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Forest Protection

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Department of Forestry and Environmental Science
School of Earth and Environmental Science

Uttarakhand Open University
Haldwani, Nainital (U.K.)

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Board of Studies

Compilation by

Department of Forestry and Environmental Science, (SoEES),
Uttarakhand Open University

Cover page design

Krishna Kumar Tamta, Beena Tewari Fulara, H.C. Joshi

Printed at: Uttarayan Prakashan, Haldwani, Nainital (Uttarakhand)

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UNIT 1: INTRODUCTION TO FOREST PROTECTION

Unit Structure

1.0 Learning Objectives

After going through this unit you shall be able to know:

- the kinds of agencies that damage forest
- various forest protection measures
- factors affecting forest protection actions

1.2 Introduction

We know that a forest ecosystem is inhibited by beneficial as well as harmful factors that affect the growth and development of the concerned forest crop. These factors vary with age of the crop and season, produce hindrance by one or other mean in the growth and development processes directly or indirectly. In order achieve the goals of sustainable forest management, it is utmost need to remove at least reduce the harmful factors or agencies from the forest so that the forest crop may get the best opportunities for its survival, growth and development. Such efforts which are directed towards removal or reduction of harmful factors or agencies from forest crop are known as forest protection. Thus, forest protection deals with protection of forest crop against various **injurious or harmful factors or agencies**. In other words, it is a discipline of forestry that utilizes the different scientific or traditional methods in order to bring about protection to our forest crops as various abiotic (non-living) and biotic (living) factors have potential to weaken the growth or damage the crop. It is one of the most important disciplines of forestry in which the end result depends and at the same time it is the most complex discipline as it demands the understanding and knowledge from various other branches of life sciences (forest ecology, entomology, botany, mycology, genetics, vertebratology and game management or phytopathology etc.) also of chemistry and physics.

The forest protection measures vary from one place to another place and from one country to another country and one crop to another crop. The measures applicable in one forest crop might not be useful in another forest crop because the factors that damage the forest also vary from one forest type to another. Therefore, forest specific protection measures are required.

In this unit, we will learn about the various kinds of agencies or factors damaging forest and this protection measures.

1.2Kinds of factors or agencies damaging forest crops

There are a number of factors that cause damage to forest crops. Among these factors humans are considered as the most important factor as they affect the forests in a diversity of ways. Since the beginning of humankind, humans have started affecting forests as many of his daily necessities are fulfilled from forests. However, it was only after the Industrial revolution when maximum effects to the forests were caused in different parts of the globe. Apart from humans, other factors include wild animals, domestic animals, insects, pathogens and forest fires. It is important to note that use of forest or forest products in a sustainable way does not have adverse effects on forests but it is only when its use becomes unsustainable the forest degradation sets in. In general, there are three main factors which bring about major impacts on forest ecosystems. These are:

(i) change in tree species composition;

(ii) change in length of rotation period; and

(iii) change in forest cover

The injurious agencies are of diverse nature and many of them are very destructive and results in loss in tree crop production. Therefore, adequate protection measures are needed. Plant protection is basic or fundamental requirement of growth of agricultural or forest crops. Although each forest or region has peculiar kinds of forest protection related requirements, yet the broad categories of enemies are more or less same throughout the globe i.e., fire, insects, fungi, wild animals and domestic grazing animals. The various damaging agencies can be broadly divided into two categories:

1. **Damage by Biotic component i.e., organic nature**
    - Man
    - Animals (Harmful insects, domestic animals, wild animals)
    - Harmful plants (fungi, mistletoes and weeds)
2. **Damage by abiotic components i.e., inorganic Nature**
    - Damage by adverse atmospheric agencies and climate (Heat, Frost, Snow)
    - Protection against storm, erosion, sand drifts, noxious gases, forest fires

The general there are six general classes of injurious agencies as follows:

- Forest fires.
- Plants, including fungi, mistletoes, and forest weed.
- Insects.
- Domestic animals.
- Wildlife (animals other than insects and domestic species).
- Atmospheric agencies.

1.3Importance of Prevention in Forest Protections

The most important principle in forest protection for all types of infurious agencies is that prevention of the start or development of an injurious agency is far more effective than attacking after the damage is under way. Within recent year's recognition of prevention as the most important principle in forest protection has come to be universal. However, it is doubtful whether the extension of this idea throughout all silvicultural and forest management operations for the long-period viewpoint has yet gained adequate application. Results in preventing damage to the

forest secured by wise application of management and silviculture are a long time in coming, but ultimately the results so secured are more enduring and less expensive than more direct methods of protection.

A thorough appreciation of forest protection is fundamental for intelligent management of a forest property. The protection goal is the safeguarding of the continuous productivity of the property. This can be accomplished most effectively by growing a forest of such character that injury of an extensive and serious nature is prevented.

Wagner (1930) has stressed this idea, which he considers of primary importance if the new and increased possibilities of injury, introduced by forest management, are to be overcome.

Evidently the word "prevention" should be used with a broader meaning than ordinarily is given to it in forest protection. Admittedly the fact has been stressed that prevention is of primary importance in securing cheap and effective protection. This, however, has usually been interpreted as meaning the taking of certain definite steps toward hindering one of the many injurious agencies from developing to a point where it could cause serious damage.

In addition, prevention should be interpreted as implying the development, through long-continued and careful management, of a forest that inherently will be safeguarded against the total of injurious agencies which might cause serious destruction. Ultimately the forester himself, through his understanding of this important principle and through this long-continued and skillful molding of the forest into the character desired, will be more powerful in preventing and controlling the work of injurious agencies than the numerous protection specialists.

References

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Unit 2: Man as a source of injury to forests

Unit Structure

2.0 Learning Objectives

After going through this unit you shall be able to:

- Various kinds of injury to forests by human interventions
- Protection measures

2.1Introduction

In the previous unit, you learnt about the different ways forests are affected or damaged. You come to know about seven (07) major agencies involved in damaging affect to forests.

In this unit, particular attention is given to humans as one of the important factor that bring about damage to forests. The injury caused by human is of primary source. Part of the injuries is caused directly by humans and his activities whereas partly are caused indirectly which are consequences of his developmental and other activities.

Man has inherited forests as a gift from nature. It has been man's responsibility to preserve, develop, and utilize this bountiful resource with its large varieties of life forms. For food, clothes and shelter man has ever remained dependent on forests. In all developing countries forests have formed one of the potent factors of economy. Growing population and simultaneous growth of demand of forest produce, typical of a developing economy, have thus resulted in severe damage to forests in our country through human interfaces. In a word, we have consumed more of forests than they could regenerate. The issue of conservation of forests and their biodiversity has therefore assumed great significance and importance in the context of development. The National Forest Policy 1988 has explained that the term 'conservation' includes preservation, maintenance, sustainable utilization, restoration, and enhancement of the natural environment. All the damage inflicted through human interface has to be addressed and controlled by measures which are compatible with the above aims of conservation.

In this unit you will be acquainted with various harmful effects that human and his activities have brought about in forest ecosystem.

2.2Humans and damage to Forests

Man himself is a primary source of injury to the forest. Part of this injury is directly caused by him and part follows indirectly as a consequence of his activities. He contributes to so much of the damage caused in the forest that his influence is felt either directly or indirectly under each of the other six classes of injurious agencies. A large share of the damage resulting from forest fires is chargeable to man since a major proportion of all the forest fires are caused by his carelessness. Some of these fires were set intentionally, but most of them resulted from careless use of fire. The education of man for the purpose not only of correcting his carelessness and preventing his intentional setting of fires but also to give him the right viewpoint on forest protection is one of the most important and far-reaching lines of protection activity which can be undertaken. Man has been directly responsible for establishing dangerous plant pests through the introduction of harmful insects and fungi from foreign countries, usually on importations of plant materials.

Domestic animals are often placed by man in the forest and allowed to graze there. The injury caused by these animals, which at the worst may amount to destruction of the forest, can thus be attributed indirectly to him. It is within his power to withdraw the animals or to regulate their use of the forest. Most, and possibly all, severe cases of injury to the forest by wild life are caused by man as a result of his protection of wild life. Such a protection usually results in abnormal increase in numbers of certain forms of wild life without corresponding increases in available food. The forest suffers accordingly.

Following kinds of damage are caused by humans:

• Deforestation

• Illicit felling

• Forest fire

• Faulty management

• Miscellaneous other damage

2.3 Deforestation

Deforestation means removal of forest crop from a piece of land without any plan or intention to reforest the land. The major factors that are responsible for deforestation are:

(i) Diversion of forest land for non-forestry purpose,

(ii) Shifting Cultivation,

(iii) Mining, and

(iv) Encroachment

2.3.1 Diversion of forest land for non-forestry purpose

Large areas of forest lands have been diverted to other uses over the years. Extensions of agriculture and industrial development have both taken their toll on forests. In fact forests have been the first charge to meet the demands of land for any land based economic activity. In our country, until the middle of 20th century, diversion of forest lands to other uses was considered only natural and there had been little concern for the devastating consequence such indiscriminate deforestation process could lead to. Since the middle of last century, the realization that forests are necessary for the survival of humans seems to have found reflection in our forest policies and legislations. There has been awakening that any proposal for deforestation should go through a stringent process of examination and scrutiny and should be allowed only if diversion of forest land is unavoidable. It has also been realized that such diversion of forest land should be subject to regulatory conditions that will more or less try to compensate the loss apparent due to diversion.

A) **Factors leading to diversion of forest lands:** Normally following factors or circumstances lead to diversion or excision of forest lands:

- **Relinquishment of forests for agricultural purpose**: Throughout the world the agriculture has been the greatest driver for deforestation. India has been no exception. The Forest Policy of 1894 had clearly favoured diversion of forest land for agricultural purposes. It said that “whenever an effective demand for cultivable land exists and can only be supplied from forest area, the land should ordinarily be relinquished without hesitation;…” Thus the growing demand of agricultural land had been met at the expense of forests. Destruction of forest had been accentuated by adoption of agricultural practices which had often been non-scientific. Instead of improving land productivity, more and more forest lands had been put to tilling as forest lands were easily available.
- **Relinquishment of forests for development projects:** The 1952 national forest Policy stated that the role of forests in the national economy entitles forests to lay claim to an adequate share of land, and envisaged a bar on relinquishment of forest land for agricultural purposes. However, the said policy did not recommend any regulation or bar on diversion of forest land for development projects. Deforestation continued for agriculture and various development works. It is noteworthy that the central government had little regulatory role in this regard as the forest was a state subject. It was through the 42nd amendment of the Constitution in 1976 that forest was brought under concurrent list and thus empowered the parliament to make laws in respect of

forests. This led to enactment of the Forest Conservation Act 1980. Under the provisions of this Act, no state government can divert forest land for non-forestry purpose without prior approval of the central government. This Act and the rules made there under also lay down several regulatory provisions for according approval for diversion of forest land.

Forest lands have been excised for various non-forestry purposes over the years, and continue to be excised notwithstanding promulgation of the Forest (Conservation) Act, 1980. The development projects that are mainly responsible for excision of forest lands are:

- River valley projects (RVP) and their reservoirs;
- Rehabilitation of people displaced by RVPs.
- Construction/extension/widening of roads;
- Laying/widening of railway lines;
- Erection of electric transmission lines;
- Construction of irrigation canals;
- Establishment of power projects, thermal and hydroelectric.
- Other industrial projects

B) Extent of diversion of forest lands.

• River valley projects alone have taken a heavy toll on forest lands. During the period 1951-52 to 1975-76 (prior to promulgation of FCA, 1980), the quantum of lands deforested for river valley projects are as follows:

State	Area in ha
West Bengal	1,700
All India Total	4,79,000

(Source: L S Khanna 1998 Forest Protection)

• The following table shows extent of forest lands deforested during the period 1951-52 to 1975-76 (prior to promulgation of FCA, 1980) for various development projects other than RVPs.

State	Agricultural purposes (ha)	Establishment of industries (ha)	Miscellaneous purposes (ha)	Total (ha)
West Bengal	3,13,700	2,900	6,200	3,22,800
All India Total	24,55,700	1,20,100	9,83,000	35,58,800

(Source: L S Khanna 1998 Forest Protection)

2.3.2Preventive and Remedial measures

It is natural that socio-economic advancement would be accompanied by economic activities that would demand availability of land. Inevitably forests have to bear the pressure to meet a part of this demand. Given the circumstances that land is required to meet the growing demands of food, energy, infrastructure etc., it becomes expedient to take measures to prevent and contain the exercise of the easy option of relinquishing forest lands to meet the requirement. And in case diversion of forest lands for development works becomes unavoidable, we need to undertake remedial measures to neutralize or minimize the ill effects of diversion. The measures – both preventive and remedial – to contain diversion of forest land flow from the FCA, 1980, the rules made under this Act and the guidelines issued by the MoEF, GoI in this regard. Some of the measures are mentioned below:

1) Strict compliance of FCA – The Forest (Conservation) Act should be strictly complied with. Section 2 of the Act prohibits use of forest land for non-forestry purpose except with the prior approval of the central government. Any proposal or move for diversion of forest land for non-forestry purpose should be brought under scrutiny and examination under the Forest (Conservation) Act. The issue whether any particular use of forest land constitutes non-forest purpose and thus attracts section 2 should be determined upon examination of whether such use or activity is essential for or relating to conservation of forests and wildlife.

2) Consideration of other alternatives - While considering or recommending any proposal for diversion of forest land, a forest officer should satisfy himself that all other alternatives have been considered and that no other alternative is feasible, and the required area is the minimum needed for the purpose;

3) Undertaking for compensatory afforestation on equivalent area – Any proposal for diversion of forest land must accompany the undertaking by the concerned authority to provide at its cost acquisition of land of equivalent area and afforestation thereof.

