitioners is written purposely to support the forestry practioners and other experts in the field of forestry in order to effectively implement their duties. It covers topics such as silviculture, botany, protection, utilization, forest resources assessments, harvesting and economics.

Areas of coverage organized in chapters include Introduction to forestry; Silvicultural practices in plantation and natural forests; tree morphology, taxonomy, physiology and ecology; Plantation and natural forests; Survey and resources inventory in the field of forestry; Harvesting techniques and utilization of forest and forest products and Economics of forest products utilization.

Generally the book is an important reference book about forestry and forestry practices in Tanzania. It can be used as reference materials in training, research and forest management practices in different locations throughout Tanzania and worldwide.

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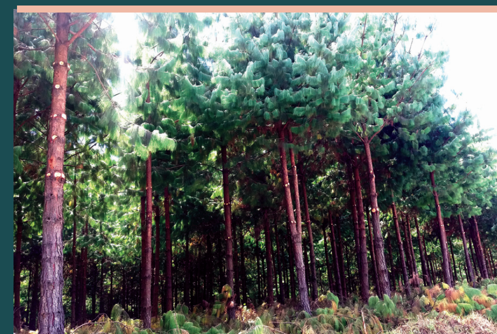

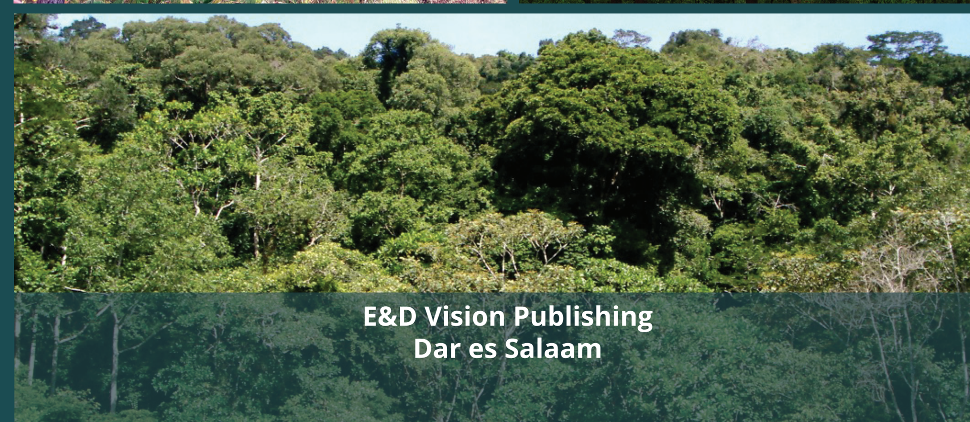

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CHAPTER 4

Forest Protection

J.Z. Katani, S. Mawinda and W.A. Mugasha

Forest Fire

Concepts and Key Terminologies

For the fire to occur, three elements which forms the fire triangle (Figure 4.1) are required; namely an ignition source, fuel and oxygen.

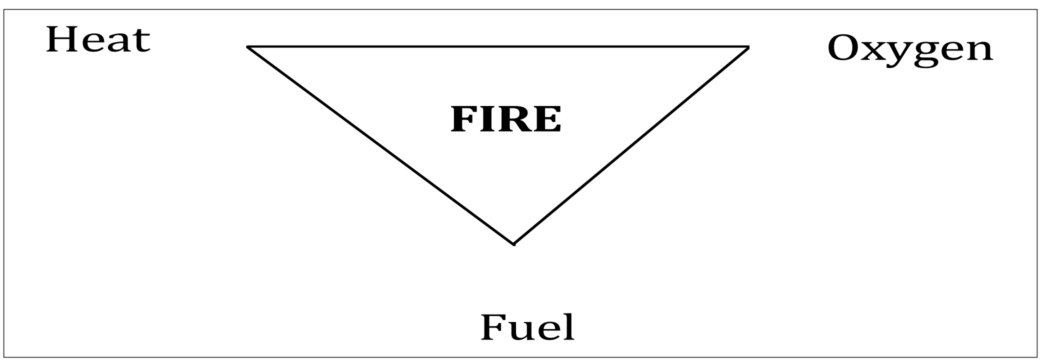

Figure 4.1. Fire triangle

A fire regime concept is comprised of pattern, frequency and intensity of the forest fire that prevail in an area over a long period of time. It is an integral part of fire ecology, art and science of understanding natural and human fire history as well as fire effects on the environment, species, ecosystems and landscapes. Fire ecology concept is about the interactions, ecological effects and roles fire plays in ecosystem process. For example, some tree species in certain ecosystem need fire to germinate or reproduce (Chidumayo, 1988; Richard, 2008).

There are various terminologies used in the subject of fire. Some of these terminologies are defined/explained in Box 4.1.

Fingers of a fire: Are the long narrow extensions of a fire projecting from the main body.

Fire analysis: Is a review of fire management actions taken on a specific fire, group of fire, or fire season in order to identify reasons for both effective and ineffective actions, and to recommend or prescribe ways and means of doing a more efficient job.

Fire attack: Is extinguishing the spread of fire by any appropriate means.

Fire break: Is a gap in vegetation or other combustible materials which save as a barrier to stop or slow down progress of wildfire.

Fire cache: Is a supply of fire tools and equipment assembled in planned quantities or standard units at a strategic point for exclusive use in fire suppression.

Fire control: Is the prevention and monitoring forest fire.

Fire crew: Is a general term for two or more fire fighters organized to work as a unit.

Fire damage: Detrimental effects of fire expressed in monetary or other units, including unfavourable effects of fire-induced changes in the forest resource base affecting attainment of organizational goals.

Fire frequency: Is a general term referring to the recurrence of fire in a given area over time.

Fire reduction strategy: Is a plan or initiative set well in advance to prevent and control forest fire.

Fire: is a rapid oxidation process of a material in the exothermic chemical reaction that results into release of heat, light and various products.

Forest fire: Is an uncontrolled fire occurring in forest land. Forest fire incidences can be so large to cause damages to natural resources, diminish the range and diversity of species and degrade forest status.

Forest fire detection: Is the act/system of discovering and locating fires.

Head fire: The side of the fire having the fastest rate of spread.

Fire frequency: The number of fires that occur per unit time and area.

Fire season: The period(s) of the year during which fires start and spread sufficiently to warrant organized fire suppression.

Fire size: The total area burned and size class distribution for a given area.

Fire severity: The combined ground and above ground effects resulting from smouldering and flaming combustion on either a wildfire or prescribed fire site as manifested in various fire behaviour characteristics (i.e. fire intensity, flame height and length, residence and burnout-times). It is inferred after-the-fact from the fire impact(s).

Fire intensity: The rate of heat energy release in kilowatts per meter. Determines fire effects and difficulty of control.

Fire management: Is the process of planning, preventing and fighting fires to protect people, property and the forest resource. It also involves fire to attain forestry, wildlife and land-use objectives.

Fire suppression: all the procedures used to prevent spread of and extinguish fire.

Box 4.1. Definitions/explanations of some forest fire terminologies
Source: FAO (1986); Alexander (1987; 2000); DeBano et al. (1998)

Types of Forest Fire

Generally, fire scientists have categorized fire according to layers in which the vegetation burns. This results into three main types, namely, ground, surface and crown fires (Figure 4.2).

Figure 4.2. Different types of fire (Picture from SAO hill forest plantation in Tanzaia)

Sahin (2007) provides details of the three types of forest fire as follows: *Ground fire*: Is the fire that burns below the surface of the ground in deep layers of organic material and plant debris on the forest floor and produce intense heat but practically no flame. It is slow moving but happens to be very destructive if not controlled. This kind of fire is the most difficult to detect because they are undetectable until they blaze up. At the time they are detected, the forest undergrowth is already reduced to ashes, killing all organisms that live underground.

Surface fire: It is a fire that burns the surface of the forest. The most common form is grass fire either in grassland or in the understorey of wooded communities. In this type, the spread of fire is regular and usually depends on wind speed.

Crown fire: Is the one that advances from top to top of trees and shrubs and can be more or less independent of surface fire. It destroys foliage and usually kills trees. Crown fires are the most dangerous fires for a forest, it spreads rapidly and widely.

In practice, forests may experience predominantly one of these fire regime, or a mix of the three.

Forest fire can also be classified based on its intensity and extent of spread, from small, medium and large fires as follows:

- Small fire: One that has not yet built up to serious proportions of intensity and spread. It can be easily and manually controlled by initial direct attack,
- Medium fire: Is of serious intensity, depending on the fire fuel and weather conditions. They can burn both as a surface and crown fire, and
- Large fire: The most damaging fire, often reaching catastrophic proportions. Many are a result of adverse conditions of weather (wind, drought, temperature) and topography.

Causes of Forest Fire

The causes of forest fire can be categorized into natural and athropogenic (human activities) as described below:

Natural Causes

These include:

- Lightnings: Are common in deciduous and semi deciduous forest biomes. They are not often (infrequent) in the tropics;
- Volcanic eruption: Volcanic fire occur in localized areas restricted to volcanicity; and
- Electric discharge: Fire caused by the flow of an electric current or by a discharge of static electricity. It is not defined as a fire involving an electrical device. An example could be fire started by a spontaneous combustion of dry fuel such as sawdusts and dry leaves.