4) Examination of equivalent land proposed for compensatory afforestation – Making provision for equivalent non-forest land is not enough. It needs to be satisfied that:

- The non-forest lands to be provided for compensatory afforestation are consolidated as far as possible, and not fragmented in too small parcels; and if such non-forest land constitutes of discreet blocks, afforestation and conservation of such blocks is feasible and viable under normal forest management practices;
- The non-forest lands provided are suitable for planting and raising forest species.
- The non-forest lands provided should be as close to original forest lands being diverted as possible.

5) Mutation of equivalent non-forest land – When diversion of forest land is approved and given effect to in terms FCA, equivalent non-forest lands identified for compensatory afforestation are to be transferred and mutated in favour of the State Forest Department, and declared as reserved / protected forests. The transfer must take prior to the commencement of the project.

6) Compensatory Afforestation –

- Should include all phases necessary for creation and establishment of the plantation spanning over a number of years;
- Nature of plantation, mode of planting including selection of species should be in keeping with the prescriptions of working plan;
- Species planned for regeneration should be, as far as possible, indigenous, covering large varieties. If the area identified for compensatory afforestation is located adjoining or close to the forest areas being relinquished, the list of select species for regeneration should include as many of the species of the forest area as possible.

2.4 Shifting Cultivation

Considering the country-wide landscape, shifting cultivation turns out to be one of the serious causes of deforestation, though it is not a menace in the context of West Bengal forests. Shifting cultivation is defined as a method of cyclical cultivation, where the cultivators cut the tree crop, burn the area, and raise field crops for one or more years before moving on to another forest site and repeating the process (L S Khanna 1998 Forest Protection). This method of cultivation is known as ‘taungya’ in Myanmar (Burma), as ‘jhum’ in Assam, Tripura and Arunachal Pradesh, and by different names in different states of the country. It is a serious problem in the hilly tracts of the north eastern states of our country. It is also noteworthy that quite a large population of tribals depends on shifting cultivation for their livelihood.

2.4.1 Technique of shifting cultivation

While the technique practiced in different states may vary in certain details, by and large it consists of the following steps.

- Cutting down trees and other vegetation on the site during the period from January to March;
- Burning the debris as it dries up in the month of April;
- Ash is mixed in the soil and seeds are broadcast during pre-monsoon shower;
- Crop is harvested during September-October.
- The process is repeated on the same site for 2 to 4 years, after which the site becomes thoroughly infertile for any cultivation; the site loses fertility because of repeated cultivation without manure and due to soil erosion.
- Thereafter a new forest patch next to the previous one is taken up and the same cycle of operation is repeated;
- The process continues until the forest within the limits of cultivation of a village is exhausted and cultivation comes back to the area in which it was started, after a period known as jhumming cycle. The jhumming cycle that is the interval after which the same area is cultivated again gradually shortens due to rise in population and decrease in fertility. After every cycle the land becomes poorer and, after a stage, is abandoned as unfit for cultivation.

2.4.2 Adverse effects of shifting cultivation

- It reduces soil fertility and ultimately makes the land unfit for cultivation.
- It leads to soil erosion which continues unchecked.
- It operates on a low productivity level, that is, production per unit area remains low.
- Considering the hard work and low productivity, the practice of shifting cultivation is actually uneconomic and undoubtedly unscientific.
- In hilly terrains it is a source of increased run off and may lead to floods causing damage to life and property.

2.4.3 Measures to control shifting cultivation

- Awareness among the fringe population – The villagers living in the fringe areas, particularly the tribal population, who practice shifting cultivation, should be made aware of the adverse effects of shifting cultivation and of those damage which are irreversible.
- Induce to settled and scientific cultivation – The shifting cultivators may be induced and encouraged to switch over to settled cultivation under scientific methods. The primary requirement to do this is to provide land. Implementation of the Forest Rights Act (FRA) 2006 may come in good stead in this connection. The right to hold and live in the forest land vested in forest dwelling scheduled tribes and other traditional forest dwellers under the FRA for self-cultivation may be suitably made use of to induce such dwellers to adopt settled and scientific cultivation. Any such move would also require proper counseling, appropriate training and supply of farming inputs and technical knowhow.
- Proper Land Use – It is necessary to make the forest and fringe dwellers understand that all available lands should not be ploughed indiscriminately and brought under settled cultivation. It would not only result in gradual diminishing return from the land but also may cause irreparable damage to the land in question. The scientific approach would be to use a piece of land according to its capability. Thus depending on the slope and soil depth, lands may be put to appropriate use. For example, some lands (e.g. land in the valleys) may be suitable for settled cultivation for agriculture, while some other lands may be kept for horticulture, some for cash crop, and some for forests and pastures.
- Alternative means of livelihood – In order to reduce pressure of shifting cultivation on forest land, the cultivators should be provided with alternative means of livelihood.

These may include –

- Development of animal husbandry and dairy farming
- Vocational training and development of handicrafts
- Value addition to and marketing of non-wood forest produce
- Distribution of usufruct share in forest produce

- Employment in forestry works and forest based industries.

- **Making beneficial use of shifting cultivation –** Taungiya method of cultivation has been successfully used and adopted in Sal regeneration in North Bengal forests. Artificial regeneration in Sal Working Circles in North Bengal is done by sowing, and the seedlings that sprout from the seeds need clear space over and all around for growth and survival. However, the forests of North Bengal are characterized with heavy and vigorous growth of weeds that invade any clear space in no time and suppress the young plants. In fact, regular cleaning and weeding, at least 5 times in the first year of plantation, is a crucial operation in the afforestation programme. Invasive weeds is not only a menace to young plantations, their removal is a labour intensive operation that increases the cost of the plantation. Taungiya system of cultivation comes in good stead to contain and suppress the weeds and help the Sal seedlings grow healthy in profuse numbers. The procedure is to allow the dwellers to raise agricultural crop or vegetables in the intervening spaces between the strips of Sal in the first year. Regular weeding and cleaning undertaken by the villagers to raise the agricultural crop automatically keep the weeds away from the forest crop. This turns out to be highly beneficial for the Sal seedlings as they are saved from invasion of weeds which otherwise would have denied them light, moisture and soil nutrients. Taungiya employed in the intervening spaces between lines of Sal associates also help those seedlings, particularly those which are slow growing, establish easily. Thus Taungiya method becomes beneficial for a sal plantation as a whole. Depending on the growth of the forest crops, taungiya cultivation in plantation sites may be done in the second year, thus reducing the number of cleaning- weeding of forest crop which would have been otherwise necessary. When the forest crops become tall and do not permit enough light and space for taungiya cultivation in the intervening spaces, cultivation is shifted to other sites of new plantations. The cycle thus continues.

- **Legal measures –** While the above measures, as deemed appropriate in a case, can be considered for adoption to contain shifting cultivation or make it beneficial, there will be cases where shifting cultivation should not be allowed or at least should be fairly regulated. Under such situations, shifting cultivation should be regulated and, if necessary, stopped altogether by taking recourse to legal measures. For example, shifting cultivation should not be allowed in wildlife protected areas, around water springs and close to hill roads.

2.5 Mining

Mining is a potential cause for destruction of forests. The irony is that with increasing population and industrialization, social demand for materials and energy has been on the rise and mining has been a major economic activity in our country. Like other land based development projects, mining has also taken its share of forest land. Being an important economic activity, mining at the cost of forest resource will continue and the issue to be addressed is how mining can be done causing least damage to forests and environment. According to Forest (Conservation) Act (FCA) 1980,

- Mining including underground mining is a non-forest activity and requires prior approval of the central government; and
- Renewal of an existing mining lease requires prior approval of Central Govt.

Therefore, mining should not be allowed in forest lands without prior approval of the central government.

2.5.1 Damage caused by mining

Mining causes destruction of forests in the following ways.

- Destroys vegetation while prospecting for the mineral.
- In underground mining, vegetation and soil are lost while digging pits for shaft and dumping the subsoil and the rocks in the surrounding areas.
- In open or surface mining, the entire vegetation and soil of the mined area is lost.
- Construction of roads for transportation occupies forest lands and in hilly terrain, such roads, if constructed on steep slopes, accelerate soil erosion.

2.5.2 Preventive measures

Following preventive measures may be taken to minimize the damage due to mining

- First and foremost, a forest manager should enforce strict watch over the forests to ensure that no illegal mining takes place. Illegal mining means those mining activities which take place in contravention of the FCA.

- Investigation and survey for mining should not involve felling of trees. If it does, such survey will attract provisions of the FCA and will require prior approval of the central government under the FCA. Whether or not felling of trees is involved, such survey shall not be carried out in wildlife sanctuaries, national parks and sample plots without prior approval of Central Govt.
- If a proposal for mining in forest land merits approval, the conditions accompanying the approval may stipulate that deforestation should be on the minimum scale and restricted to the area in which mining is actually to take place.
- The dug-up soil should be deposited outside in such a manner that layers of coarse subsoil remain underneath the weathered top soil. The deposited soil thus becomes ready for plantation.

2.5.3 Remedial measures

Following remedial measures may be taken to ameliorate the damage being caused by mining.

- In terms of approval granted under the FCA, non-forest land, at least equal in area to the forest land being lost to mining, should be made over to the forest department for raising compensatory afforestation. The cost of such non-forest land and that of afforestation should be borne by the mining agency.
- A shelter belt of trees may be raised around the actual mining area to minimize the pollution and such other anti-pollution measures may be taken as the competent authority granting sanction of mining may specify.
- Mining is a temporary form of land use and it causes destruction of natural eco-system and extensive soil damage. Thus it becomes imperative on the part of the mining agency to plan long term land use goals by way of ecological restoration of the mined lands to productive and beneficial use. Ecological Restoration is the management process whose goal is to recreate an eco-system as close as possible to one that existed in the past prior to mining. The restoration technique should follow site specific approaches that normally include revegetation programme coupled with ameliorative and adaptive measures. The detailed steps to undertake and the extent of success would largely depend on the degree of toxicity, salinity and acidity of the mining waste materials of the site.

2.6 Encroachment

Encroachment in respect of forest land is the act of illegally seizing possession of some forest land. Generally it is caused by people living in the outskirts of forests or in hamlets /villages honey-combing government forests. The root cause of encroachment of forest land lies in the socio-economic fabric of our society. People who are landless or having marginal land holdings would have a tendency to encroach forest land which lies open apparently without any owner. They are driven by poverty, hunger and lack of means of livelihood. While this may be the most common scenario of encroachment, there have been also instances where people indulge in encroachment due to land-greed and availability of easy option to enhance land assets. Encroachment of forest land, wherever it takes place, is also indicative of lax attitude of forest managers towards forest protection.

2.6.1 Factors responsible for encroachment

Some common factors that lead to encroachment of forest lands are mentioned below.

- No clear demarcation of forest boundary – If the boundary of forest is not clearly demarcated on the ground, there is every possibility that owners of adjoining lands will encroach into forest land. It is advisable that –
    - Boundary pillars are in place and visible from a distance.
    - The boundary between consecutive pillars is a straight line
    - Ideally, the consecutive boundary pillars should be visible from each other.
- **Lack of field inspection** – Inspection of forest areas and forest boundary is the primary job of a forester. In fact inspection and patrol on foot should form a part of daily job of the frontline staff. It is only through regular patrol that occurrence of encroachment can be prevented or can be noticed by a forester.
- **Leaving forest land barren** – When a forest land is left barren without any forest crop for a long time, encroachers are tempted and they find it easy to encroach.
- **Lack of prompt action** – Delay in detection of encroachment or in taking legal measures to remove the existing encroachment (those which do not come under FRA) encourage new encroachment and continuance of encroachment.

- **Socio-economic condition of the fringe population** – As already stated, the socioeconomic condition of the villagers living in the fringe area of forests is primarily responsible for encroachment of forest land. Factors like poverty, living with little or no land, no adequate means of livelihood etc drive some of the villagers to take recourse to the illegal act of encroachment.

2.6.2 Preventive Measures

Following preventive measures may be taken to reduce the chances of encroachment:

- **Clear demarcation of forest boundary and complete records –** In hilly terrain, boundary of forest block/compartment is generally made by ridges, nalas or rivers. In absence of prominent physical features and generally in plains, boundary may be demarcated by maintaining a clear strip of suitable width. On natural or artificial boundary, concrete/masonry pillars are erected. Generally, it is the responsibility of the Working Plan Division to erect the forest boundary pillars. While fixing boundary pillars, following guidelines may be observed –
- Each boundary pillar should bear (i) a unique serial number, and (ii) latitude and longitude (lat-long) to be determined by GPS, indicating the location of the pillar.
- Bearings and distances from pillar to pillar should also be recorded, so that locations of pillars may be exactly determined by ground survey.
- The locations of the pillars should appear on the compartment/mouza map of appropriate scale. Lat-long of each pillar and, bearings and distances between consecutive pillars should appear on the map.
- Locations of the pillars should be so decided that the boundary between consecutive pillars remains a straight line, and two consecutive pillars remain visible from each other.
- Record indicating numbers and locations (lat-long of individual pillar and bearing-distance between successive pillars) of boundary pillars should be maintained at Beat/Range/ Division level and should reflect appropriately in the Working Plan document.

- **Regular inspection of boundary –** Needless to say that distinct boundary defined by boundary pillars properly erected will not be enough to prevent encroachment unless the boundary is inspected properly on a regular basis. The frontline forest personnel should be assigned the duty of making regular inspection of the boundary of forests under their respective jurisdiction. A work schedule may be drawn stipulating which part of the boundary should be inspected by a forest personnel at what interval. After every inspection the concerned personnel should make a report on what he has observed in respect of the boundary and the pillars. In the event of detection of any encroachment or if it is found that any pillar has been removed or damaged or shifted, the matter should be reported forthwith to the superior authority for taking immediate action.
- **Strengthening JFM committees** – The villagers living in the outskirts of forests are mostly small and marginal farmers or agricultural labourers. In view of low land productivity and having few options of livelihood, the villagers get inclined to encroach forest land. Thus one important measure to prevent them from falling prey to such allurement is to provide them with employment opportunities in forestry or other development projects and increase their level of income. This can be done by strengthening the JFM committees, and utilizing their collective efforts in fruitful economic activities.