Human Causes

Most tropical forest fires are caused by anthropogenic activities as follows:

- Conversion of forests to other land uses by slash and burn and burning of herbaceous cover of grass through land clearing for agriculture, exploitation of other natural resources and charcoal burning, These burning are usually done carelessly;
- Pastoralism (burn dry vegetation to attract sprouting of fresh grasses), hunters (burn to trap animals) and honey harvesting (burn to scare away honey bees) ;

- Wild land /residential interface at the beginning of every dry season for reasons of scaring snakes, vermin and games around village houses, removing vegetation to increase accessibility, burning grass houses and campfires cooking torches; and
- Along roads, paths and railways from cooking fires near roads, cigarette buts, exhaust from vehicles, smokers.

Fire incidences in forests are very frequent due to existence of conditions which favour the start and spread. Among such conditions are:

- Climate with prolonged dry season;
- The predominant natural herbaceous vegetation which is always ready to burn;
- People's traditions, beliefs and attitudes toward use of fire; and
- Lack of efficient means of avoiding, combating or extinguishing forest fires.

Fire Behaviour

Fire behaviour is the way in which fire starts, develops and spreads. It could also refer to the dynamic properties such as rate of spread, the energy profile and the rate of energy release intensity (Pyne *et al*., 1996). Fire behaviour is influenced by the interactions of fuel, weather and topography.

Fuel: Is any organic material either dead or living (needles, leaves, branches and twigs) that can ignite and burn. The intensity of fire is determined by size of fuel, its arrangement/compactness, continuity, volume, condition, location and types.

Weather: Time of the day and season influence weather which in turn influences fire behaviour. The basic weather elements which should be taken into account in forest fire are precipitation, temperature, wind and relative humidity. Each of these elements contributes to the atmospheric stability of an area. They are also important in fire fighting.

Topography: Physical features of Earth's surface such as slope, shape and aspect have great influence on fire behaviour. For example, burning speed increases with shape of valley. Fire burning spread is higher in narrow valley than in the wide valley. Aspect is a position of the land surface in relation to the sun. The occurrence of fire and their rate of spread vary according to aspect.

Fire Regimes

A fire regime is the pattern, frequency and intensity of the forest fire that prevail in an area over long periods of time. Its analysis helps to evaluate ecological elements of forest fire. Components of fire regimes that can be used to evaluate and identify areas on the landscape that are fire driven and dependant include fire intensity, fire frequency, season of burning, the extent (or patchiness) of and type of fire (Govender *et al*., 2006).

In general, a fire regime characterizes the spatial and temporal patterns and ecosystem impacts of fire on the landscape (Bradstock, Williams, and Gill 2002; Morgan et al. 2001; Brown and Smith 2000; Keeley *et al*. 2009). The two most important factors for determining fire regimes are vegetation type (or ecosystem) and weather/climate patterns. Fire regimes may also be affected by terrain features, slope exposure, management regimes, landscape pattern, and ignition loads (both from natural such as lighting and from human activities) (Taylor and Skinner 2003; Odion *et al*., 2004; Frost 2000; Agee 1993). At a minimum, fire regimes may be distinguished by how often fires typically occur (frequency, fire interval, fire rotation) and some assessment of impact on the ecosystem (e.g. mortality of overstory or surface vegetation). Some fire regime classifications include additional features such as fire characteristics (e.g. surface fire, crown fire, ground fire), the typical extent (or size) of fires (patch size), fire severity (impact of fire on the ecosystem; degree of mortality, depth of burn, fuel consumption etc.), intensity or other measures of fire behaviour.

Effects of Forest Fire

Tanzania, like many other tropical countries, is seriously affected by forest fires. According to Andreae (1991); Grace *et al*. (2006); Montzka *et al.* (2011) these effects can be environmental, social and economic.

Environmental Effects of Forest Fire

The environmental effects of fire include:

- Injects trace gases and aerosols into the atmosphere causing air pollution;
- Causes forest degradation and deforestation releasing carbon dioxide into the atmosphere;
- Affects forest habitat (depending on the soil and the fire's intensity);
- Create heavy smog that is harmful to human and animal life;
- Its damage prevents the natural process in which soil and leafage normally absorb rainfall;
- Generates ash and destroys available plant nutrients, thereby affecting the biodiversity of forests; and
- With an increase in water runoff, forest fire can engender flash flood conditions and enable soil erosion.

Social effects of forest fire include:

- Fire causes damage to human properties and buildings;
- Fire causes human death; and
- Collapse of social services including communication, electricity and water supplies.

Economic effects of forest fire include:

- A lot of money is spent to fight forest fires with chemicals, logistics, aircrafts and trucks, time and personnel;
- Economic impact of mitigating air quality changes arising from forest fires that posses substantial human health risks;
- Cost affects state and local budgets in the long-term including replacement of lost facilities, infrastructure, watershed mitigation, as well as sensitive species and habitat restoration;
- Costs to support fire prevention including: building firelines, providing fire fighting teams with food, equipment, allowances and temporary shelters;
- Can burn forest products, make recreation and tourism unappealing, and affect agricultural production; and

- depending on the severity and location of a forest fire, post-disaster recovery can come with a considerable price/budget.

Ecological Effects of Forest Fire

The effect of fire in any ecosystem is one of the most important facets of fire ecology. Fire influences the structure, composition and dynamics of many ecosystems. In Southern Africa, grassland, savanna and forest ecosystems are subjected to recurrent fires. Fire is considered to have been of major importance in the evolution and maintenance of forests (Andreae and Goldammer, 1992). The following are the ecological effects of fire (Oliveira and Marquis, 2002; Booysen and Tainton, 2012):

- Highest seedling abundance, cover and biomass generally occur in lightly burnt areas. In some cases, in range management grass develops fairly rapid after burning;
- Direct heating of the soil and seed bank can affect seed germination, change soil structure, colour and nutrients, and/or volatize allelochemics;
- Temporary reduction in competition by removing above-ground vegetation, thereby allowing seedlings to have greater access to light and water, and reduce allelopathic influences (i.e. interference through toxic chemicals);
- Temporary reduction of habitats affects herbivores, especially small mammals which depends on shurbs for cover;
- Temporary reduction of litter and humus which act as barriers to seedling establishments;
- Some flora has evolved with fire e.g. in tropical Africa miombo forests have developed with fire for many years;
- Fire is also the major cause of secondary succession and furthermore, it is responsible for persistence of some species in these communities;
- Fire may act directly on an individual tree, either through causing its death or by damaging or destroying tissues, thereby affecting growth and reproduction;
- Some seeds can be stimulated to germinate by fires;
- Trees could be made vulnerable to insect or pathogen attacks;
- Organic matter which form habitat for several fauna and mulch for different plants are destroyed;

- Soil chemistry is changed mainly due to ash, while volatile elements such as Nitrogen, Sulphur, and Chlorine are lost as gases;
- Phosphorus, Potassium, Calcium and Magnesium usually increase on the upper mineral layer and consequently increases the soil pH; and
- Predators e.g. birds may find abundant prey during and after a fire and may disturb the ecological equilibrium.

Forest Fire Management

Globally, it was estimated that over 350 million ha of forest were burnt in 2000, the large proportion of this is in the sub-Saharan Africa (FAO, 2011). In Tanzania, it has been estimated that between 2000 and 2009, forest fires affected about 65,000 ha of forests and woodlands annually of which more than 75% occurred in miombo woodlands (FAO, 2011). Forest fire is both beneficial and detrimental. It is essential to maintain ecosystem dynamics, biodiversity and productivity as well as a tool to meet land management goals. However, fire has negative impacts such as causing losses to human and biodiversity in terms of resource destruction (MNRT, 2006). Due to both positive and negative impacts of fires on forests, appropriate management options are needed.

In tropical forestry, there are three basic fire management options, namely; fire exclusion, no fire management and integrated fire management.

- Fire exclusion: It is applicable to those forests in which any fire effect would be undesirable and counter-productive to resource management and conservation objectives;
- No fire management: It entails uncontrolled forest fire occurrence which is applicable in many of the savannas, the savannah-forest ecotones and in open deciduous woodlands throughout the tropics; and
- Integrated fire management: It is based on a thorough understanding of the impacts of fire in a specific forest type. It requires the capacity to actively manage all fire situations to; prevent and suppress all undesirable fires, use prescribed fire in order to obtain resource management goals, as well as define and control the threshold between the desired effects of uncontrolled natural and human-caused fires.

Forest Fire Detection

The occurrence of a forest fire must be observed and reported as soon as possible in order to start suppression activities while the fire is small. Fire detection could be done by general public or forest workers. There are several approaches being used for detecting fire incidences. Some of the approaches that can be used are such as fire weather forecast, watch towers, optical smoke detection, spotter planes and smart phone calls (Alkhatib, 2014). Generally, detection and monitoring systems are divided into two basic groups namely:

- Volunteer reporting: This include public reporting of fires, public aircraft and ground based field staff; and
- Operational detection systems: This includes fire towers, aerial patrols, electronic lightning detectors and automatic detection systems.

In cost effective scenarios, the following could be applied in detecting fire incidences:

- Ground patrolling: All forest staff and public should be alerted during fire season. Patrol men or rangers can travel in the forest on foot, bicycles, motorcycles or vehicles, and should be equipped to take instant action against any small fire that may be found;
- Fixed lookouts stations: Can be lookout towers or lookout points. They are vantage points selected for fire detection and built on the top of high hills. Lookout towers are built of wood or steel, and the height usually depends on the tallness of the surrounding forest and any visual obstructions; and
- Air patrols: Air patrolling though expensive is an appropriate method of fire detection in extensive, sparsely populated areas. It gives prompt and reliable information, and accurate location of the fire.

Forest Fire Suppression Techniques

For effective fire suppression, fire crew and equipment need to be considered. The crew must understand what to do; should be available on need; have reliable labourers to reinforce the crew; and equipments should be available and be operational (Alexander, 2000). The following are phases involved in forest fire suppression:

- Initial attack: This aims to cut-off and/or restricts the fire spread. A well trained crew is needed to put the fire out while they are small. Basic equipment includes, car with two-way communications with headquarters and hand tools. A mix of hand and modern fire fighting equipment could increase efficiency. The crew should be healthy and well motivated;
- Containment: Indicates that spread of fire has been stopped through construction of control line. However, suppression work has not been completed;
- Control: At this stage the control lines have already been completed and work along the edges of the fire to fully extinguish it has begun. Fire is said to be controlled if the "fire boss" is satisfied that there is no chance for it to spread further;
- Mopping-up: Is the action of making the fire safe after it is controlled such as extinguishing or removing burning material along or near the control line, felling snags and trenching of logs to prevent rolling. In large areas it does not include whole burnt area, only specific spots; and
- Patrol: Done to mobilize several crews depending on the area to ascertain fire suppression. The crew move in fire areas and extinguish any isolated fire that has been missed during mop-up. After this exercise the area could be rechecked after 24 hours.

Successful forest fire suppression depends on a well balanced combination of people, equipment, tools and training.

Forest Fire Fighting Equipment

The type and quantity of equipment required depends on local conditions, size of forest, climate, topography and economic considerations. These can be grouped into:

Hand tools: Basic works in forest fire control where hand tools are used includes line location, clearing and construction of trails, grubbing, trimming, trenching, burning off and suppression/mop-up. In choosing hand fire fighting tools, the following should be taken into consideration: effectiveness, efficiency, productivity, versatility, portability, durability, maintenance/ replacebility and standardization. The hand tools commonly used are: axes, bush knives, saws (bow-saws and chains-saws), mattock, rakes, hoes, hovels, forks, bush hooks, fire-beaters and swatters, backpack pumps, heath way pump, flamethrower and foam extinguisher (Mishra, 2009). Examples of hand fire fighting equipment are presented in Figure 4.3.

Backpack Pumps

Fire Beaters

Hoe, Rake and Bush Knife

Figure 4.3. Examples of fire fighting equipment (A photo from SAO hill forest plantation in Tanzania)

Mechanical equipment: Mechanical equipment is relatively expensive but most efficient in fire fighting. Example of mechanical equipment include: vehicle for crew and equipment; water bowsers; reliable mechanical water pump fitted with engine or powered from tractor or vehicle. Aircrafts; helicopters for delivering extinguishants (water, chemical fire retardants, foam); and in some countries they use parachutes (Figure 4.4).

Fire Engine　　Fire Line Grader

Figure 4.4. Examples of mechanical equipment used for fire fighting (A photo from SAO hill forest plantation in Tanzania)

Safety

Fire fighting is always a dangerous activity which can result into injuries and sometimes deaths. It is therefore important to adhere to safety procedures. The fire boss is responsible for the crew safety. On the other hand, the fire fighting crews must work safely and observe the fire fighting safety instructions. Safety activities should include welfare and first aid services in the field. The main reasons for accidents in forest fire fighting include: failure to observe safety regulations, under staffing crews and inadequate training. Safety is a matter of common sense, it should be adhered to avoid accidents by crews and other people.

Methods of Controlling/Preventing Forest Fire

Forest fire control/prevention is one of the most important elements of forest protection against fire. The responsible bodies and their responsibilities in fire control must be clearly outlined from village/ local level to the highest level of the government.

The central government can contribute to forest fire control in three ways: promote investigation and research on problems related to forest fires; create public awareness through education on fire problems and control; and enact and promulgate legislation aiming at limiting occurrence of forest fires, also to ensure enforcement of such legislation.

At village/local level: protective measures aiming at preventing forest fire spread are properly observed; steps to ensure that laws aiming at fire control are enforced; and penalties which could reduce deliberate fires are emphasized. Protection of forests from fires embraces a wide range of measures that; modify the fuels around/within the fire threatened resources to reduce the spread and intensity, reduce human-caused ignition sources and facilitate early detection and suppression.

Forest Pathology

Concept, Terminologies and Scope

Pathology derives from the Greek words *pathos* means suffering and *ology* means study of, to give us "the study of disease". Forest pathology - is a branch of plant pathology that deals with the diseases of forest trees (Tainter and Baker, 1996).

A tree is said to be healthy or normal when it can carry out its physiological functions to the best of its genetic potential. These functions include normal cell division, differentiation and development; absorption of water and mineral soils and translocation of these throughout the plant; translocation of the photosynthesis products to the areas of utilization or storage; reproduction as well as storage of food supplies (Agrios, 2005). The normal physiological functions of plants are disturbed when they are affected by pathogenic living organisms or by some environmental factors. These effects cause changes in plant physiological functions expressed as symptoms of the disease which can be visualized macroscopically. This interference can result to plant changes in appearance and/or yield less than normal compared to a healthy plant of the same variety (Tainter and Baker, 1996). In summary, plants disease is a function of three important agents namely hosts, pathogen and environment as illustrated in Figure 4.5.

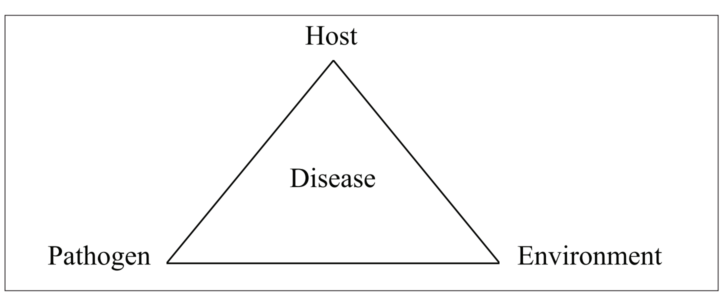

Figure 4.5. Disease triangle

A favourable environment is critically important for disease development. Even the most susceptible plants exposed to huge amounts of a pathogen will not develop disease unless environmental conditions are favourable.

Forest pathology is important because of time and resource involved in forest investment. Forests that are under monoculture system provide a favourable environment for diseases spread, and in some cases the management practice become a cause for a disease; causing loss to the investment. Climate change increases diseases incidences and severelity to plants, therefore it is important to understand about forest pathology. Forest pathology acquaint practitioner with common diseases, causes and system and how they can be managed. Some of the terminologies that are frequently used in forest pathology are defined in Box 4.2:

Climate change: Change of weather patterns over a number of years ranging from decades and these changes might come with a number of effects to the ecosystem.

Colonization: Growth of a pathogen, particularly a fungus, in the host after infection.

Deficiency: Abnormality or disease caused by lack or sub-normal level of availability of one or more essential nutrients.

Dissemination: Situation whereby pathogens are transmitted/spread from one host to the other; some of the main agents are wind, insects, water, man, animals and birds.

Host: Organism that harbours another organism or the plant invaded by the pathogen and serving as its food source.

Infection: Initiation and establishment of a parasite within a host plant.

Inoculum: Portion of pathogen which is transferred to plant and cause disease.

Invasion: Penetration and spread of a pathogen to the host.

Pathogen: Entity that can cause disease in a host (e.g. tree). Pathogens can be biotic (infectious and transmittable) or abiotic (non-infectious and non-transmittable).

Pathogenesis: Chain of events that takes place during the development of disease.

Pathogenicity: Ability of a pathogen to cause disease by interfering with one or more of the essential plant cell functions.

Penetration: Initial invasion of pathogen (mostly fungi and nematodes) to the substrate which can happen by direct penetration or through natural opening or wounds.

Reproduction: Situation where a population of pathogen increases in number.

Resistance: Ability of an individual host tree to use genetically encoded mechanisms and resist against attack of the pathogen or withstand attack by an invading organism.

Sign: Physical evidence of the presence of disease agent or indication of disease from direct observation of a pathogen or its parts (e.g. mold or fungal spores, bacterial ooze, dwarf mistletoe).

Susceptibility: Inability of the host to resist attack of the pathogen.

Symptom: Expression of a disease by a plant as a response to the activities of a pathogen or another type of persistent agent. Symptoms may be localized or systemic.

Tolerance: Type of defense that minimizes losses without restricting the disease development.

Virulence: Degree of infectivity of a given pathogen.

Box 4.2. Some of forest pathology terminologies
Source: Pandey (1992); Telford et al. (2014).

Controlling or managing forest diseases require understanding of: causal agents, how trees are affected, the mechanism of development i.e. processes of infection and colonization of the host by the pathogen, and the interaction between the causal agent and the diseased plants in relation to environmental conditions.

Botany, microbiology, soil science, ecology, molecular biology, and physiology sub-disciplines provide necessary background for the interdisciplinary science of forest pathology. Plant diseases are important to humans because they cause damage to trees, therefore reducing quality, yield and values/profits of trees. Forest pathology in this chapter focuses only on classifications and development of forest diseases, common diseases, effects of forest diseases and the link between forest diseases and climate change.