2.6.3 Remedial measures

Adoption of all preventive measures notwithstanding, there may still be some cases of encroachment. Obviously, the land found encroached should be got vacated as early as possible. Following measures may be taken to remove encroachment.

- **Prompt detection of encroachment –** The prerequisite for remedial measure against encroachment is quick detection of offence and prompt reporting to the superior authority. The more one delays in detection and report, more is the encouragement to the offenders to continue and expand the encroachment. Further, with passage of time it becomes more difficult to evict the encroacher. Therefore, as soon as any case of encroachment is noticed, the forest guard or the officer in charge of Beat should promptly report the matter to the Range Officer, who in turn should report it to the Divisional Forest Officer.

- **Legal actions**

  (1) If the encroachment is of petty nature and does not involve alteration of boundary marks, and the offender vacates the land, the case may be compounded as per provisions of IFA (section 68).

  (2) However, if the offender does not compound the case and refuses to vacate the land, the case should be sent to court immediately.

  (3) In reserved forest –

  - Encroachment in the form of clearing or breaking of land, but without any damage or alteration of boundary marks, can be prosecuted under sec 26(1)(h) of IFA.
  - It is noteworthy that notwithstanding any penalty that the court may impose, the WB Amendment Act XXII of 1988 of IFA empowers the Forest Officer to evict the person who has made the encroachment, and to demolish any building erected or construction made by such person on forest land. Further, according to the said amendment act, any agricultural or other crop or any illegal construction shall be liable to confiscation by an order of DFO.
  - It is also important to note that according to sec 65A of IFA (inserted by WB Amendment Act XXII of 1988), clearing or breaking up of any land in reserved forest for cultivation or any other purpose is a non-bailable offence.

  (4) In a protected forest –

  - Encroachment in the form of clearing or breaking of land, but without any damage or alteration of boundary marks, can be prosecuted under sec 33(1)(c) of IFA, if such encroachment is contrary to any prohibition under section 30.
  - It means that the accused can be prosecuted if he has committed the offence in contravention of notification under section 30. Thus to prove the guilt of theaccused, the existence of a notification under section 30 prohibiting such encroachment and wide circulation of such notification by the Collector has to be established before the court.

- It is noteworthy that notwithstanding any penalty that the court may impose, the WB Amendment Act XXII of 1988 of IFA empowers the Forest Officer to evict the person who, contrary to any prohibition under section 30, clears or breaks forest land for cultivation or any other purpose.
- In protected forest too, according to sec 65A of IFA (inserted by WB Amendment Act XXII of 1988), clearing or breaking of any land, in contrary to any prohibition under section 30, for cultivation or any other purpose is a non-bailable offence.

(5) In case of altering boundary marks – If the encroachment also involves alteration of the boundary marks by the offender, that is, if the offender alters, moves, destroys or defaces any boundary-mark of any forest, the offence will also attract section 63 of IFA. Therefore in such case the prosecution should be under sec 26(1)(h) or sec 33(1)(c), as the case may be, as well as sec 63 of IFA. It may be noted that according to sec 65A of IFA (inserted by WB Amendment Act XXII of 1988), offence punishable under section 63 is a non-bailable offence.

2.7 Illicit felling and illicit removal of forest produce

Illicit felling and removal of forest produce constitute the most frequent and common damage to forests. It is also the most frequent among all forest offences. Of the various forest produce, trees of commercially valuable timber are highly vulnerable to damage in the process. By way of indiscriminate felling and clandestine removal of the produce, the forests lose, in varying extent, their valuable assets, biodiversity and capacity to regenerate. Any measure of forest protection would not be meaningful, unless forests are protected from illicit felling.

Forest officer accords sanction to felling in terms of approved working plan. Illicit felling means those which are caused without express sanction or permission of forest officer. Needless to say, illicit felling is done without any regard to public or national interest and to regeneration of forests. Damage due to illicit felling occurs mostly in the forests lying in the neighbourhood of villages and towns, that is, in areas close to human habitation.

2.7.1 Factors responsible for illicit felling

Factors that generally cause illicit felling are described below.

- **The household requirement of the villagers -** Villagers living in the areas adjoining to the forests depend very much on forests to meet their regular household requirements. In their day-to-day life the villagers need timber for making huts/building, small timber for agricultural implements, bamboos and posts for various constructions, and firewood for fuel . When these requirements are not fully met through legal means or rights, they are constrained to indulge in illicit felling and removal of forest produce. In particular, collection of firewood which they need daily takes a heavy toll on forest resources. Their demand for fuel is fulfilled, to some extent, by fallen branches, twigs and leaves whichthey collect from the forest floor. However, with increasing population pressure, when supply of fuel from forest floor becomes inadequate, the villagers get inclined to make illicit felling of small trees or cutting live branches, which they carry as head loads.
- **Villagers earning a livelihood –** When forests lie close to large human habitations like small towns or cities, use of firewood as fuel becomes popular, and a great demand for firewood is automatically generated in the markets of such habitations. In view of the potential of easy income that markets in such towns/cities do provide, the villagersliving in the forest fringe are tempted to make a living through sale of firewood in the markets of those town/cities. The villagers are then prompted to do illicit felling of trees and make firewood billets to sell in the market. Thus while providing a good option of livelihood to the villagers, the forests get impoverished. The effect may be disastrous in forests which bear only small trees/ pole crops, and large chunks of such forest may get barren within a short period.
- **By unscrupulous contractors /Timber merchants –** There is no reason to believe that illicit felling is caused by the villagers alone. Working of forest coupes by contractors has been long discontinued in west Bengal. Harvesting of forest produce from annual coupes or thinning areas is now done departmentally and produce is transported togovernment depots. Contractors /timber merchants buy timber and firewood lots from the depots. Thus access of contractors/timber merchants to forests is now largely restricted. However, departmental timber operation also involves engagement of contractors and labours from outside. The contractors and timber merchants or theiraccomplice thus still get opportunities to enter forests. A section of them, who are unscrupulous, sometimes tempt the labours with easy money to make illicit felling of trees, particularly those timber

species whose timber is commercially valuable. High price of timber in the market acts as a catalyst to illicit timber trade. While the localvillagers may be got engaged as labours in the process, the illicit trade is primarily engineered by the timber merchants/contractors who provide money, transport and other logistics.

- **Activities of miscreants –** Forests are huge resource of wood that lie open in the nature. It is neither possible nor advisable to have protective fencing for the entire forest areas. The protection force at the disposal of forest department is also limited. As against this, special quality timber is a high priced commodity in the market. Given the circumstances, a section of people, mostly from the towns, find forests an easy target to make quick money. They organize illicit felling and clandestine removal of timber. These miscreants also exploit the poor villagers by engaging them in the illegal operations.

2.7.2 Preventive Measures

Illicit felling and illicit removal of produce from forest can be contained by taking the following preventive measures:

- **Forest patrolling, field visits/inspection** – Central to forest protection measures is forest patrolling, field visits and inspection on a regular basis by the foresters working at various levels. In fact there is no alternative to intensive forest patrolling for control of forest offense. The prerequisite for an effective patrolling arrangement is availability of adequate field staff who can be assigned forest areas of reasonable extent for regular field visit. The idea is that the forest frontline staff, particularly the forest guard should be able to thoroughly inspect the forest compartment /areas placed in their charge at least once or twice a week. Depending on the vulnerability of the forest areas in question, the frequency of patrol may be increased and suitably adjusted. The forest areas which need intensive and careful inspection are the following –
    - Forest blocks / compartments adjoining to human habitation.
    - Clear felling coupes , thinning coupes and areas adjoining to these coupes

- It should be ensured that trees felled and logged are immediately recorded in the Timber Measurement Note Book (TMNB) and produce duly passed transported to government timber depots as early as possible.

- Felling coupes are hubs of various forestry operations involving movement of lot many people. As such, forest blocks adjoining to felling coupes become very vulnerable, since such blocks provide easy access to many, while foresters' attention remain more focused to the operations of the felling coupes.

• **Checking in transit –** Prevention of illicit felling is definitely the first and foremost preventive measure to control forest offence. Illicit felling may still occur despite rigorous patrol and inspection. So checking of forest produce in transit should be made to prevent illicit removal of forest produce. It also acts as a deterrent to illicit felling. Forest produce in transit, except minor produce given free of cost to JFMC members, must always be accompanied by some challan or pass duly issued by forest officer authorized in this regard. Following are the types of common challan or pass that are in use for transport of timber/firewood/poles etc.

- **Intermediate Transit Challan (ITC) -** ITCs are issues by the passing officers, generally of the rank of Dy Ranger/Forester, to transport frost produce from felling coups to timber depots, while the harvesting operation is in progress.
- **Transit Pass -** transit pass are issued by officers of the rank Dy Ranger/Forester Range officer, authorized in this regard, to allow movement of timber or other forest product from any place within the state to the destination.

Thus while ITCs are Internal pass for movement of timber mostly within forests, from one forest location to another forest location, the transit passes (TP) are documents authorizing movement of forest product from any place to any destination, mostly within the state. Both ITC and TP contain, among other things, (i) description of the produce, (ii) place of origin and destination and (iii) facsimile of the hammer mark used for passing /sale-marking the produce. While checking the produce in transit, the forest personal should verify whether the produce actually in transit match with the description given in the ITC/TP, and whether such produce bear the hammer mark matching with the facsimile shown in the challan/TP . Sec 52 (3) of IFA (amendment by WB Act XXII of 1988) empowers a forest officer or police officer to stop a vehicle, cause it to remain stationary, and examine the contents of the vehicle, including inspection of all records. The West Bengal Forest Produce Transit Rules, 1959 also provide that any vehicle, cart, boat, or other vessel carrying forest produce shall be liable to stoppage by any forest officer for the propose of examination and check.

• **Meeting reasonable demands of the villages -** when villagers living in the outskirts of forest are found to be involved in theft of forest produce for their daily needs, it indicates that the existing arrangement does not meet their reasonable demand. In order to address the reasonable expectation of the villagers living in forest fringe areas , the concept of Joint Forest Management (JFM) has been put in practice in West Bengal since long. The government resolutions issued in this regards provide a share of forest produce to the JFMC members subject to certain terms and conditions. Forest Management should ensure –

 That forest is duly protected with joint participation and that such forest sustains growing stock harvestable at specified intervals;

 Produce out of intermediate and final harvest is duly shared with the JFMC members at regular intervals in a manner prescribed by the government resolutions.

In short, one of the major objectives of forest management should be fulfillment of reasonable demand of the fringe villagers. As they appreciate that the management practice by the department is geared towards meeting their demands, the villagers will seldom indulge in felling or removal of forest produce.

• **Creation of alternative means of livelihood -** The villagers who have adopted illicit collection and sale of forest produce as their means of living need to be prevented from indulging in forest offence and provided alternative means of livelihood. As has been stated, the villagers get inclined to forest offence due to poverty. The management practice therefore should try to ensure –

- That forestry operations generate employment opportunities for the villagers as much as possible;
- That the forests afford collection of minor forest produce on a sustainable basis.
- That forest management includes undertaking of development projects enhancing rural employment and economy.
- That the department also makes arrangement for vocational training in various disciplines, including non-forestry ones, to reduce the dependence of the villagers on forest to earn their livelihood.

2.7.3 Remedial Measures

Despite making all preventive measures it is difficult to have foolproof arrangement against illicit forest felling. Even in the best possible management, some offences relating to forest felling and removal of produce may occur. In such cases the remedial measures to be taken are legal course of actions to deal with the offences. It is also very important to remember that legal actions are to be taken promptly. In connection with remedial measures, it would be useful to go through the Sections in Chapter IX of IFA, relevant provisions of CrPC and the Human Rights issues. It is advised to go through Lesson 15 of Forest Law.

Powers that a forest Officer may exercise: In order to combat illicit felling, the forest officer can exercise the following powers vested by the IFA, 1927.

• Power to seize – Section 52 of IFA empowers a Forest Officer or Police Officer to seize any forest produce togetherwith all tools, ropes, chains, boats, vehicles or cattle, if there are reasons to believe that forest offence has been committed.

Procedure to follow

- While making seizure, the officer must place the mark of seizure hammer, issued in his name for the purpose of seizure, on the property being seized and the receptacle containing the property, and
- Record the act of seizure including the description of seized articles in the Timber Measurement Notebook (TMNB);
- The officer who has made a seizure will draw a seizure report. Details of what a seizure report should contain have been described in Lesson 15 of Forest Law.
- The officer has to make, as soon as may be, a report of seizure to the Magistrate. However, making a report to the Magistrate will not be necessary, if (a) the forest produce is the property of the state government, and the offender isunknown, or (b) if the offence falls under the purview of section 59A, or (c) if the offender agrees in writing to compound the offence. In case (a), the officer making seizure will make a report of the circumstances to his superior; such report is known as UDOR (Undetected Offence Report), which is described later. In case (b), the officer will make a seizure report and produce

the seized articles before the Authorized officer for proceeding under section 59A. In case (c), If the offence is compoundable and merits compounding, a forest officer not below the rank of a forester, may compound the offence in terms of section 68 of IFA, and make a report, known as COR (Compounding Offence Report), to his superior. The COR has been described further later.

• **Power to arrest without warrant –** Section 64 of IFA empowers a forest officer to arrest a person without warrant or without orders from a Magistrate, if there is reasonable suspicion that the person is involved in a forest offence which attracts punishment of imprisonment of at least one month.