Classification and Causes of Forest Diseases

Plant diseases can be classified into different orders depending on the objective. This arises due to the fact that each kind of plant can be affected by one or more pathogens. Pandey (1992) suggested the following basis of diseases classification:

- Symptoms or signs (e.g. rust, smut, blight root rot, cankers, wilts leaf spot, scabs, blights, rust, mosaic, yellows and ring spots);
- Nature of infection (systemic or localized);
- Causing organism/pathogen;
- Mode of perpetuation and spread (soil-, seed- and air-borne);
- Host part affected (root disease, stem diseases, foliage diseases, fruit diseases); and
- Types of the host trees infected.

The most useful classification criterion has been made based on the type of agent that causes the diseases. This classification has the advantage of indicating the causes of the diseases, knowledge of which suggests the probable development and its spread as well as possible control measures for the disease. The disease agents can either be classified as infectious or non infectious agents' depending upon their ability or inability to multiply and spread.

Infectious Plant Diseases

These are diseases caused by the living agents namely pathogens. Pathogens that colonize living plant tissues are called parasites; while those on non-living are called saprophytes. The pathogen is introduced into its host in a form known as an inoculum. The act of introducing a pathogen is called inoculation. The point of entry for the pathogen is called infection court. The term infection refers to the successful establishment of a pathogen within its host. Infectious agents are grouped according to their similarities as fungi, bacteria, parasitic higher plants, nematodes, protozoa as well as viruses and viroids (Chaube and Pundhir, 2005). Disease causing pathogens fall under different forms as explained below:

Viral Plant Diseases

Viruses cause human and animal diseases, such as influenza, polio, rabies, smallpox and warts. Viruses, on the other hand are responsible for several plant diseases. Examples of tree diseases caused by virus are Elm mosaic, ash ring spot, beach line pattern. According to Matthew (1981) a virus is a set of one or more nucleic acid template molecules, normally encased in protective coat/coats of protein or lipoprotein, and is able to organize its own replication within suitable host cells. They are very small in size and can only be seen with electronic microscopes. Their mode of multiplication is by inducing the host cells to form more viruses instead of undergoing normal cell processes. Since viruses survive in living cells, their spread from diseased to healthy plants depends on its enhancement by transmission caused by vectors, such as aphids and leafhoppers. Other agents of transmission can be equipment or people spread sap or juice from diseased plants to healthy plants.

Bacterial Tree Diseases

These are microscopic, unicellular microorganisms with relatively simple cellular organization (Blanchard and Tattar, 1981). They are typically not obligate and are unable to penetrate tree tissue directly. They enter through natural opening such as stomata and lenticels or through wounds. They can be destructive tree pathogens; however, many of them are harmless and beneficial to human such as the nitrogen-fixing bacteria of legume plants. They reproduce by individual cell splitting into nearly equal halves, each becoming a fully developed bacterium. This makes a bacterial population increase to very large number within a short period of time. As bacteria divide, the cells tend to cluster together in masses called colonies. Bacterial cells and colonies vary in size, shape, colour and growth habit. These characteristics are used to identify specific bacteria. In addition, bacteria cannot make their own food, they obtain either from dead/decaying organic matter, or living tissue. Nearly all bacteria have the ability to grow and develop on dead tissue.

Fungal Plant Diseases

Fungi are the largest group of plant pathogens which live on variety of substrates including living animals and plants tissues, wood, paper, fabrics, insects' carcasses, leather, food produces, glue, paint, twine and wax in human ears. The basic unit of fungus is the cell with cell wall, plasma membrane and nucleus (Blanchard and Tattar, 1981). Although, the majority of fungi are beneficial, over 20,000 species of fungi are parasites and cause disease in crops and plants (USEPA, 2005). Fungal parasites are by far the most prevalent plant pathogenic organism. All plants are attacked by one species or another of phytopathogenic fungi. Individual species of fungi can parasitize one or many different kinds of plants. For example *Cryphonectria cubensis* is a serious fungus in trees, often causing canker in species such as Eucalyptus spp, Syzygium and Cloves. The fungi can cause reduced growth and can lead to stem breakage (Roux *et al*., 2004; Marieka *et al*., 2005).

Parasitic Higher Plants

Higher plants which produce seeds can also be parasitic. Generally, parasitic higher plants lack true roots, leaves or both and rely upon a host plant to supply them with water and nutrients. They do this by developing specialized root system composed of structures that are specifically adapted for absorbing water and nutrients from a host plant (Blanchard and Tattar, 1981). For example, *Tapinanthus subulatus* mistletoes is a parasitic plant in *Pyrus communis* (Pear fruit tree) and *Albizia* species in Lushoto district, Tanzania.

Nematodes

These are non-segmented, invertebrate animals belonging to a round, slender worm. Plant parasitic nematodes possess a hollow dagger-like feeding structure known as stylet which is used to penetrate plant tissues and feed on injured cells. Nematodes can attack any part of the plant but most frequent area of attack is a root system, where they interfere water and nutrient uptake. Root injury cause plants to be short of moisture and nutrients, even when water and minerals are adequate at the soil. Presence of high population densities of nematodes can be recognized by the plant's stunting growth, yellowing, loss of vigor, general decline and eventual death (Blanchard and Tattar, 1981). Examples of nematodes include Dagger nematodes in apple trees, and the Root Lesion nematode in Cherry and Pear trees.

Development of Infectious Diseases

Disease development process is a series of events that takes place over a period of time; called disease cycle. According to Chaube and Pundhir (2005) if disease is to be managed effectively, understanding each stage of the process is important. Disease management addresses each disease differently depending on the stage of its development and magnitude of its damage to plants. Management options can include breaking the disease cycle which prevent or reduce development of the disease. Diseases development cycle goes through the following sequence: inoculation, penetration, infection and reproduction and dissemination.

Common Infectious Diseases in Tanzania

Many diseases that affect forest trees both the infectious and non infectious occur either in nurseries or forest plantations. Diseases occurring in the nurseries affect seedlings or transplants while those occurring in plantations affect older or mature trees that have not developed resistance. In this Chapter, only common infectious diseases which commonly occur at nurseries or forest plantations are discussed. These include damping-off, foliage disease, canker, root/butt rot and red band needle blight diseases.

Damping off

This disease attacks young seedlings before or after germination. It is caused by soil-inhabiting fungi that are facultative parasites and are not host specific. Some of them may include *Pithium, Fusarium*, *Rhizoctonia* and *Cylindrocladium species*. The disease destroys all seedbeds of the species in a particular site. The main conditions that favour its occurrence include high soil pH, low light, high nitrogen levels and humidity, heavy and frequent watering. There are two types of the disease, namely, pre-emergence and post-emergence damping off.

Symptoms: The disease is noticed by early decay and death of seedlings with soft/succulent stems. This happens by hyphae of the fungus spreading through the soil and penetrating succulent tissues of stems. In pre-emergence damping off, seeds are decayed or killed by the infection before emerging from the soil. With the post-emergence, seedlings are attacked after they have appeared above ground.

Control: The disease can be managed by avoiding heavy or excessive watering and keeping seedbeds well ventilated. The fungi causing damping off reproduce and spread fast under humid conditions. It can also be controlled by avoiding use of excessive humus/top soil/animal dungs in the nursery soil mixture. In some cases, the mixture could be steam sterilized.

Foliage Diseases

This occurs in tree nurseries and forest plantations. The disease is caused by a group of fungi called *Mycosphaerella species.* Many foliage diseases are caused by parasitic fungi which may extend their activities to the flower, fruits and young twigs. Crown gall is the major foliage disease. The minor ones are such as needle blight, leaf spot and powdery mildew. The leaf spot has more effects to seedlings in nurseries and trees in field. For example, the leaf spotting fungus, *Molleriana species* was first observed in Tanzania in 1991 attacking *Eucalyptus maidenii* and causing severe necrotic spots leading to foliage drying and defoliation (Nsolomo and Venn, 1994).

Symptoms: these vary markedly from simple localized necrotic spots on leaves to total necrosis and shriveling. Very heavy infections may cause premature defoliation of deciduous hardwoods and production of a second crop in the same growing season. New shoots and foliage may be produced from adventitious buds. The disease also causes red to brown discoloration of leaves that may turn grey. The discoloration is often regular, the leaves dying and turning color uniformly. Normally, not all leaves are affected by the disease. The irregular distribution of affected leaves within can be useful in distinguishing foliar diseases from abiotic diseases that affect needles.

Control: the disease can be controlled through integrated approach, including such measures as sanitation and cultural practices. Applications of fungicides such as Bavistin 0.1% a.i. and Blitox 0.2% a.i have also been found to be effective.

Canker disease

This refers to a localized dead region on the bark, branch or stem (Figure 4.6). The important casual organisms include fungal species such as *Dothichiza species, Cryptodiaporthe*, *Diplodia* and *Botryodiplodia species*. The disease is mostly common in Tanzania since 1940 where it was found attacking *Cupressus macrocarpa* (cypress canker) in Shume-Magamba Plantation. The disease caused serious damages to the species, eventually forced its abandonment and replaced by *Cupressus Lusitanica* (Nsolomo and Venn, 1994). *Botryosphaeria* stem canker has been attacking *Eucalyptus* species. It has been reported to be a common disease attacking *Eucalyptus species* in East Africa. The attacks cause cracking of stems and produce gums.

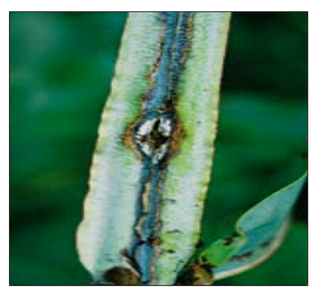

Figure 4.6. Fungal canker on young eucalyptus Source: Wylie et al. (2006).

Symptoms: The disease appears as lesions or canker on the trunks and large branches of affected trees. Cankers are developed by gradual killing of the diseased bark in more or less circular areas. Young infections can be recognised by the presence of brownish shrunken patches. The diseased area may be fairly regular or irregular or girdled.

Control: This includes measures such as use of fertilizer and other cultural activities that will improve the development of the plants. Healthy growth plants suppress attack of canker disease. Remove of affected tree is also one of the effective measures to control the disease

Root/butt rot

The disease mainly attack seedlings in forest plantation, but can remain unnoticed until the trees reach two or three years old. The same factors that favour damping off favour the disease. The tree species widely attacked by the disease is *Tectona grandis* (Teak) although minor incidences have been reported on *Pinus species* (Pines) and *Grevillea robusta* (Nsolomo and Venn, 1994). The major causative agent for this disease is fungus *Armillaria mellea* which is found throughout the temperate and tropical regions of the world.

Symptoms: The disease is not noticed in plantations until trees are two or three years old. At this age, leaves of affected trees often fail to reach normal size, turn yellow, losing their green colour and fall prematurely. The infected trees begin to die in groups. The leaf symptom is easily noticed at leaf flush i.e. when affected trees produce new foliages at a slow rate than the healthy ones. It can also be noticed shortly before normal leaf-fall when the affected trees lose leaves much earlier than the healthy ones.

Control: The disease can be controlled through cultural, biological and chemical applications. The cultural methods for managing the disease include site selection, stump removal and trench digging. Water logged and shallow lateritic soils sites should be avoided. During site preparation, stumps should be removed because they play major roles in the initial colonization and infection in a young Plantation. Leguminous cover crops such as *Pueraria phaseoloides* and *Flemingia congesta* are the most economical biological control. The legumes encourage futile growth of the pathogen and by this large inoculation potentials are dissipated into small infective ones.

Red Band Needle Blight

This is a fungal disease previous referred to as *Dothistroma* blight. Its first incident was reported in 1958 in northern Tanzania at Shume forest

Plantation. The disease had spread vigorously causing wiping out of young plantation of fast growing *Pinus radiata*. The magnitude of infestation led to the abandonment of the species and replaced by a relative slow growing *Pinus patula* (Ciesla *et al*., 1995). The disease is caused by a *Dothistroma pini*.

Symptoms: Older needles are the most affected whereby they develop yellow, tan colored spots and bands which rapidly turn red. Infected needles turn reddish-brown at the tips whilst the bases remain green. Carefulness is needed because the red banding is not always evident and the needles may have an overall brown or reddish coloration easily confusing with symptoms of other diseases.

Control: Reducing humidity levels can reduce the level of infection. Good weed control is also important with young trees, including nursery stock. For older crops, thinning is the main management option available to facilitate air movement and lower humidity in the canopy. Fungicides have not been very successful in controlling the disease. Use of copper-based fungicides can suppress the symptoms and might be a realistic option for individual or small groups of specimen trees. Fungicides may also be used on nursery stock.

Non Infectious or Non Parasitic or Physiological Diseases

These are agents that infect plants causing either some form of permanent damage or substandard rate and quality of growth (Blanchard and Tattar, 1981). The agents may not necessarily kill the plant. The most common and damaging non infectious agents of tree disease are related to weather conditions (e.g. too low or too high temperatures, precipitation, wind, lighting), atmosphere (e.g. smoke, chemicals, lack or excess of light, lack of oxygen, air pollution), soil (lack or excess of soil mixture, nutrients deficiencies, toxins, soil pH) and animal damage.

Effects of Forest Disease Pathogens on Trees

There are several negative effects caused by forest disease pathogens to trees. These are:

- Utilizing host cell contents;

- Killing host or interfering with its metabolic processes through their enzymes, toxins;
- Weakening the host due to continuous loss of the nutrients;
- Interfering with the translocation of the food, minerals and water;
- Can suppress the chlorophyll content;
- Can reduce the leaf area hence slow photosynthesis;
- Curbing the movement of solutes and water through the stems;
- Reducing the water-absorbing capacity of the roots;
- Suppressing the translocation of photosynthetic products away from the leaves;
- Promoting wasteful use of the products of photosynthesis as in the formation of galls;
- Causing death of cells; through its enzymes, toxins and growth regulators
- Cankers can girdle, killing the tree;
- Heart and root rot fungi can utilize cell wall materials-disrupt root function, structural failure, reduced growth; and
- Viruses and some bacteria can highjack the plants DNA replication mechanism and cause severe symptoms such as galls, chlorosis, rigidity and mosaic of leaves.

Diseases Resistance in Trees

Mechanisms which give resistance may be embedded in the genes of the tree, under environmental control, or result from an interaction between the genotype and the environment (Telford *et al.,* 2014). Disease resistance is very important for the protection of trees. If the forest is to be harnessed against pathogens, the most approach is to enhance genetical resistance within trees. This can be achieved through the following:

- Recognizing specific mechanisms of resistance that trees use in defense of biotic threats;
- Genetic control of resistance variation in trees;
- Environmental control of resistance variation in trees; and
- Consideration of phenotypic variation.

Plants make use of a range of phenological, morphological and physiological mechanisms to reduce damage by herbivores and pathogens. These mechanisms can be both passive (spatial and temporal avoidance of threats, tolerance to infection or herbivore) and active (confrontation through inter-active resistance mechanisms which slow or prevent infection or attack). Active resistance mechanisms exist in various forms including mechanical or structural barriers, production of toxic, anti-microbial chemicals or proteins, attraction of predators which target the pest, reallocation of resources to unaffected regions of the plant and compensatory increases in growth or reproduction (Tollrian and Harvell, 1999). In some cases, plants may use a combination of these mechanisms in a coordinated and integrated response.

A science of variation in host disease resistance traits is genetically controlled by a range of genes whose effects may be additive, dominant, heterotic (is the improved or increased function of any biological quality in a hybrid offspring) or epistatic (the effect of one gene is dependent on the presence of one or more 'modifier genes'). The genes may have evolved to defend the plant against threats, control differences in growth, phenology and metabolism that result in differential vulnerability of the host (Telford *et al.*, 2014). The durability of specific inherited quality contributes to the heritable resistance characters that protect forests from pathogens. Durability may be affected by a number of factors including heritability of the trait, climate and genetic diversity (Telford *et al.,* 2014).

Relationship between Climate Change and Forest Diseases

Many disease agents are likely to benefit from the changing climate through increased breeding activity and reduced resilience of the host. Sturrock *et al.* (2011) has predicted the following to be outcomes of climate change on plant health:

- Most plant diseases are strongly influenced by environmental conditions. Climate change may affect the pathogen, the host and the interaction between them, resulting in changes in disease impact;
- Abiotic factors such as temperature and moisture increase host susceptibility to pathogens through pathogen growth, reproduction and infection ability;
- Distribution of hosts and diseases will change due to increased temperature and variations in precipitation. This might allow ranges of species to expand, whilst contracting elsewhere. Pathogens that typically affect water-stressed hosts are likely to increase impact on forests in regions where precipitation is reduced;

- Roles of pathogens as disturbance agents might increase, as their ability to adapt to new climatic conditions become greater than that of their long-lived hosts;
- Most pathogens can migrate to locations where climate is suitable for their survival and reproduction at a faster rate than tree species/host; and
- The life cycles and biological synchronization of many forest trees and pathogens will be affected resulting in distribution and phenology changes such as bud break in tree hosts, spore release by pathogens, alter disease incidences and severity.

Forest Entomology

The Concept of Entomology

Entomology stands for two Greek words; *entomo* means insects and *logy* means study, thus forest entomology is the study of insects especially those that damage forests and tree products. One million species of insects have been described so far although it is estimated that they range from 2.6 to 7.8 million species. Here it is worth to note that insects represent by far the largest group of organisms colonizing the Earth because in total, two million species of both animals and plants have been named and described, implying that half of them are insects. Beetles (Coleoptera) make up 40% of described insect species, while the proportion of flies (Diptera) and wasps, bees and ants (Hymenoptera) is also big. Five orders of insects stand out in their levels of species richness: Hymenoptera, Diptera, Coleoptera, Lepidoptera, and the Hemiptera. Under normal circumstances, the number of inscects is controlled by preditors and diseases (Gullan and Cranston, 2009).

Importance of Entomology

The study of insects is important because they are numerous and dominate food chains and web. Their feeding behaviour is different and range from rotting materials, dead and living wood, sap feeding and parasitic and predators. Therefore insects have the following ecological roles:

- Nutrients' cycling, via leaf litter and wood degradation, disposal or carrion and dung, and soil turnover;
- Plant propagation including pollination and dispersal;
- Maintenance of plant community composition and structure; and
- Food for insectivorous invertebrate.

Furthermore, insects are playing a crucial role in maintaining animal community structure through transmission of diseases to large animals and predation and parasitism to the smaller ones. The negative effects of insects on forests threaten human survival. Insects provide environmental and economical benefits; characteristics of certain insects make them useful model for understanding general biological processes. High fecundity, short generation time of drosofila fly have made it easy for laboratory rearing and makes it ideal for scientific studies (e.g. in genetic and cytology).