- Thus before making arrest under section 64, the forest officer should be certain of 'reasonable suspicion' against the offender, and also of the fact that the offence for which arrest is made is serious enough to attract punishment of imprisonment of at least one month.
- It should be borne in mind that a forest officer cannot make arrest under section 64 for any offence committed in a Protected Forest, unless such act is prohibited under section 30(c). Therefore, for making arrest in an offencein a Protected Forest, following conditions have to be satisfied

– That there exists a notification issued under section 30(c); and

- That such notification prohibits the said act.

Procedure on arrest – The officer making arrest will have to take or send the person, without unnecessary delay, and within 24 hours, before the Magistrate or the officer in charge of the nearest Police Station. In terms of section 65 , the Forest Officer, not below the rank of Range Officer, may release the arrested officer on execution of a bond.

It is advised to go through Lesson 15 of Forest Law to know the stipulations under CrPC and Human Rights in connection with arrest.

Power to Compound Offences – Section 68 of IFA read with WB Amendment Act XIV of 1975 empowers a forest officer, not below the rank of a forester, to compound a forest offence except under certain circumstances provided in the said Act.

Power to prevent commission of offence - Under section 66 of IFA, every forest officer is empowered to interfere for the purpose of preventing the commission of forest offence. Thus a forest officer is authorized to take such actions as he thinks are necessary for prevention of forest offence. In essence, the section also vests in the forest officer the responsibility of taking such preventive measures.

Offence Reports: Forest offences relating to illicit felling and illicit removal of forest produce are dealt with inthree different manners and accordingly the offence reports are classified into three different types, which are mentioned below.

1) Undetected Forest Offence Report (UDOR) – Offences under the following circumstances come under the purview of UDOR. • The offender is unknown; and • The forest produce in respect of which offence has been committed belongs to the State Government. Once such offence is detected, the forest officer, authorized to seize forest produce, will make seizure of trees/logs/ wood illicitly felled as well as of stumps where trees have been illicitly felled, following the procedure described earlier. Since the produce is the property of the State Government, such produce on seizure may be sent to timberdepot of the department to form depot lot. The said lot will add to the depot stock and will be disposed like other lots by the competent authority.

The officer making seizure will draw a UDOR which should contain the following information –

• Place of occurrence of offence;

• Date of detection of offence;

• Names of the officers present and circumstances leading to detection of offence;

• A brief account of offence indicating number of trees species wise that have been felled, Volume of wood, actual or estimated (if part of produce has been illicitly removed), involved in the offence.

• Seizure report (Details of seizure report may be seen in Lesson 15 of Forest Law.)

2) Compounding Offence Report (COR) – Offences under the following circumstances come under the purview COR.

• The offender agrees in writing to compound the case.

• The offence is compoundable. (Please see Lesson 4 of Forest Law, portion relating to Sec 68 of IFA, to know the cases when the offence cannot be compounded.). The officer compounding an offence under sec 68 of IFA will draw a COR which should contain the following information –

- Place and date of detection of offence;
- Names of the officers present and circumstances leading to detection of offence;
- A brief account of the offence; description and measurement of forest produce, if any, in respect of which offence has been committed;
- Name and other particulars of the offender who is suspected to have committed the offence;
- Whether any property has been seized as liable to confiscation, if so, the seizure report (Details of seizure report may be seen in Lesson 15 of Forest Law.);

• Statement of the offender expressing his willingness to compound;

• Amount realized as compensation for the offence;

• Market value of the seized property, if any; • Amount, if any, realized being double the market value of such property;

• Whether the seized property has been released on payment by the offender of an amount equivalent to double the market value;

• Whether the offender was taken in forest custody and discharged on payment of compensation;

Prosecution Offence Report (POR) - It is a complaint made by the Forest Officer to a Magistrate, alleging about an offence committed by some person(s), and praying for issue of process under the law. Offences under the following circumstances come under the purview POR.

• Offences that do not come under UDOR and COR;

• The offender is known. There could be following likely situations

  - The offender was arrested under section 64 of IFA and produced before the Magistrate earlier; or
  - The offender was arrested under section 64 and released under section 65 on execution of a bond to appear before the magistrate; or
  - The offender could not be arrested, but on due investigation, there appears reasonable suspicion of his having been concerned in the forest offence, and thus the case merits prosecution under the law.

Details of what a POR should contain have been described in Lesson 15 of Forest Law, which may please be seen.

2.8 Faulty Management

Through faulty management man does damage to forests. Defects creep in the management practice in two ways. Firstly, prescription in the management plan may be defective, and secondly, execution of working plan may be faulty.

2.8.1 Defects in management plan

Forest is a complex and sensitive ecosystem about which human knowledge is insufficient and incomplete. Thus though forest managers may always try to adopt scientific system of management based on their understanding and knowledge, slight error in their judgment may produce adverse effect on the forest ecosystem. The management planner also finds his job quite difficult as he has to judiciously balance people's demands of forest resources with the silvicultural and ecological requirement of forests. It is thus quite likely that prescriptions in one working planturn out to be not appropriate and put to revision in the next plan. Making management plan to ensure sustainable eco system services from forests becomes more difficult with increasing population and rising dependence on forests whose capacity to produce is limited.

Some salient points in a management plan

- **Defect in the perception-** Wrong perception about objective of forest management may invite defects in management. For example, if aim of management is over-influenced by the idea of earning quick revenue in a shortterm by intensive production of raw materials to meet the demands of industry and household, forests may be subjected to over-exploitation and their potential of supplying ecosystem services may suffer in the long run. Conversely, if the forests are preserved with little exploitation so much so that they do not supply even the legitimate demands of the JFMC members, particularly in respect of the non-wood products, the management prescription will be counter-productive, and participatory forest protection may lose its significance.
- **Bias towards Timber management -** Working plan or management plan often turns out to be timber or wood management plan. Focus is on trees, particularly on trees of commercial value. However, non-wood forest products, though known as

minor forest produce, are an important component of forest resources. People's dependence on forests in terms of their daily needs and livelihood is more through non-wood forest products than timber. Even in terms of money value which the villagers (JFMC members) may earn as usufruct share, the non-wood forest products are by no means inferior to timber products. A good working plan should therefore provide prescriptions for regeneration and harvest of non- timber species, including medicinal plants, that can supply nonwood products sustainably.

- **Perfunctory treatment of soil and moisture conservation measures -** Working Plan often deals with soil and moisture conservation works perfunctorily. A sound plan for soil and moisture conservation is a prerequisite for supporting a healthy forest crop.
- **Focus on fast growing and commercially valuable species -** The regeneration plan is sometimes biased towards commercially important species, or those trees which are fast growing and easy to establish. While those species are definitely important constituents of planting stock, we cannot exclude from regeneration plan those species which are slow-growing and difficult to raise, especially when they are important members of the indigenous group of species of the locality and whose existence is threatened. A good management plan will identify the spectrum of indigenous species and those which are already threatened locally or in the region. Among other species, plantation programme should have mandatory obligation to establish the threatened indigenous species.
- **Rotation age -** The rotation age or frequency of harvest should not be guided by silvicultural consideration alone. Areas of a forest division are distributed in different working circles which may be worked, depending on their objective of management, on different rotations. Different from silvicultural rotation, they may be of shorter duration to meet local demands or industrial demands. While fixing shorter rotations for local or industrial demands, the limiting factor is not to allow much compromise on production potential and to ensure that frequency of harvest does not affect the sustainability of production.
- **Harvest in eco-fragile zones -** Driven by the concern to enhance production level, the management plan should not encourage extensive harvest in forests in high altitude, estuarine forests with fragile ecosystem, and forests bearing highly

endangered species. Rather in such areas, the plan should regulate, as far as possible, human interference and allow only such management intervention which is necessary for protection against fire, epidemic or natural calamities.

2.8.2 Defects in execution of plan

It is obvious that even though a management plan is faultless, its impact on forests will depend on the quality of execution. Nature of defects in execution may be many. We discuss only some common defects.

- Harvest not commensurate with regeneration - Harvesting plan should be commensurate with regeneration. In other words, area harvested every year should be invariably planted in the following planting season. The management plan will definitely prescribe this stipulation. But, it will be a gross defect in execution, if area successfully planted falls short of area harvested, which may happen due to many reasons like, paucity of fund, shortage of staff, faulty regeneration plan, natural calamities etc. If for any reason, plantation in a year falls short of harvest which had immediately preceded such plantation, area of succeeding harvest should be reduced bythe area of deficiency in plantation. For example- Suppose according to prescription, in a working circle, area of annual harvest and annual plantation is 100 ha each. However, against harvest in 2014-15 (October 2014-March 2015) over 100 ha, plantation in 2015-16 (April 2015 – Sept 2015) could be done on 80 ha, leaving a deficiency of 20 ha in plantation. In such circumstances following adjustment in succeeding harvest area may be done.
  In Year 2015-16
  Area of Harvest (October 2015 – March 2016) should be 80 ha.
  The plantation to be done in 2016-17 (April 2016 – September 2016) will be again as per Plan prescription, that is, over 100 ha, comprising land of 80 ha harvested in 2015-16 and part of land of 20 ha which was harvested in 2014-15 but left unplanted.
- **Harvest without due regard to illicit removal of timber –** Area or extent of harvest prescribed also needs to be adjusted against illicit removal of produce. Otherwise, effective harvest will exceed the prescribed felling. It isexplained below. Suppose in 2014-15, the annual harvest as per plan in a working circle is 100 ha, and illicit removal of produce recorded in the previous year (2013-14) in the same

working circle is equivalent to produce over 10 ha area. The harvest in 2014-15 should be undertaken over an area of 90 (=100-10) ha. It would ensure that felling including illicit felling will not exceed the annual felling prescribed in the Working Plan.

- **Easy option to raise mono-crop and only fast growing species -** Keeping species diversity in view, the plan normally prescribes planting/sowing of planting materials of varieties of species compatible with the local environment. However, during execution, a forest manager may take an easy option of planting mono-crop or a few species which are easy to grow, not prone to grazing damage, and which do not need much care and protection. The purpose of greening may be served by such strategy, but it is a poor quality forest that will be raised. Going for mono-crop or a few numbers of easy-to-grow species is a serious defect in execution.
- **Introduction of exotic species or plants of new provenance without trial** – Forest managers are sometimes inclined to introduce in plantation exotic species (species of foreign origin) or individuals of native species of new provenance without trial, though such introduction is not permitted in the working plan. If it is considered worthwhile to explore new species or new provenances, it is necessary to conduct field trial and assess the performanceof such planting materials in the areas under afforestation. It is the responsibility of the Research Wing to conduct such trial and communicate their observation to the Working Plan wing.
- **Omission of soil and moisture conservation works –** The working plan normally recommends, as part of an afforestation programme, soil works for the purpose of soil and moisture conservation. However, quite often such conservation works are either omitted or done very casually. The quality of plantation and the object of eco-conservation are thereby adversely affected.

2.9 Other Damage

Humans cause damage to forests in many other ways. We describe some of this damage.

- **Lopping –** Some of the forest trees are regularly lopped to provide fodder. It was observed in the past in south West Bengal forests that young Sal trees were being lopped to serve as tusser host. Repeated lopping weakens the trees, retard their growth and render such trees prone to attack by insects.

- **Removal of leaf litter –** In certain forest areas the villagers remove leaf litter from the forest floor on a regular basis for fuel. It is a common scene in the forests of *Acacia auriculiformis* (Akashmoni) in south West Bengal that forest floors are swept clean of Akashmoni leaves, as these leaves are excellent fuel and of good use by the villagers. It is well known that leaf litter on decomposition improves the physical characters of the soil, and adds to the soil nutrients. Leaf litter also reduces runoff and checks to some extent soil erosion. The practice of removing leaf litter thus causes damage to forests on all these counts. However, if it is a practice of the villagers to collect leaf litter for fuel or some other purpose, it is not advisable to try to stop the practice altogether, because trees are saved as much as leaf litter serves as fuel. It is rather desirable to try to control and regulate collection of leaf litter from the forest floor.
- **Poaching –** Fauna and flora together constitute the biotic components of forest ecosystem. Both flora and fauna discharge important functions in maintaining the dynamic equilibrium of the ecosystem. Their existence and role are interdependent. It is thus natural that destruction of forest fauna by poaching or otherwise will upset the food chain and ecological balance resulting in damage to the forests. Therefore protection of wildlife should form a major task in forest management. Protection measures should include (1) creation of awareness among people, (2) intensive patrol and field visit, and (3) legal measures in wildlife offences.
- **Environmental Pollution –** Environmental pollution is increasing due to growing population, increasing demand of energy and rapid industrialization. Pollution badly affects the three major components of environment, namely, soil, water and air. As these components get polluted, their capacity and quality to support life degenerate. Consequently, pollution creates an adverse impact on the varieties of life borne by forests.

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Unit 3: Protection against Atmospheric Agencies I

Unit Structure

3.0 Learning Objectives

After going through this unit you shall be able to:

- Know the various atmospheric agencies that harm the forests
- Damage caused by very high temperature
- Damage caused by low temperature
- Damage caused by drought

3.1 Introduction

Forests from the seedling stage up to maturity are subject to the influence of the weather, and may thus be injured in various ways. The chief meteorological phenomena in question are frost, heat, wind, heavy rainfall, hail, snow, rime and ice. As a matter of course, these phenomena frequently act beneficially on vegetation ; frost disintegrates the soil and prepares it for the reception of seed and the growth of forest plants ; the wind disseminates the seed of many trees and shakes snow from off their crowns which might otherwise be broken by its accumulating weight ; atmospheric precipitation and heat are indispensable for vegetable growth ; snow is a bad conductor of heat, it keeps the soil comparatively warm in winter, and protects young plants from frost.