The study of insects entails detection, identification, population estimation, analysis of outbreak causes and assessment of damage forecasting and the formulation of preventive or control measures. The study of forest entomology is usually based on understanding insect biology, life cycles, classifacations, interactions with plants and other living organisms, and insect control/management strategy.

Insect Biology

Morphology

The study of external features of insects involves analysis of its body wall which serves as an external skeleton (exoskeleton) to support the internal soft tissues (Richards, 2012). Exoskeleton consists of hard plates (sclerites), which join to each other by flexible membrane (suture). The sutures permit movement of the various parts of the body and its appendages. The functions of body wall are:

- Protection: It protects internal parts of insects against shock and abrasion; and prevent excess loss of water and penetration of substances;
- Service as exoskeleton: Exoskeleton consists of chitin which is tough and flexible materials to support muscle attachment thus facilitate locomotion; and
- Reception of external stimuli: It has most of the sensory organs.

The insect body is divided into three main parts (Figure 4.7) namely head, thorax and abdomen.

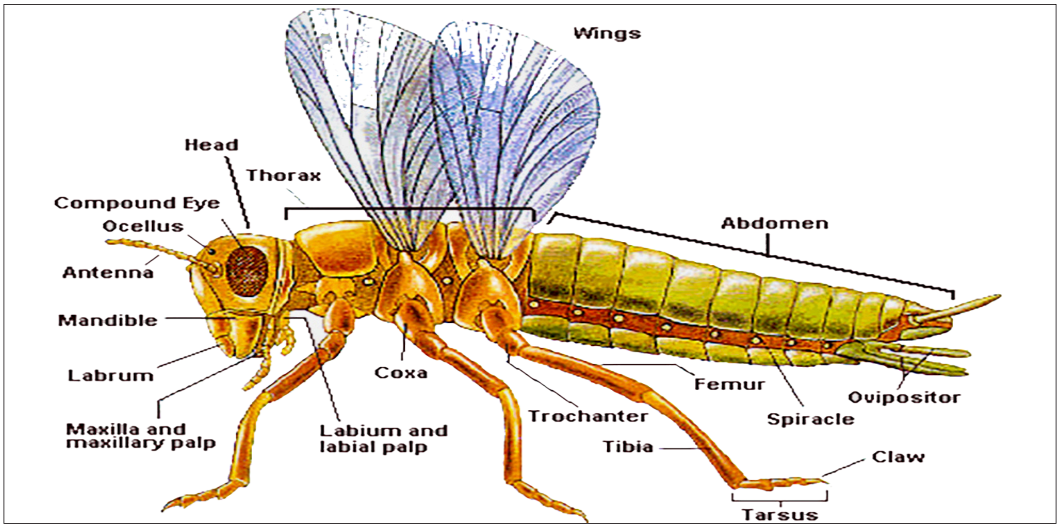

Figure 4.7. Parts of insect body
Source: Madoffe (2008)

The Head

Heavily sclerotised and connected with the thorax by membranous cervix. The head bears the mouthparts and a number of sensory organs: antennae, palps and eyes parts. Mouth is used for eating through which it can cause damage to forests. Their different shape facilitates classification and identification. Insect mouthparts are modified to perform ingestion of various food types by different methods. Various shapes of mouths have been described by Nair (2007) as follows:

- Chewing type: The mandibles (jaws) cut off and grind solid food, and the maxillae and labium push it into the oesophagus. Grasshoppers and lepidopterous larvae are common examples (Figure 4.8).

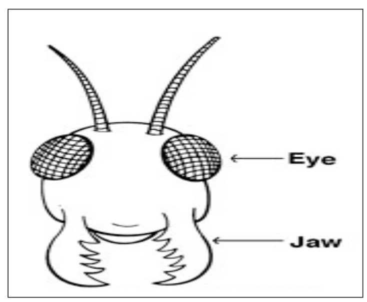

Figure 4.8. Chewing mouth type

- Cutting-sponging type:Mandibles are produced into sharp blades, and the maxillae into long probing styles. The two cut and tear integument of a mammal, cause the blood to flow from the wound. This blood is collected by the sponge like development of the labium and conveyed to the end of the hypopharynx. The hypopharynx and epipharynx fit together to form a tube through which the blood is sucked into the oesophagus.

- Sponging type: A large number of the non-biting flies e.g. house flies have this type of mouth that are designed for foods which are either liquid or readily soluble in saliva. This type is most similar to the cutting-sponging type, but the mandibles and maxillae are non-functional, and the remaining parts form a proboscis with a sponge like apex or labella (Figure 4.9).

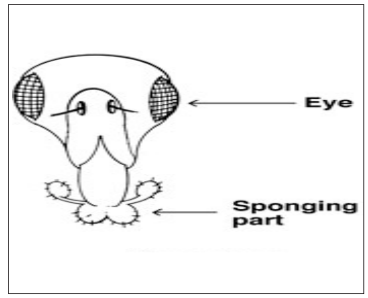

Figure 4.9. Sponging mouth type

- Chewing-lapping type: Another type of mouthparts for taking up liquid food is found in the bees and wasps exemplified by the honey bees. The mandibles and labrum are of the chewing type and are used for grasping prey or molding wax or nest materials.
- Piercing-sucking type: The labrum, mandibles and maxillae (sometimes the hypopharynx) are slender, long and fit together to form a delicate hollow needle (Figure 4.10). To feed, the insect presses the entire beak against the host, then inserts needle into host tissues, and sucks juices of the host through the needle into the oesophagus. Examples include aphids, cicadas, leafhoppers, scale insects, and others which suck juices from plants; assassin bugs, water striders, mosquitoes, bedbugs and lice.

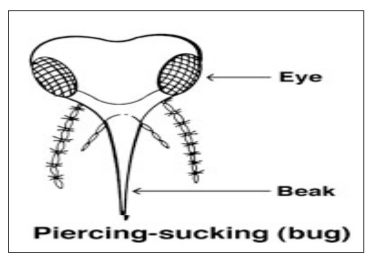

Figure 4.10. Piercing-sucking mouth type

- Siphoning-tube type: Sucking is done by long proboscis, composed only of the united galea of each maxilla. These form a tube which opens into the oesophagus. They feed on nectar and other liquid food. Adult Lepidoptera is an example of this group (Figure 4.11).

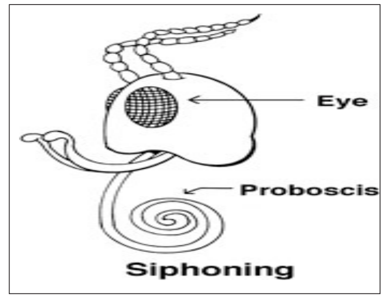

Figure 4.11. Siphoning mouth type

Antenna is a sensory organ and performs a function of smelling and hearing. Since there are different size and form, they have been used in classification studies. Eyes have a pair of compound eyes with sensory units which are light sensitive.

The Thorax

This is a locomotory segment of the body bearing legs and wings. It has three segments, from front to back, namely the prothorax, mesothorax and metathorax. Each thoracic segment typically bears a pair of legs. Wings (when present) are borne by the mesothorax and metathorax (collectively known as the pterothorax); and two pairs of spiracles on prothorax and mesothorax (Gullan and Cranston, 2009).

The legs usually have six segments as well as their characteristics are often used for identification due to the fact that there are great variations in leg size, shape, number and location of spines. Most of adult insects have two pairs of membranous wings located dorsally on the meso and metathorax. Hind wing (tegmen) helps in flight, while fore wing (elytron) helps in protection. Wings are also used in identifying insects because they vary in number, size, shape, texture, venation pattern and position held while at rest.

The Abdomen

Made up of eleven segments, the eleventh segment is usually much reduced in size. In the lower orders, the eleventh segment bears two lateral appendages called cerci. The abdomen contains many of the important organs for digestion, excretion and reproduction (Gullan and Cranston, 2009).

Insect Anatomy

It is a study of internal organs of insects which include haemocoel, gut, saliva gland, dorsal blood vessel, excretory tubules, ovarioles and spermatotheca. These internal organ perform different functions.

Haemocoel

Is the insect body cavity that is full of insect blood (known as haemolymph). This cavity allows freely fluid movement between the organs carrying digested food and excretory products. Generally, insects have no haemoglobin or blood cells.

Gut

Foregut stores ingested food and passes it to the gizzard which helps to grind it into smaller fragments. Digestion and absorption take place in the mid gut. In the hind gut, water is absorbed from the faeces before they are egested.

Salivary Gland

Secretes and delivers saliva through the salivary duct. The saliva contains digestive enzymes and, in the case of biting insects, it gives an anti-coagulant.

Dorsal Blood Vessel

Pumps insect blood forward and releases it into the haemocoel so maintaining a slow circulation. The blood enters the dorsal vessel through openings in its side.

Excretory Tubules

Extract nitrogenous waste from the blood, concentrate it to a semi-solid and pass it into the hind gut, to be expelled with the faeces.

Ovarioles and Spermatotheca

Make up the ovary which produces the eggs. The eggs pass down the oviduct to be laid with the help of the ovipositor. As they pass the spermatotheca, sperms are added and fertilize them. Spermatotheca is a sac or reservoir in the female insect that receives sperm during coition.

Insects life cycles

Insect Development

The development of insects from egg to adult is known as metamorphosis. There are three types of metamorphosis namely holometabalous, hemitabalous and ametabolous:

Holometabalous (complete metamorphosis)

The insect undergo all four stages of development from an egg to adult. These stages are egg, larva, pupa and adult. The larva and adult appear very different and their shapes are not the same (Figure 4.12). During the larval stage there are usually several molts, between which the insect is actively feeding and growing. The pupa is a resting stage, many of the organs and tissues needed as a larva is reformed into tissues and organs needed by the adult. The adult needs wings to disperse, muscles to power the wings and reproductive organs.

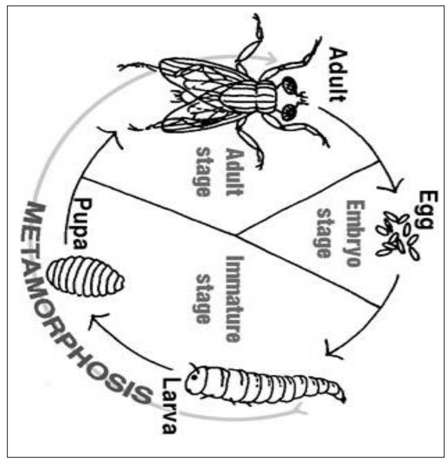

Figure 4.12. Stages of complete metamorphosis

Hemitabalous (partial or incomplete metamorphosis)

In most species, the adult is recognized by the fully developed wings on its back. However, apart from the development of wings, gradual metamorphosis is very similar to simple metamorphosis. The nymph is similar in shape to the adults, smaller and without wings (Figure 4.13). Immature insects in this group and incomplete metamorphosis often consume the same types of food as the adults.

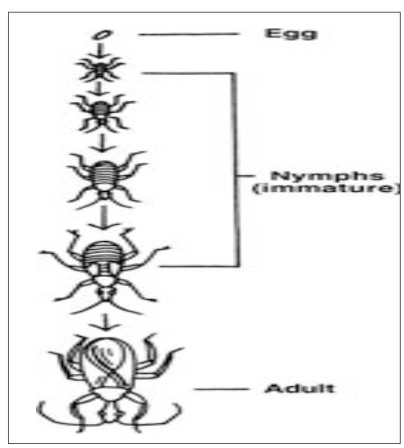

Figure 4.13. Stages of incomplete metamorphosis

Ametabolous (simple/no metamorphosis)

It is when insects grow in size, but show little change in shape throughout their life. Firebrats have the same body form as adults, are smaller; egg hatch to a form resembling miniature adult but lack genitalia. Simple metamorphosis occurs with silverfish, firebrats, springtails and some other groups. One important difference with this type of metamorphosis is that these insects never develop wings.

As it is already highlighted above, insects have basically four main phases in a course of their development as outlined below:

- The egg phase: This begins as soon as the female deposits the mature eggs. The eggs are different in shape and colour, may be laid singly or in groups and deposited on different habitats;
- Larvae or nymphal phase: The larvae of insects are wormlike creatures that look completely different from their parents. Among many species, the larvae live in different places and eat different foods. They do not have compound eyes and wings. Most have chewing mouth parts, though their parents may have sucking mouth parts. Some larvae have no legs, while others may posses extra leg like structures on the abdomen. The larvae of many species have special names for example; the larvae of butterflies and moths are called *caterpillars*; those of flies, *maggots*; those of beetles, *grubs*; and those of mosquitoes, *wrigglers*. Larvae eat, grow and moult several times as their skin becomes too tight. In one day, a caterpillar may eat leaves several times its weight;
- Pupa: After a larva completes its growth, it stops eating and then becomes a pupa. In preparation for this stage, some larvae spin a cocoon or form some other protective covering around their bodies. Most pupae lie quietly and appear lifeless but inside the protective cocoon; and
- Adult phase: This begins at the occlusion from a pupal cuticle. Metamorphosis however may be complete for some hours or days previously and the adult rests in a pupal cuticle until the appropriate environment allows. The newly emerged adults have soft skin which allows expansion by swallowing air or pumping more blood.

Insect Growth

Insect growth is discontinuous, because of the rigid cuticle. Their size increases by moulting or ecdysis process which is a periodical formation of new cuticle of greater surface area and shedding of old ones. The shedding process begins with a splitting of the old cuticle along lines of weakness, usually in the middle of dorsal side of thorax. The split is induced by blood pressure forced into the thorax. The moulting of ecdysis process is happening due to hormones influence produced by an insect. The successive stages between the moulting are referred to as instar. A number of moults vary from insects to insects but more common ones are from 4 to 8, and could be more for some insects (Gullan and Cranston, 2009).

Insects Classifications

Globally, insect diversity is very high, with about 1 million species described so far and about 2 to 7 million species remaining undescribed. Species diversity makes it important to classify insects into groups according to their similarity or relatedness. The groups are commonly refered to as taxa (singular taxon). Taxonomy is a Greek word divided into two parts *taxis* which stands for arrangement and *nomos* which stands for law, therefore, Taxonomy is the theory and practice of describing, naming and classifying organisms. The arrangement of taxa follows a hierarchal pattern with the main groups being kingdom, phylum, class, order, family, genus and species. In biological classification, the levels represented in this hierarch bear names assigned following the rules of nomenclature as already described in Chapter three on forest Botany.

Dominant Orders of Tropical Forest Insects

Tropics contain numerous orders of insects. Some of the insects' orders are more dominant, more abundant, or more conspicuous (Samways, 2005). However some are more important in forestry, because of their negative impacts on trees, particularly plantations as compared to natural forests. Insects that cause damage to forests in the tropics belong to six main orders namely: Coleoptera, Lepidoptera, Hymenoptera, Hemiptera, Isoptera and Orthoptera (Nair, 2007).

Coleoptera (beetles)

This is the largest order of insects worldwide as well as in the tropical forests in terms of the number of species. It is also of greatest importance in terms of damage it causes to trees and decomposition of organic matter. Its distribution covers all major forest habitats, because of their feeding habit which is indiscriminate (Nair, 2007). This group contains several varieties of beetles that feed on freshly felled wood, drier wood, rotten wood, leaves, vegetables and humus.

Lepidoptera (moths and butterflies)

This is considered the second largest order of insects in terms of number of species. Economically the Order is also ranked second in importance after Coleoptera because of the damage it causes to trees. While the short lived adults (moths and butterflies) feed on nectar and other fluids, caterpillars of most species feed on foliage while others bore into young shoots and branches, bark, seeds and fruits, and others are carnivorous (Nair, 2007). A large number of members of this group is distributed along different altitudinal gradients (Beck and Kitching, 2009).

Some of the well-known forest pests under Lepidoptera include teak defoliator *Hyblaea puera* (Hyblaeidae), teak bee hole borer *Xyleutes ceramicus* (Cossidae), mahogany shoot borers *Hypsipyla robusta* and *H. grandella* (Pyralidae). This order also includes some economically useful species of silkworm (Hogue, 1993).

Hymenoptera (ants, bees and wasps)

This order is the third largest in number of insect species worldwide. Its members play an important role in ecology of tropical forests as pollinators and parasitoids of injurious insects. For example, tropical honey bees provide subsistence and commercial benefits to human societies since ancient times through honey, beeswax and nectar. Honeybees also offer pollination increasing multiplication of flowering. However, the carpenter bees are destructive to solid wood through their nature of boring into wood (Nair, 2007).

Hemiptera (bugs)

This order contains whiteflies, scale insects, aphids and jumping plant lice (psyllids). Belonging to Hemiptera also is Auchenorrhyncha which includes the leaf hoppers, tree hoppers and cicadas. In all bugs, the mouthparts are of a piercing and sucking type, generally, the bugs suck the sap of plants. Cicadas are well-known insects of the tropical forests and feed on the sap of tender shoots and twigs of trees. Tingidae include the pest *Tingis beesoni* which causes dieback of *Gmelina arborea* saplings in Plantations. Psyllidae include the well-known pests *Heteropsylla cubana*, which attacks *Leucaena* species and *Phytolyma* species that attack *Milicia* species.

Isoptera (termites)

This group contains termites that feed on dead wood or on living trees making them amongst the most serious pests of tropical forests (Nair, 2007). They are social insects, with caste differentiation among individuals. Some of its species live within wood, but the majorities are ground dwellers. The nests of ground dwellers are either subterranean or projected above the ground in the form of small or large noticeable mounds. Some species make carton nests, attached to tree trunks. Generally, termites forage underground or under cover of mud tunnels. A few species like to forage above ground where they cut pieces of grass and carry them in procession to subterranean galleries where they process them into edible fungi. Some of the species feed by attacking trunks of mature trees and hollow them out.

Orthoptera (grasshoppers and crickets)

Members of this group are popular for their production of unique sound e.g. crickets (Capinera, 2001). In many cases, locusts have been known to be agricultural pests, but in cases of outbreaks they may cause damage to forests. Although grasshoppers have been ever-present in tropical forests, their number has not been very big to cause serious damage to trees (Nair, 2007).

Importance of Insects

Insects provide various benefits to human beings as summarized below. In terms of ecosystem values, insects play critical roles in ecosystem processes by acting as primary consumers and as decomposers. In some cases they act as secondary and tertiary consumers (Price *et al.*, 2011). The direct and indirect effects of insects on biophysical environment can influence primary production, succession and evolution of plant communities. This could be through decomposition, pollination and involvement in food chain.