As regards locality, not only the soil and configuration of the ground, but also the nature of the soil-covering may be of importance. Since then, all these items may be combined in great variety of ways, the damage done must vary greatly according to circumstances.

3.2 Atmospheric agencies affecting plant life

A variety of agencies affecting plant life are included in this chapter. They are largely the effect of natural phenomena such as heat, cold, precipitation, and wind. These natural factors exert both a beneficial and an injurious influence upon the life and growth of plants. Most atmospheric agencies when acting in normal manner are essential for tree growth. A plant must have water and a certain amount of heat for its growth, and, when these factors arc secured in the proper measure, the plant grows most rapidly. When, however, one or more atmospheric agencies are either present in an abnormal amount or lacking in the desirable quantity or when they so operate as to affect trees in an unusual manner, the results upon tree growth and development may be injurious rather than beneficial. It is impossible to control or change the atmospheric agencies themselves for climate is beyond the control of man. He cannot change the essential features of climate, which in a broad way expresses a summation of those points which are usually included under the term atmospheric agencies. Since the factors themselves which influence tree growth and development cannot be altered, the only recourse for the forester is to so manage his forest as to obtain the most favorable re- action of the atmospheric agencies upon its development. As a consequence of the wide range in values of a given atmospheric factor which may be experienced in a given place, a certain amount of loss from natural atmospheric factors should be anticipated as in- evitable in all forest crop production. The extent and character of such a loss can be modified and partly controlled by proper methods of management. Prevention in this case, then, is not so much the elimination of the occurrence of dangerous climatic influences as it is the developing of the forest into such a condition, and its maintenance in this condition, as will prevent or minimize the injurious effect of the climatic factors. Poisonous gases and smoke cast into the atmosphere are largely within the control of man and can be prevented by regulatory measures. They differ in this respect from the other atmospheric agencies here included. It might even be questioned whether they should be placed here along with such factors as precipitation and heat, since they are not directly a part of the natural climate. However, smoke and poison- ous gases in the air are certainly a part of the atmosphere, and, even though they are produced as a result of man's negligence, they should be classed and considered among the atmospheric agencies against which the forest needs protection. In addition to the direct effect upon the forest which atmospheric agencies exert they may have serious indirect effects through weakening of the individual trees, and thereby encouraging the entrance of fungi and insects. Atmospheric factors include a number of independent subjects, each of which is discussed separately. Though this treatment is advisable in studying the subject, yet actually the atmospheric factors do not act independently of one another. They are intimately interrelated, and as the forester contends with them in practice he finds that their effect is a combined one in which the influence exerted by a given factor is oftentimes difficult to measure accurately. Trees which have been grown under conditions prevailing in a closed stand are more easily affected by atmospheric factors than trees which have been grown in a relatively open position. The latter have more symmetrical, deeper, and more luxuriant crowns which act as a sheltering cover to the tender parts of the stem and branches. Trees grown in an open position have been accustomed by long exposure to be resistant to atmospheric influences. The individual trees in a closed stand when opened up by the removal of several of their associates are exceedingly vulnerable, as their crowns come only part way down the trunk—often less than one-quarter of the total height—and leave a long, slender, bare stem exposed to the atmospheric elements. Forest crops, of course, must be grown in closed stands, and it is desirable that the lower portion of the tree trunk should be free of branches. Granting these facts, it is evident that careful attention must be given to protecting forest-grown trees from injurious atmospheric agencies.

3.2.1 Atmospheric factors

The classification of the atmospheric factors affecting forests injuriously, as arranged for the purposes of this discussion, includes: Temperature so high as to injure plant tissues. Frost (temperature injuriously low). Drought, or a shortage of water available for the tree. Water in excess of that required for the proper development of the tree. Under this heading are included such manifestations of an excess of water as floods, landslides, and erosion as far as such soil movement is occasioned by water; frozen water in the form of snow, ice, hail, and avalanches, the last being the movement of water in a mass of snow and ice. Wind in its various manifestations, among which are included drifting sands and erosion as far as caused by the wind movement of soil. Lightning. Poisonous gases and smoke in the atmosphere.

3.3. Temperature

High temperatures may result in the death of small seedlings and in injury to sensitive portions where tender bark is exposed in trees of all sizes. Fire furnishes a special example of overheating, but otherwise temperatures excessive for forest trees are produced by heat of the sun. Such injuries occur chiefly on the southern and southwestern sides of the tree. Excessive temperatures beyond the maximum suitable for a given tree are frequently encountered on open areas. Hence, the greatest ef- fect of excessive heat is felt by young reproduction. Different investi- gators have secured slightly different results as far as lethal temperatures are concerned. They all agree, however, in considering temperatures above 150° F. fatal to young plant tissues. As temperatures above 160° F. are frequently experienced at the surface of the ground and in the top soil layer, reproduction may be entirely prevented on such areas. Both Bates and Roeser (1924) and Baker (1929) show that the maximum air temperature may be the climatic factor preventing the survival of small seedlings and thereby making natural regeneration impossible. Excessive heat causes stem lesions close to the surface of the ground, where the temperatures are the highest, or sometimes in the top soil itself. Heat lesions on seedlings frequently have been mistaken for a similar type of injury caused by damping-off fungi. The two should not ordi narily be confused. Hartley (1918) shows that the damping-off fungi spread progressively upward and downward, whereas the heat lesion usually is definitely limited to one spot for some time, the upper stem and cotyledons remaining turgid. The heat lesions are often found only on one side of the stem, and this the southern side. Sometimes seedlings may recover from heat lesions. As seedlings advance in age, the bark becomes thicker and they are less exposed to the effects of excessive surface temperatures. Plants up to several years in age, however, may be injured, particularly if the stems stand at such an angle as to be perpendicular to the rays of the sun. Transplants either while growing in the nursery or after having been set in their field location may suffer death from excessive heat. Korstian and Fetherolf (1921) carried on experiments in Utah with Engelmann and Norway spruces and found a significant difference in the percentage of trees killed by excessive heat among transplants whose stems inclined toward the north as contrasted to those whose stems inclined toward the south. The tops of the trees shaded the stems inclined toward the south from the direct rays of the sun and hence the injury from excessive heat was small, whereas those inclined to the north had fully exposed stems nearly perpendicular to the rays of the sun and suffered heavy loss. Shirley (1936), working with white, Norway, and jack pines and white spruce in the Lake states, found recovery after heat injury to seedlings to be dependent upon their ability to send out epitomic branches from the stem, below the point of injury. White pine exceeded the other species in ability to send out epitomic shoots. Jack and Norway pines were deficient in this respect. There was little difference between species in ability to withstand heat. The injury known as sunscald is sometimes attributed to high temperatures. It is usually found among older trees in places where a dense stand has been opened on the south or southwest side and certain portions of the trunks of the trees which had previously been densely shaded are now left exposed directly to the sun. Where this situation occurs the cambium under areas of thin bark is likely to be killed. The areas of dead tissue may be confined to small spots or may extend in a continuous strip for several feet along the stem of the tree. This type of injury appears to be caused not by temperatures high enough to kill plant tissues but rather by the action of sun and low temperatures on bright cold winter days (Huberman 1943). The sun warms the plant tissues in late afternoon, and after sunset a rapid drop in temperature kills the plant tissues by freezing.

3.3.1. Control Measures:

Injury from excessively high temperatures can be avoided in forest nurseries by furnishing the tender seedlings with the requisite amount of shade. Natural reproduction on areas being regenerated may need shelter the first year or two of its life. Frequently it will be practical to provide such shelter by making partial cuttings instead of removing all the old timber at one time. Where severe loss to young seedlings is anticipated from excessive temperatures on cutover areas, cuttings of the shelter wood or selection types may be needed. In some situations it may be necessary in order to secure adequate natural regeneration to make the cuttings of a strip character, advancing in direction toward the sun. Reproduction would be expected on the sheltered side of the stand away from the sun. Among the most difficult situations upon which to establish natural reproduction are the south and southwest exposed edges of an old stand. Here the young seedlings not only must endure severe root competition from the neighboring old trees, but they also are exposed to excessively high temperatures at the ground surface along the edges of the old stand. Observation in many places will lend support to the statement that reproduction tends to be better on the northerly than on the southerly edges of an old exposed stand, owing primarily to higher temperatures on the southern edge. Clear cutting or even heavy partial cutting on the south side of stands being reproduced should be avoided, wherever the climate makes excessively high temperatures possible and the species grown is sensitive to this factor. Based upon a study made in Greece, Moulopoulos

(1947) concludes that planting using coniferous stock not less than 0.15 meter (5.85 inches) tall and so planted as to shade the stem is the only method indicated for successful reforestation technique in hot and dry countries. Similarly, to prevent injury to the trees in older stands from sunscald, or bark-scorching, as it is often designated, exposure on the southern and western sides of trees and stands, which previously have been densely grown and are susceptible to the injury, should be avoided. On areas being artificially regenerated where high temperatures sufficient to kill the planted trees are expected, it may be best to plant the trees with their stems inclined toward the south and thus secure the benefit of the top in shading the stem. Planting the trees on the northeast side of logs, stumps, and rocks will serve to furnish some protection from the sun and is likely to increase survival.

3.4. Frost

Trees may be injured in various ways or even killed outright by low temperatures. The injurious effects of low temperatures upon trees may be classified into four groups as follows: injury from late frosts in the spring, injury from early frosts in the fall, injury during the winter, and frost heaving. The most commonly noticed effect of low temperatures is the killing of new terminal and side shoots and tender foliage by the action of late spring frosts coming after growth have begun. Such injury may be quite local and restricted to small areas or frost pockets with poor air drainage or may be general over large areas. A striking example of the general type of injury, which damaged the beech throughout the eastern United States, took place in May 1936, as a result of a heavy frost. Foliage and new growth on beech trees of all sizes were killed. Small trees under older timber suffered as well as those standing in the open. New growth on many conifers is likely to be killed by late spring frosts whenever they occur. Late spring frosts cause serious interference with tree growth, since they catch the new leaves, twigs, and buds at a time when they are succulent, tender, and without the protecting woody tissues developed later in the season. Consequently all the new growth may be frozen and the tree forced to put out new foliage before it can go ahead with its growth for the season. Evidences of frost injury may be wilting followed by discoloration and dying back of the affected shoots and leaves. Frost injury often results, on both conifers and hardwoods, in a forking of the main stem when the terminal is killed and more than one lateral survives. This type of injury is particularly serious in plantations not yet closed. Crooks are produced when a terminal is killed or a frost canker is made on the stem. Sometimes frost injury results in partial defoliation. Frost may be responsible for changing forest composition in some places, particularly in transition zones between forest regions. Mesavage (1939) reports in northern New Jersey serious injuries by a late spring frost to oaks, locust, sycamore, yellow poplar, and hickory—all species of the central hardwood forest—while black cherry, sugar maple, big tooth aspen, yellow birch, American elm, basswood, and beech—^northern forest species—^were not affected. Frosts coming early in the fall, before the current season's growth has become sufficiently lignified to withstand cold, cause injury similar to that resulting from late spring frosts. The damage is not so serious since the foliage and shoots are less succulent and woodier. The result is mainly a loss of a portion of the growth which took place during the year. Injury from early fall frosts is experienced most fre- quently by young plants which for some reason have continued vigor- ous growth abnormally late in the season. Stump sprouts and nursery stock too liberally fertilized suffer especially from early fall frosts. Plant tissues endure without injury much lower temperatures during the dormant period than they are able to withstand in the growing season, yet they may be injured by periods of extreme winter cold. A type of frost injury, termed ^^winter killing" or "red belt," is the result of thawing during the cold winter season which induces transpiration of water from the foliage. Since the trees cannot at this season replace the water transpired width a supply drawn from the frozen ground, they suffer from drought. Such injury occurs only to conifers. Hardwoods not bearing foliage during the winter are not subject to injury of this type. Low temperatures in themselves are evidently not entirely to blame for injury caused by winter killing, as other climatic factors are involved. Sunscald, described on page 282, is now considered a winter injury and attributed to the rapid freezing of cambial tissues which have first been warmed by the late afternoon sun. Roots of small trees may be killed by freezing in the winter, especially when growing in wet soils. Another effect of winter cold usually seen every year is the production of frost cracks. This injury results from freezing of the stem in which tension is set up causing splitting in a vertical plane from the bark toward the pith. These frost cracks are likely to open year after year. Wind may be partly responsible for the continued existence and enlargement of frost cracks, particularly on dominant trees with ex- posed crowns. A callus growth is stimulated on the two outer edges of the forest crack, and in the effort to heal over the crack a protuberant ridge is produced running vertically up and down the tree. This ridge is plainly seen from the outside and usually starts at or near the ground, often in the hollow between two large roots, and extends upward for several feet. Sometimes frost shakes, or circular cracks, are produced. The result of either type of injury is to render the section of the trunk affected less valuable for lumber than it otherwise would have been. The extent of the damage depends on the skill of the sawyer in sawing the log. Broad-leafed species of trees, especially oak, elm, and ash, because of their wood structure, are more subject to frost cracks than the conifers. Large trees placed in a free position are considered more subject to frost cracks than those in a closed stand. Kienholz and Bidwell (1938) in a study made in Connecticut found scarlet oak, black ash, black oak, and red maple to be the species most frequently cracked. Most of the frost cracks were in the first 8-foot log, and more were on the sunny (south and west) sides of the trees than elsewhere, presumably because of the greater range there in temperature changes. The larger and dominant trees were more often cracked than smaller and lower-class trees. Frost heaving, another type of injury attributed to low temperatures, results in damage of a mechanical nature to the roots of young plants. In the process of frost heaving, ice crystals *form in the soil and raise both soil and plant, pulling the roots of the plants upward from unfrozen soil below or breaking the roots (Haasis 1923). When the soil thaws it falls back and leaves the plant roots partly exposed. When this alternate freezing and thawing of the soil is repeated numerous times, as may happen on exposed sites in many parts of the country, the plant ultimately is left lying on top of the soil and may be destroyed. Injury from frost heaving is particularly bad in regions where there is not an adequate covering of snow during the winter. Trees planted in the fall on bare soil are very susceptible to frost heaving, as their roots have not had time to develop a deep, firm anchorage. Shallow-rooted species are more easily heaved out than deep-rooted trees. Heavy and wet soils and sunny aspects, where alternate freezing and thawing is characteristic, are subject to frost heaving. Another effect of frost heaving which has been observed (Tryon 1943) is girdling of small seedlings by the frozen soil. In the heaving process the frozen soil pushed up the stem may slide the bark and cambial tissue up the stem causing a girdle usually % to 1 inch above the soil surface. An indirect effect of low temperatures upon trees is the creation of wounds which may serve as points of entrance for fungi and insects. In some species this may prove a serious matter. Frost injury may occur in all regions where the air temperatures go below the freezing point of water (32® F.). Within a given forest area there are likely to be small areas, termed frost pockets, of depressed topography, such as the potholes in glaciated country, where the cold air settles with a consequent large amount of frost injury. These frost pockets if cleared of their forest cover are difficult to restock. Frost pockets sometimes may be created artificially by unskillful treatment in reproducing a mature stand. The trees on valley bottoms and lower slopes are more likely to be injured by low temperatures than those on upper slopes and ridges. Oftentimes small differences in topography result in widely divergent amounts of frost injury. The net result of frost injuries as far as forest crop production is concerned is a decrease in growth rate and a weakened condition of those trees that are not killed outright. Species indigenous to a relatively warm region, when introduced into a colder climate, suffer severely from low temperatures.