Insects act as primary consumers by facilitating the release of the nutrients locked up in the trees into the soil (Chhokar *et al.*, 2004). Insect being secondary and tertiary consumers (predators) consume other insects as well as animals, for example, ants which act as predators and scavengers in tropical forests (Nair, 2007). Also insects play a vital role in nutrient cycling enhancing a decomposition process. Litter consisting of dead plant materials including leaves, twigs, barks, flowers, fruits and seeds fall on the ground then insects recycle them through the decomposition process involving a sequence of physical and biological processes and finally transformed into humus. Insects can as well work on animal dung and carcasses on the forest floor (Stork and Eggleton, 1992).

A wide range of tree species are pollinated by insect. Insect pollination is common in the tropics than in the temperate regions (Bawa, 1990). The main pollinators belong to Hymenoptera (solitary and social bees), Diptera (flies), Lepidoptera (butterflies and moths) and Coleoptera (beetles) (Nair 2007).

Insects also form part of the food chain as food material to other insects, animals, such as amphibians, reptiles, birds and mammals and human beings. Because of their large number and variety, insects constitute an important link in the food chain. Bees produce honey which is used as food, medicine and source of income. In addition, some insects e.g. locusts, grasshoppers, termites, lepidopteran larvae and pupae form part of the human diet (Nair, 2007).

Insects often act as vectors of plant and animal diseases in the tropics and thus influence the dynamics of plant and animal populations. Diseases transmission occurs in two main forms, namely, mechanical and biological transfer. Most vectors that cause diseases belong to Diptera.

Damage to Forest Trees

Insects are among the major causes of damage to forest trees and in some cases they are reported to be severe. Damages occur when parts of the tree are consumed to serve as food for the insects. All parts of the tree can be damaged by insects i.e. leaves, shoots, flowers, buds, fruit, twigs, branches, stem and roots. Insects can be categorised based on parts of the tree damaged as detailed below:

Tip and Shoot Insects

These cause damage by attacking the apical terminal of the tree, resulting in irregular stem growth or multiple branching. Trees which have been subjected to repeated attack by such insects may have a stunted, bushy appearance or malformed/ forked boles. This reduce value of the tree for timber and poles. Attacks on buds and terminals of young seedlings result to death or stunted growth.

Defoliators

These are insects that feed on leaf tissue, and their actions result to partial or complete destruction of leaves. This feeding group also includes: leaf-mining insects (feed within the leaf just below the upper or lower surface), leaf tiers, leaf rollers and leaf skeletonises which feed the leaf tissue between veins (Figure 4.14). Defoliation by insects reduces the tree's rate of photosynthesis and transpiration. Effects vary considerably, depending on severity, age of leaves, position in the canopy, time of year the defoliation occurs, the site and current stresses on the tree.

(a)Mining on a leaf caused by a caterpillar

(b)Larvae of beetle feeding on foliage

(c)Leaf sceletonized by moth caterpillars

Figure 4.14. Examples of insect defoliators
Source: Wylie et al. (2006)

Bark and Wood Feeding Insects

These insects affect hosts depending on condition of the tree when attacked, tissue attacked and the activity of associated agencies such as symbiotic fungi, bacteria and predators. An example of this includes structural weakness in stems and branches resulting from extensive tunnelling. The most destructive include bark beetles, ambrosia beetles, longhorn beetles, scarab beetles, weevils, termites and wood moths (Figure 4.15).

(a) Mahogany tree being attacked by termites

(b) Longhorn beetle attacked a stem tree causing it to break

Figure 4.15. Examples of bark and wood feeding insects
Source: Wylie et al. (2006)

Insects Feeding on the Roots

These insects are not a problem for established trees with well-developed and extensive root systems. However, they can cause serious damage in nurseries and young forest plantations, where the trees have small and fragile roots. The problem can be intensified when site preparation removes existing vegetations, forcing the root insects to feed on the roots of newly planted seedlings. There is wide range of insects that feeds on roots of trees. Some examples include white grubs, termites, weevils, larvae of longhorn, buprestid beetles and root aphids (Figure 4.16).

Figure 4.16. Example of roots attacked by termites
Source: Wylie et al., 2006

Fruit and Seed Boring

Several different groups of insects attack fruits, cones or seeds of forest trees. Examples of seed boring insects include torymid wasps (lay their eggs directly into the seed of young cones and their larvae feed within the seed), bruchid beetles (lay their eggs on the exterior of the pod or fruit and the larvae tunnel inwards to the seed), which they consume.

Flower, Fruit and Seed Feeders

They affect both plantation and natural forests at varying scale. In seed orchards, such damage is more serious and losses can be considerable since the supply of seeds can be significantly reduced. Feeding on seeds can sometimes be desirable when for instance gall wasps and seed beetles aid removal of seed dormancy.

Insect Control Strategy

Insect control is about managing its population to tolerable level which does not result to substantive economical loss. The emphasis is on regulating the population size, not killing all the pest insects. Curently, the intention is to limit the damage caused by insects rather than total elimination (Metcalf and Luckmann, 1994). The most commonly used insect control measures are preventive and remedial measures as well as integrated pest management (IPM).

Preventive Measures

This consists of Silvicultural interventions that aim at enhancing tree health and defence mechanisms. Quarantine measures are used to prevent introduction of pests from other countries or from one area to another within the country. Use of pest-resistant trees is also a preventive measure. The aim is to keep insect pest populations at low densities. These measures are possible in cases where the causes of population build up are known.

Remedial Measures

The aim is to reduce the pest population levels by killing the insects. Several approaches are used as remedial measures as described below.

- Insecticides: Are used either prophylactically or remedially. Prophylactic use involves application of the insecticide before the insects appear, as in the case of control of root-feeding termites of Eucalypt saplings. Other examples are insecticidal treatment of nursery soil to control ants and white grubs or mixing of insecticide with seeds while in storage.

  In remedial application, insecticides are applied to the insects and the trees after the infestation is noticed. The main advantages of pesticides are: effective within a short period of time, broad spectrum and readily available. The main disadvantages are: unintended effect on non-target organisms, particularly parasitoids, predators and pollinators, development of resistance by pests and temporary nature of the effect, necessitating repeated applications. Some problems like long persistence and bioconcentration in the human food chain have been overcome by the development of new easily degradable pesticides. The drift of pesticides in the environment has also been reduced by improvements in application of technology.

- Biological control: Refers to the use of natural enemies to maintain the population density of insect pests below damaging levels. The important concept is the term 'maintain', since the majority of biological control systems are expected to persist over time and to regulate a pest population below an economic threshold. All insects have natural enemies including vertebrate predators (birds, bats, reptiles), insect predators, insect parasitoids, nematodes and protozoan parasites or pathogenic micro-organisms like fungi, bacteria and viruses.

  Biological control is generally considered the most appropriate method for management of forest pests. It can be extended to include any technique of human intervention employing biological means. The use of naturally occurring genetically resistant trees, transgenic trees or even spray application of commercially formulated bacterial or baculovirus preparations are all methods which make use of biological means of intervention. Three methods of biological control are generally recognised: introducing a natural enemy to a location where it did not previously exist, conserving the existing natural enemies through habitat management and inundative or inoculative release of mass-multiplied natural enemies.

- Integrated Pest Management (IPM): It envisages the use of all the available techniques in an integrated manner to reduce the economic damage caused by pests, with the least negative effects on the environment. In other words, IPM is a combination of techniques consisting of the balanced use of biological, cultural and chemical procedures that are environmentally compatible, economically feasible and socially acceptable to reduce pest populations to tolerable levels.

Climate Change and Insects

It has been estimated that with a 2° C temperature increase, insects might experience one to five additional life cycles per season (Yamamura and Kiritani, 1998). Climate change resulting in increased temperature could impact insect pests populations in several complex ways. Although temperature increases due to climate change tend to depress insect populations in hot climates, warmer temperatures in cold climates might favour emergence of new and increased insects population (Kangalawe and Lyimo, 2013; Reddy, 2015).

Insect species diversity per area tends to decrease with higher latitude and altitude (Gaston and Williams, 1996), meaning that rising temperatures could result in more insect species attacking more hosts. Based on evidence developed by studying fossil, Bale *et al.* (2002) reported that diversity of insect species and the intensity of feeding increase with temperature.

There is scant information on impacts of climate change to forest insects in Tanzania. Some insects are sensitive to precipitation and are killed or removed from trees by heavy rains. Some insects' hibernate during adverse weather conditions such as flooding (Vincent *et al.*, 2003). However, one would expect that high intensity and more frequent precipitation negatively impact insects. Fungal pathogens of insects are favoured by high humidity and their incidence would be increased by climate change that lengthen periods of high humidity and reduce drier conditions. Also, increased carbon to nitrogen ratios in plant tissue resulting from increased CO_2 levels may slow insect development and increase the length of life stages vulnerable to be attacked by parasitoids (Coviella and Trumble, 1999).

Summary

Forest protection is a practice of preventing and controlling both biotic and abiotic agents, which affect forests and their associated products. There are two agents responsible for tree injury and diseases namely non-pathogenic and pathogenic, they are also known as abiotic and biotic respectively. Non-pathogenic agents include fire, climatic conditions (e.g. wind, drought, rain, and heat), soil conditions and air pollutants. Pathogenic agents cause diseases and they include viruses, bacteria, fungi, mycoplasmas (e.g. protozoa and algae); parasitic plants (e.g. mistletoes), nematodes, arthropods (e.g. insects), birds and mammals. Forest fire, pathology and entomology are discussed in detail in this chapter.

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