3.4.1. Damage by Frost

Frost effect on plants: Low temperature affects living plants and their structures. If the temperature goes below zero degrees, then chilling and freezing damage occurs. Freezing risk often depends on the conditions of the formation of ice.

Frost damage to plant cells: Frost is an important event because a plant’s tissues get damage when there are ice crystals, or the temperature goes below zero degrees. When the temperature goes below 0 C, there will be crystals around the nucleus. Tissues that are in secondary growth are usually get affected by freezing; this can also cause a shrinkage effect on cells. As intracellular ice is created, exothermic ice is produced at a low temperature than extra-cellular ice creation. Lower temperature induces species and seasonal variations. It interacts with molecular bonds such as hydrogen, prominent to membrane destruction and inhibition of macromolecules along with enzymes and operational proteins. Intracellular ice development naturally prevents cell death under natural conditions.

Frost damage to plant structure: The ice presents on the outside of the plant cell puts a strain on cell walls and creates osmotic disturbances. The increased volume of this ice results in frost cracks in the wood. Once the sap freezes, it increases the stiffness of wood, which can tolerate the weight of ice and snow. Apo plastic water makes water fluxes when there are consecutive melting and freezing. Ice expands during freezing, and then air bubbles are expelled, making the xylem embolism. The diameter of the conductor is a significant element in the sensitivity of xylene. Due to the freezing event, embolism damage 100% of the water content in Quercus robur, but only 0% in Pinus sylvestris. However, species that are having narrow xylem elements can also make embolisms after the freezing event. Hydraulic conductivity is lost due to the low temperature in xylem conduits. Trees that contain narrow xylem do not get affected by freezing and grew more energetically. Therefore, winter embolism is a significant aspect of controlling tree appearance. Consecutive melting and freezing can also cause a deficiency in apple trees, and this phenomenon is well-known as ''frost-fatigue.''

3.4.2. Control measures

Injury from low temperatures is difficult to avoid or even effectively minimize except by intensive and skillful management of the forest over a long period of time. Even then a large proportion of the damage cannot be prevented. Since frost, at least those types of frost in- jury that are sometimes susceptible of control, affects young plants principally, it follows that the efforts of the forester as concerns frost control should be directed toward safeguarding reproduction. Nothing can be done to prevent losses from the exceptional periods of winter cold, but sensitive species which need shelter in early youth can often be protected against late spring and early fall frosts and against frost heaving. Fortunately not all the commercial species in the United States are sufficiently sensitive to frost to require protection. Where natural regeneration is relied upon, the only feasible control against early and late frosts is to apply a partial-cutting method rather than clear cutting in removing the old timber. The shelter of the old timber oftentimes will protect the young seedlings. That this is not always true was shown throughout northeastern United States by the frosts of May 1936, which proved disastrous to beech reproduction under old timber, even when no cutting had taken place, as well as in the open. Special care should be taken in frost pockets or in low-lying level country subject to frosts not to expose reproduction until it is 3 to 6 feet in height, after which time it should be fairly well above the worst frost line. A frost pocket once cleared of timber is difficult to restock. A strip-shelterwood system advancing toward the south or southeast gives reproduction the most thorough protection against frost. Where artificial regeneration is employed better protection is possible. In the first place, nurseries should be established only on site relatively free from frost injury. Hardy species and races of these species which begin growth late in the season should be chosen for reforestation on sites subject to frost. A race which starts growth late in the season will usually avoid injury in late spring frosts. Seedlings in the nursery can be protected by covering during the winter with a variety of materials such as leaves, straw, or burlap and if necessary during the early spring with lath screens and burlap. Where planting is done in frost pockets, strong transplant stock as tall as can be economically handled should be used to get the plants above the frost line as soon as possible. Where the danger from frost is great and the species wanted on the site is frost sensitive, it may be necessary to plant first a crop of fast- growing frost-hardy trees and later establish beneath this nurse crop the species wanted in the final stand. This is too expensive a method for general use. Injury from frost heaving can be lessened by keeping all sites subject to heaving completely stocked with the densest possible soil cover. In planting dangerous sites, methods which do not leave the bare soil exposed should be employed. Planting should not be done in the fall, and only deep-rooted species and large-sized planting stock should be used. Sometimes drainage of wet soils may be worthwhile, both to lessen the frost heaving and to improve the rate of growth. Practical methods of securing protection against the formation of frost cracks are as yet unknown. It may be that maintaining a good understory close around the best trees will lessen the damage from this source of injury.

3.5. Drought

Drought may be defined as a deficiency of soil moisture. A shortage in the normal precipitation, particularly at the time of year during which plants are growing rapidly and consequently require the most water, is the primary cause of drought. Danger from drought is made more acute by atmospheric conditions such as clear days, high temperatures, low relative humidifies, and strong winds, all of which stimulate a high rate of evaporation, thereby rapidly reducing the already scanty supply of soil moisture. In nearly all regions the annual precipitation is subject to considerable fluctuation. Occasionally a year of abnormally low precipitation occurs, resulting in a serious deficiency of soil moisture. Where the precipitation falls to half or less of the normal, dangerous drought conditions are created, especially if the deficit comes in the growing season.

3.5.1. Damage by drought

From the standpoint of damage to trees the fluctuation in total annual precipitation is less important than shortage of precipitation during the growing season. The distribution over parts of the growing season may have pronounced effect. For example, in the Lake states (Anonymous 1935) a wet spring in 1933 was followed by a warm, early summer. As a result trees produced long succulent shoots and had no chance to develop resistance to drought. Then followed a July-August precipitation lowest on record with disastrous results to young trees. The following year, spring was drier than normal and consequently trees had short shoots. Although the total precipitation was less, no monthly total was as low as during 1933 and the result was better survival. Lack of sufficient water to provide for the needs of the forest results in extensive injury. The extent of the damage ranges from a slight diminution in growth to the death of the tree. Stickel (1933) in studying damage from the 1930 drought in Connecticut recognized three types of injury. The first was injury and killing of ground cover and reproduction. These plants, being rooted in the upper soil layers, are affected first and most severely. As the drought increases in duration and intensity, the main stand itself with roots extending below the upper soil layers suffers injury, and trees even of large size are killed outright. A third type of drought injury is reduction in the growth rate, not only of trees having branches killed by drought but also of trees showing no external injury. Stickel (1933) found growth after the 1930 drought reduced approximately one-third. Wilting is one characteristic sign of injury by drought exhibited by foliage and tender stems, although of course not all wilting is caused by drought. Yellowing of the foliage and premature shedding of leaves may be other symptoms of drought. In later stages particularly where the reproduction and lesser vegetation have been killed, a drought affected stand often has the appearance of a burned-over area. Sometimes entire groups of larger trees are killed by drought, but usually some individuals arc killed while others close by, apparently growing under similar conditions, remain alive. Presumably restrictions of the root system due to underlying rock result in different soil moisture supplies (Hursh and Haasis 1931). Where precipitation is abundant and well distributed throughout the growing season, injury from drought, though it may affect some of the weakest plants because of the competition of the stronger individuals, is of no practical significance. The greatest losses from drought come when prolonged and severe shortages in the normal precipitation take place.

Spaulding (1946) reports as not unusual the dying of beech in the northern forest from a combination of summer drought and excessive winter cold. In Pennsylvania forests, chestnut, red, and white oaks are relatively drought-resistant trees, while scarlet and black oaks are much less resistant. Conifers, particularly eastern hemlock, are less resistant than the hardier oaks (McIntyre and Schnur 1936). The amount and distribution of the precipitation are the major factors in determining the character of the forest. The tendency is for the stand to be as densely stocked as the water supply allows. Any pronounced decrease in the supply of water for a specific forest will be reflected in drought injury to the trees, particularly on thin soils and in regions where the normal precipitation is itself near the minimum for support of a forest. When a drought occurs, the forest on such areas may be killed outright, especially if composed of large old trees. The most serious losses from lack of water result from subnormal precipitation in the growing season, but another manifestation of water deficiency is the reddish discoloration of foliage of conifers in late winter and early spring, often spoken of as winter killing or red belt and already mentioned as an effect of low temperatures. This injury results from transpiration by the trees during unusual thawing periods in the winter when the ground and trunk of the tree are frozen. Water to replace that transpired cannot be secured, and the foliage and twigs are injured or killed. The injury may be severe enough to kill the tree, or only a decrease in growth may result. Only species that retain their foliage during the winter are affected. The indirect effects of drought are important. In addition to reducing growth, which has already been mentioned, drought has a weakening effect on the vitality of trees, making them more easily attacked by fungi and insects. The wounds created by the killing of parts of the trees offer convenient means of entry to these pests. Drought is frequently the underlying cause for damage by other injurious agencies. Hawboldt (1947) considers drought conditions extended over a 25- year period an important factor in the present alarming mortality of yellow birch in Nova Scotia. Secrest, MacAloney, and Lorenz (1941) attribute the heavy mortality in hemlock on the Menominee Indian Reservation in Wisconsin to drought as the primary cause, with the shoestring root rot as a secondary cause along with the eastern hemlock borer abundant only in dying trees. The evidence proved that the borer could not successfully attack healthy trees and succeeded only in trees with less than 60 per cent of their main lateral roots.

3.5.2. Control measures

Drought injury cannot be prevented, but the extent of the damage can sometimes be minimized by proper methods of management. Effort should be made to put the forest into such condition that it can endure without serious loss the occasional seasons of deficient moisture. The principle that should be followed is to maintain a more open forest than nature would provide on areas where drought injury is feared. Thinnings should be employed systematically, and a few vigorous stems with room for good crown expansion should be grown, instead of a large number of relatively weak competing trees. Observation has shown that less loss is experienced in thinned than in similar unthinned stands. Caution is needed not to make the thinnings so heavy that wind movement and consequently evaporation are seriously in- creased. When stands are reproduced in regions of low precipitation, partial cuttings may assist in protecting reproduction from moisture deficiency. Shirley (1934) advances this idea for the pine forests of Minnesota. Here, the remaining portion of the old standby shading the reproduction retards transpiration and hence conserves soil moisture in a region of low rainfall where evaporation losses are serious. The same idea may be applied in artificial regeneration, on sites especially subject to drought, by planting the trees in spots like the north side of a stump or log or under a light cover, where they will be shaded and somewhat protected from excessive transpiration. The rotation for forest crops on dry shallow soils, to avoid heavy loss from drought, should be relatively short, and drought-resistant species should be favored in managing the crop. Narrow strip cuttings pro- gressing either against the sun or against the prevalent wind furnish the maximum protection against drought.

3.6. Rainfall

3.6.1. Water in excess

Under this subject is included the injurious influence which water in excessive quantities exerts on the forest. The influence of water on the forest is beneficial when present in proper amount. Water is an indispensable element for tree growth and is one of the most important factors in determining the productiveness of the forest site. The harmful effects of water come entirely through an abnormal supply: either there is a deficiency, when injury to the forest results from lack of water (this effect is termed drought and has been covered in a previous section); or there is an excessive amount of water, which is the condition here discussed. Injury from excessive supplies of water will be considered under the following headings:

A. Violent rainfall
B. Floods
C. Erosion (so far as caused by water)
D. Landslides
E. Frozen water in the form of snow, ice or sleet and avalanches.

3.6.1. 1. Violent Rainfall

Nature provides precipitation at irregular intervals and frequently supplies it for short periods of time in the form of heavy downpours. Violent rainfall in the act of falling may tear or strip off the tender foliage of trees. However, precipitation itself is rarely so violent as to cause serious mechanical injury of this type. Usually injury from violent precipitation is caused not by the falling of the rain alone, but by the action of wind which is primarily responsible for the injury.

3.6.1.2. Floods

The greatest damage to the forest from water in excessive supply occurs after the water reaches the ground and is made possible by factors which allow and encourage its collection in large volume. Water so collected is designated as a flood. Not every violent rain- storm necessarily results in a flood. The forest floor and soil may be so porous as to absorb all the precipitation as it reaches the ground, thus preventing abnormal surface runoff which is the necessary forerunner of a flood. Storms of exceptional length, or a series of less severe storms or a single cloudburst, may overtax even a dense forest, with the most efficient litter and soil for hastening percolation, so that abundant surface runoff occurs and a flood results. This was the situation in the Vermont flood of 1927. Unfortunately a large share of the precipitation in most forest regions falls on land put to other uses than forest, or upon forest areas not fully effective as stores of water, and consequently heavy surface runoff is the rule and floods of greater or less volume are of frequent occurrence. So far as the forest itself is concerned the damage from floods which originate within forested areas is not of serious injury to these forests unless they have been badly managed. The principal flood damage to forests occurs in forests lying not on the headwaters of streams but on areas farther downstream and especially on watersheds which are to an appreciable extent non-forested on portions of their upstream areas. Ordinarily a flood to cause severe injury to the forest must arise on the watershed above the forest and then sweep down through the forest. The damage to the forest which floods cause is of varied character. Where the movement of water is violent young plants may be destroyed, trees may be torn out by their roots or broken off and they may be wounded by the impact of ice, stones and other materials borne along by the flood. Soil in which the trees grow may be washed away, or conversely, in lowlands where the movement of the water is slow, deposits of soil, rock and debris of various kinds may be spread over the forest floor. Where such deposits are thin and made up of fertile soil of fine texture this effect of the flood may be beneficial. Where coarse material is deposited and the layers are deep the effect is distinctly harmful. One of the most characteristic and most disastrous effects of floods is the erosion of soil. Indeed, it is practically impossible to separate the effects of floods and of erosion. Erosion caused by floods may entirely destroy a forest by carrying away the soil in which the tree anchors its roots and from which its supply of food is obtained. Another type of flood injury occurs on low-lying level lands where flood water ultimately collects and stands for appreciable periods of time at depths covering the root systems of trees. Under such circumstances the trees may be killed through lack of aeration. Swamp lands, as the name implies, are areas which have poor facilities for shedding water and which consequently have an excess of water either permanently or throughout an important part of the year. Floods add to the amount of water standing in swamps and thereby increase the damage suffered by swamp forests. Swamp forests are hindered in growth oftentimes to such an extent that only a stunted forest can be grown. The trees are relatively unhealthy and are constantly exposed to danger from wind throw, owing to the wetness of the soil and the shallowness of the soil layer in which they can develop a root system. Tree roots are most abundant in the zone of soil lying above the level at which water stands during the growing season.

3.6.1.3. Erosion

Erosion is a natural process which has been in operation throughout the past and will continue to operate in the future. The wearing down of land masses by the action of water cannot be pre- vented. Erosion may be either normal or abnormal. Normal erosions a gradual wearing a way of land surfaces which, although continually in progress, does not seriously affect the use of the land and its productive value until the vegetative cover is broken. Abnormal erosion is an accelerated type which erodes the land surface so fast as to destroy the productive capacity of the soil. It may occur either in the form of sheet or gully erosion. In sheet erosion thin layers of the topsoil are washed away, this process being repeated with each storm until eventually all the fertile soil is removed and unproductive subsoil is exposed. Sheet erosion because the general contour of the surface remains unchanged is frequently overlooked until the land is well on its way to destruction.

Gully erosion more spectacular than sheet erosion cuts gullies into the land surface and is evident as soon as it starts. Once under way this type of erosion destroys the land with startling rapidity. Erosion not only ruins the land from which the material is removed but also may destroy the value of other lands by depositing upon them the eroded material. Such deposits are harmful when the material is of coarse texture and sterile nature, but when silt and other fertile soil material are laid down the lands covered may be benefited as in the case of many river bottoms.

However, the occasional beneficial effects of erosion are more than counterbalanced by the injury to the lands from which the eroded material came. Erosion varies greatly in character in different parts of the country. The geological formation, particularly the gradient of the land uplift, is a factor influencing erosion. Precipitation itself is a primary factor since water, along with gravity, furnishes the motive power for moving the soil. Severe erosion may occur in relatively level regions which have heavy precipitation and susceptible soils. Soil formation and texture are important factors in determining the extent and amount of erosion. Heavy clays are resistant to erosion, owing to the strong cohesion between soil particles. Coarse sands and gravel are relatively resistant because of the speed with which water percolates through such material.

The soils most susceptible to erosion stand midway between these extremes and are of a loamy or silty character. Erosion cannot start in a properly managed forest. It may start in an altitudinal zone above the forest, or in exposed spots within the forest zone such as bare openings and road cuts, or it may start below the forest and work back into it. Although erosion does not start in the well-managed forest, yet there are many ways in which it may start in the forest provided the management is not perfect. Such factors as fire, lumbering, the grazing of livestock, poisonous gases which kill vegetation, agricultural use, rights-of-way for highways, railroad and other transportation lines, all furnish opportunities for erosion starting within or close to the forest. From these starting points, injury to adjoining pieces of well-managed forest may result. It is erosion accelerated beyond the normal rate by such artificial factors as those just named which is responsible for the serious phases of the erosion problem.

3.6.1.4. Landslides

Landslides are a special form of erosion. They are mass movements of soil sliding as a unit rather than the movement of soil as individual particles in a stream or sheet of water. Landslides are caused by masses of soil becoming filled with water or water-logged. If such portions of soil are located on level land, the excess water simply turns the area into a swamp and no landslide results. Where soil on slopes becomes filled with water, the entire saturated body of soil is likely to slip down to a lower level. Landslides are particularly apt to occur where some stratum either of impermeable soil or rock lies parallel to the slope and prevents deeper entrance of water into the ground. It is easy for the soil above such a stratum to slide downward when saturated with water. Not only the soil but the forest along with it is carried down, leaving a bare exposed slope. The forest in the path of a landslide is destroyed. Either the trees slide with the mass of sojl or if the roots are anchored in firmer unsat- urated strata the landslide passes through and over the forest, smash- ing the trees and burying the ground under deposits of rock, soil and debris. Injury from landslides may be expected in mountainous regions having abundant rainfall. The area affected by a landslide ordinarily is a long narrow strip running from the top to the bottom of a steep slope.

3.6.1.5. Frozen Water: Snow, Ice or Sleet

In cold climates a portion of the precipitation comes in the form of frozen water, or freezes after it reaches the trees or ground. Under certain circumstances this frozen precipitation may cause serious damage to the forest. The injury results primarily from the weight of the frozen precipitation upon the trees. Snow has a beneficial influence in that it covers the ground like a blanket and prevents deep freezing of the soil as well as the heaving of small plants which often occurs on exposed soil. The snow blanket also assists in lessening injury to reproduction at the time of logging. Since the blanket of snow retards or prevents freezing of the soil, itfacilitates percolation of water into the soil. Indeed, as the snow melts on top of the ground the snow water may enter the unfrozen soil. On the whole, the beneficial influence of snow outweighs the damage caused. Snow is particularly injurious under circumstances which cause it to fall in a moist, sticky condition so that it is caught in large proportion upon the trees. A snowstorm of dry, finely divided particles, sifts down throught the trees and little is retained on them. The greatest likelihood that a large part of the snowfall will be held on the trees is found in dense stands of conifers where all the crowns are approximately the same height and the branches interlace strongly. Under such circumstances a fall of snow on a calm day may be retained almost in its entirety upon this fiat crown of foliage. Should the snow be somewhat wet as it first falls and the temperature drop enough so that the light cover of snow on the tree tops freezes to the branches and foliage, then an exceptionally strong support may be created to hold up the succeeding snowfall. Thus a heavy sheet of wet, partly frozen snow may be laid upon the trees. The usual damage which results from snow, ice and sleet is classified either as snow-break or snow-crushing. In snow-break the stems of single trees are snapped off and branches are broken. Such injury occurs principally with ice and sleet. In climates where winter rainstorms turn into hail and sleet and freeze on the tree all parts of the foliage, branches and trunk may become coated with a film of ice. After such a storm if the weather is calm the coating of ice may melt and serious breakage be avoided. Should the storm be accompanied or followed by a strong wind before melting can take place disastrous breakage of the heavily weighted and rigid, frozen branches and tree trunks results. On the whole, climatic conditions in the eastern United States from the Southern Appalachians northward lead to greater injuries from this source than elsewhere in the United States. Abell (1934) describes this type of injury in the Southern Appalachians and states that it may be expected to occur periodically. Similar damage occurs in other parts of the country. The wounds caused by breakage afford opportunity for the entrance of fungi. A minor form of ice injury is that caused by hail which mechanically wounds tender twigs and makes holes in the foliage. Snow-crushing is caused primarily by the weight of the snow and is exhibited in the bending of single trees, sometimes way down to the ground, and in the distortion of their crowns in slighter cases of injury.

Trees which have been bent by snow but continue to grow develop crooks in the main stem which may ruin them for lumber. Under the most severe conditions entire groups in the stand may be bent out of an upright position and sometimes crushed to the ground by the weight of snow. The bending of the stems is likely to result in loosening or breaking some of the roots. Severe snow-crushing happens most frequently in young stands. Dense stands of tall, slender saplings are fully a~ susceptible to snow injury as patches of reproduction. Snow-break is most common with weak species: Conifers suffer more from snow-crushing and snow- break than hardwoods do, because their foliage is present during the snow season and there is consequently more surface upon which the snow may stick. As information in a forest region builds up with the passage of time, it probably will be found that there are certain spots or zones where climatic conditions are favorable for creating the special conditions likely to lead to extensive snow injury. Other parts of the same forest may be almost exempt from such injury. Calm weather when the snow is falling is an essential for serious snow-crushing, since when the wind blows, the falling snow, even though wet, is carried in larger part through the trees to the ground. Since wind is a factor in preventing overloads of snow on the trees, it follows that the sites most protected from wind are likely to be those which suffer most from snow. Damage from snow-crushing does not necessarily develop immediately after the snowfall. In fact, the snow may lie on the trees for some time before the injury takes place. Ultimately the dead weight itself or the increase of this weight by more snow or added water content or movement of the trees by wind results in crushing the trees. The distribution of the weight on the tree also is of importance. If the tree is symmetrical and the load of snow well distributed, loss may not be suffered, whereas an unsymmetrical tree or one loaded too heavily on one side may be bent by the same weight of snow. Curtis (1936) working in coniferous plantations found that injury from snow affected trees with one-sided crowns more seriously than those of symmetrical form. Arrangement in small age groups is particularly hazardous when snow damage is expected, since the larger trees in the older age groups may shed their load of snow down upon the groups of younger trees beside them, crushing these groups. A sparsely stocked stand of symmetrical trees appears to be the one safest from snow-crushing. In addition to the direct loss from snow-breakage and snow-crushing there is an indirect loss resulting from snow damage due to the opening up of the stand and its partial destruction.

Avalanches

An avalanche is the mass movement of a body of snow motivated by gravity. Where large bodies of snow are involved and the distance traveled by the avalanche is considerable, as down a long slope, serious injury is done to obstacles like a forest stand which may be located in its path. Avalanches when once started may break down and thus destroy the forest through which they pass. They do not start within the properly managed forest, but originate above timberline and on cutover or burned areas. Injury from avalanches is a possibility over only a small fraction of the forest area, which is so situated, on steep mountain slopes, in regions of heavy snowfall and usually adjacent to timberline, as to be threatened by sliding masses of snow from open lands at higher elevations.

3.6.2. Injury by Floods, Erosion, Landslides and Avalanches to Lands outside the Forest

It has already been stated that the forest may be seriously injured and portions even be destroyed by any of these agencies. Hence the forest should be protected against them so far as is practicable. On the other hand, the forest itself has an important part to play in furnishing protection against these agencies to lands and property lying without the forest boundaries, sometimes adjacent thereto and sometimes far distant. The worst effects of floods, erosion, landslides and avalanches are felt outside the forest, either at elevations below the forest zone or on lands which were at one time forested but are now cleared. The agricultural lands and those used for other purposes outside the forest presumably are of greater value than the forest lands. Consequently protection against the effects of water to these lands is more important than the protection of the forest itself. The control of floods, erosion, landslides and avalanches on agricultural, grazing and other types of open land outside the forest is a conservation problem of primary importance but strictly speaking is only indirectly a forest protection problem. Although the forest cannot furnish complete protection from the effects of water to lands outside, yet when properly managed it becomes a most influential agency for this purpose. Adequate forest cover on the headwaters, upper slopes and at critical points on the land of more gentle topography will appreciably lessen the injury which may be caused areas outside the forest through excessive concentration and movement of water. The primary factors responsible for floods and soil movement are abnormally high precipitation and unsatisfactory condition of the land area upon which this precipitation falls. The extent and duration of the precipitation cannot be changed, but it is possible to maintain such a good forest cover that the effects, on lands outside the forest, of floods, erosion, landslides and avalanches are minimized. Lands ruined for agricultural purposes by these natural phenomena can best be made productive again by establishing a forest cover. Hence the forester will often be called upon to reforest lands badly eroded or covered with infertile deposits of rock and soil. The large field covering methods of reclaiming and reforesting areas of this character belongs partly under the subject of artificial reforestation and partly under that of forest protection. It is, in the first place, essentially a technique of reestablishing a forest on lands originally forested. The work is made difficult because of the deteriorated condition of the soil under past abuses and because of the possible continuing action of water and soil movement during the early stages of the reforestation. As soon as the plantation is set out, its preservation lies within the field of forest protection and usually presents a difficult problem for the forester. Indeed, it is on the lands already injured by abnormal movement of water and soil that the greatest need for protecting the forest against floods, erosion, landslides and avalanches exists.

3.6.3. Control Measures

In considering methods of control it must be recognized that occasional violent downpours, either cloudbursts or long periods of heavy rain, are to be expected, and the problem in control is how to take care of this excess precipitation without injury to the forest or to lands outside the forest.

Floods: The most effective method of controlling floods is by the use of engineering works designed for storage of as large volumes of water as there is reason to believe may be accumulated in single floods. The building of such storage reservoirs is justified only for control of floods outside the forest. An exception to this statement does occur in mountainous regions where engineering works of a simple and inexpensive type above the forest zone may be justified in order to maintain the protective value of the forest. The expense of storage reservoirs is very high, and in some parts of the country the topography is such that adequate reservoirs cannot be provided. And even where adequate storage is developed, the fact remains that the forest will be needed for protection to the reservoirs against their being rapidly filled with silt, as well as for direct protection to the lands outside the forest. Ashe (1926) has shown that, where the life of a reservoir can be prolonged by reforesting the water-shed, thereby preventing or lessening the deposits of silt in the reservoir, this should be done. The forest must be kept in the best condition to absorb water. This means that the forest floor should be as sponge-like as possible, not compacted, nor swept bare of its undergrowth by fire or grazing. This will insure the largest possible amount of water absorption and percolation of water into the soil and at the same time will guarantee that what surface runoff does occur, due to excessive amounts of water falling in a short time, will not cause erosion (Meginnis 1932). To be of the greatest service in preventing floods a forest must have plentiful forest litter and ground cover. Prevention of forest fires and either elimination or close regulation of grazing within forests and on open lands above the forest are essential for the maintenance of a forest litter and ground cover adequate to guarantee satisfactory absorption of precipitation (Bailey, Forsling and Becraft 1934) and prevention of rapid surface runoff. On non-forested slopes, even though protected from fire and grazing, in regions where the danger from floods is great it may be necessary in order to prevent rapid surface runoff and erosion to build terrace like trenches and check dams to hold the water long enough for it to sink into the soil (Bailey 1935). Where the surface runoff carries off soil, quantities of silt are brought down into the storage reservoirs and may fill them up within a relatively short space of time. Even where the water is stored in under- ground reservoirs, namely, deep deposits of gravel and rock strata, as in Southern California, the presence of silt in the water is likely to seal the top layers of these storage gravels and prevent adequate percolation of water into the underground storage basins (Cecil 1932). Keeping the water clear of silt is a stronger argument for retaining a forest cover on the watersheds of storage reservoirs than is the argument that immediate surface runoff is lessened, although ordinarily this also results (Morris 1935). On forest lands periodically subject to floods, species capable of with- standing inundation should be grown. Pollarding which keeps the young shoots above the floods is a suitable method of treatment. Selection and coppice with standards, under both of which methods part of the stand always remains on the area, are better suited for application on lands subject to floods than are other reproduction methods. Drainage, where it is practicable, will lessen damage from excessive water in swamps. Although this action will benefit the forest in the swamp the territory downstream may be injured as a result. Natural swamps often make good storage reservoirs, and indeed the region which has a fairly high percentage of swamp land may be immune from dangerous floods. Draining such swamps decreases the storage capacity of the area for flood waters and tends to increase the height of floods lower down the valley.

3.7. Erosion

Erosion is best controlled by never allowing conditions favorable for its start to develop. Once started on a large scale, erosion is difficult and expensive to check, particularly on open lands. To reclaim badly eroded lands the reestablishment of a forest cover ordinarily is required. This may have to be obtained artificially. In the worst instances, as for example on the watersheds of the so-called "torrents" in the European Alps, engineering works such as dams and stone walls must first be employed to check movement of the soil before reforestation can be attempted. In many instances in this country badly eroded, mismanaged, agricultural lands must be afforested. If agricultural lands cannot by correct management be prevented from eroding they should be turned back permanently to forest. The object is to prevent abnormal or accelerated erosion. The slow degradation of the land mass as a natural process will continue, but accelerated sheet erosion and all gully erosion should be prevented. Control of erosion is essentially similar to flood control as both hinge upon preventing rapid surface runoff. To accomplish this the natural sod or herbaceous cover above the forest should be kept in good condition to absorb water and to prevent erosion of soil when surface runoff does occur. Erosion above the forest must be controlled by conservative use of the land, particularly the prevention of fires, and avoidance of overgrazing supplemented by simple engineering works. The engineering works appropriate in the zone above the forest are check dams across stream ways and incipient gullies and narrow terraces in which water may be held, until it can be absorbed into the soil. In the forest itself the most effective control measure against erosion is to maintain a fully stocked forest with an adequate forest floor. This is done by preventing the occurrence of forest fires, eliminating grazing and on critical sites avoiding heavy cuttings of timber which might be likely to tear up the forest floor and scar the ground, thereby encouraging the start of erosion. Proper maintenance of roads and trails is helpful. Roads must be carefully laid out to shed water without erosion and provided with appropriate facilities such as culverts and ditches, paved when necessary to carry off the water. Cuts and fills are particularly likely to erode and must be kept in condition by sodding, planting trees or other plants and by using correct angles of slope and sometimes by cribwork or retaining walls. Kraebel (1936) shows that the relatively straight, low-grade roads with wide curvature needed for modern fast automobile travel are out of place in mountainous regions subject to erosion, because such roads, on account of their immense cuts and fills, afford opportunities for the start of serious erosion. Mountain roads should be built with a mini- mum amount of cut and fill with the use of retaining walls, cribbing, bridges and tunnels if necessary and with careful attention to drainage. Below the forest zone or on open lands originally forested the control of erosion is a separate problem in itself. Bare lands where erosion is starting or has already occurred can best be reclaimed by establishing a new forest. Sometimes immediate planting with suitable tree species will be successful, but frequently on seriously eroded areas some preliminary treatment is necessary before planting can be done. Trees, vines, creeping plants and grasses may be used in planting eroded lands. Trees furnish the best permanent protection, but they cannot always be made to survive until other plants have become established and have stopped the most rapid erosion. The forest, because of its height and density, is a better protective soil cover than herbaceous plants or shrubs. The forest makes a heavier litter on the soil and over long periods of time is a better up builder of the soil than the lesser vegetation. Where gully erosion is actively in progress preparation of the gully before planting ordinarily will be necessary. The heads of actively eroding gullies are the critical points which should be planted first before more land is invaded and ruined by the gully. As described by Meginnis (1933) it is advisable to plow in the upper edges of the gully and catch the fertile topsoil, so distributed, on the slopes or behind wire or brush dams built across the gully. In this way the bad soil conditions of the eroded land are quickly improved and survival of the trees is made possible. In some of the worst cases in gullies or on uplands deeply eroded to the subsoil, where a cover of top soil is not easily provided, it may be necessary to dig holes in the eroded ground large enough for the trees and fill the holes with top soil. Straw, grass or some similar material should be used back of the dams to filter out and hold the silt. Dams should also slope from the ends of the dam toward the center of the gully to prevent water cutting around the ends of the dam.

Experience indicates that only the best grades of nursery stock should be employed for this difficult planting. The planting is relatively costly and is justified not on the basis of the first forest crop which will be produced on the land itself, but rather because this planting will stop further erosion on the area planted and its extension upstream, and prevent injury from deposits of debris on lands further downstream. Engineering works are expensive and should be used in erosion control only to the extent that they are indispensable to supplement the forest, or other plant cover where the forest cannot be grown, or temporarily while a vegetative cover is being established and developed to the point where it will itself prevent erosion. The simple engineering works common in erosion control may be classed as:

(1) Check dams of various types intended to check the velocity of the flowing water. They include brush dams, wire screen dams, wooden dams of logs or planks, crib dams and loose rock, masonry and concrete dams. Brush dams may last only two to three years whereas concrete dams remain useful permanently.

(2) Paving of various types: The principle is to place and maintain a layer of not easily eroded material over critical areas subject to erosion. It is used mostly in stream ways and gullies between check dams or in gullies where there are no check dams. The paving may be made either of brush, staked and wired down, or of loose rock tamped down into the soil or into a grout base. Mulch of straw or grass, placed under the brush, or loose rock pavement may be needed to stop erosion effectively.

(3) Diversion ditches: These are often needed to turn water out of eroding gullies which are being reclaimed. These may also be necessary to afford a permanent outlet for water caught on terraces.

(4) Terraces with retaining walls: On steep slopes above the forest zone it may be necessary to create terraces to check the velocity of the surface runoff and give time for the water to sink in. Stone retaining walls are sometimes needed to maintain these terraces. Best methods of constructing these engineering works vary, depending upon the soil, topography and climatic conditions encountered and the materials available for construction. Details of construction should be worked out locally.

3.8. Landslides

Landslides, as previously stated, are examples of a special type of wholesale erosion. Control measures are needed both above the forest zone and within the forest. Above the forest zone, engineering works of the same character as those used to prevent other types of erosion should be built on all slopes in danger of sliding. Grazing should be prohibited and complete fire protection be secured. Inside the forest zone wherever danger from landslides exists complete fire prevention and elimination of grazing should be the rule. Clear cutting of timber should be avoided, and partial cuttings of the selection type, which always retain a large proportion of the stand, should be employed. It will often be necessary not only to maintain a good soil cover, but also to anchor sheets of soil so that they cannot move. This may be done on loose banks by driving in a series of stakes, preferably of live wood which may sprout, and sometimes connecting these stakes with wire. The tree roots form the best insurance for holding large layers of soil once the forest is established.

3.9. Snow, Ice or Sleet and Avalanches

Control of snow, ice and sleet damage can be secured only through making the individual trees strong and providing room for the snow to fall through to the ground. When snow-damage zones are located, species not easily broken or crushed by snow should be favored and an arrangement of age classes planned which will prevent the dumping of snow on young age groups. Dense, even stocking must be avoided as well as mixtures of species ill suited to resist snow damage. For example, a mixture in which one species outgrows the other usually results in the slow-growing species forming slim stems which are broken or crushed by the snow dropped upon them by the faster-growing species. An ideal mixture for protection against snow is composed of a conifer and a hardwood, the conifer being the faster growing of the two. The conifer sheds its snow upon the hardwood, which species, being without foliage in the winter, allows the snow to fall through to the ground. Skillful thinning is the forester's chief tool for developing strong individuals capable of resisting snow damage. Trees with one-sided crowns should be eliminated from the stand in the thinning unless they are needed in the dominant stand. Curtis (1936) suggests that trees with one-sided crowns should be brought to symmetrical form by artificial pruning and thus be safe-guarded against being bent over by the weight of an unequally distributed load of snow. He also advises that thinning be made after the year's heavy snowfall is completed, so that the remaining trees may have the advantage of a season's growth in this new, more exposed position before being subjected to heavy snowfall. Where snow damage is threatening, thinning of the low thinning type rather than crown thinning may be safer. The subordinate stand maintained in the crown-thinning method is likely to be ruined by the snow sliding down from the trees in the upper canopy. Nothing can be done to prevent the damage caused by sleet storms other than the gradual strengthening of the individual trees by thinning to develop sturdy stems and crowns. Avalanches, or the mass movement of snow on slopes, once started are difficult to stop, hence protective measures should be directed toward preventing their origin. Long grass, ground cover of any kind, brush and reproduction hold the snow and assist in preventing the start of avalanches. Above timberline, protective measures include the encouragement of all woody plant vegetation, the preservation of a grass sod and at the most dangerous points the construction of ditches, walls and fences. Below timberline, protective measures require the maintenance of a protection forest. Munger (1911) mentions four requirements for treatment of such a forest.

(1)Complete fire protection encourages the development of ground cover, underbrush and reproduction.

(2)Exclusion of grazing with the same object in view of keeping the soil densely covered. (3) Careful cutting of timber on steep slopes with a gradient exceeding 50 percent. Single tree selection is the proper method of reproduction to use. Clear cutting should be prohibited.

(4)Prompt reforestation of denuded areas, in order to reestablish forest conditions.

3.10. Wind

Wind affects the forest in a variety of ways but on the whole is injuri- ous. These effects of wind may for our purpose be classified under the following headings: Effects upon the soil; effects upon the forest atmosphere; direct physiological injury to trees; Mechanical injuries. The beneficial influence of wind is found primarily in the dissemination of seed and pollen (Forbes 1925). Natural regeneration relies largely upon wind-borne seed for stocking cutover areas. Another beneficial influence of wind is the mixing of the soil which occurs as a result of large trees being uprooted. Oftentimes the forest litter is buried and mineral soil exposed, which may afford a favorable seedbed for species not then abundant in the stand. Over a long period of time in the virgin forest an appreciable portion of the forest floor may be disturbed in this way. This action is of more significance in affecting soil conditions and the composition of forests in their natural state than in the managed forest. **Effects upon the Soil:** The wind exerts a distinctly injurious influence upon the soil in two ways --first by blowing it away, which is commonly spoken of as wind erosion, and second by its drying effect upon the soil in place. Accelerated air movements increase the evaporation and tend to exhaust soil moisture. The continued drying action of the wind upon the soil interferes with the building up of the better types of humus, is apt to develop instead a tough, peaty acid humus layer, and also curtails the activity of the soil bacteria and fauna necessary for proper functioning of the soil (Fritzsche 1933). Often- times the entire cover of leaves is blown off, leaving the soil bare, and conversely in other spots these leaves are heaped up thickly, with bad results both for regeneration and for condition of the soil. Wind erosion, the other type of wind action on the soil, results in the movement of the soil particles themselves and their removal from their existing position. Fine earth is continually being blown away from exposed portions of the soil in the forest. This occurs especially on the warmer, drier exposures such as southern-facing slopes. In the long run, this removal by the wind of fine particles of soil results in making the soil shallower and less fertile. Since the fertility of the soil determines the productive power of that area for tree growth, any injury to the soil affects unfavorably the growth rate of the forest. Not only are fine earth particles constantly being removed from exposed spots in the forest, but a most striking type of action occurs where the wind blowing over areas outside the forest causes wholesale movement of soil. This is usually discussed under the head of shifting sand dunes, although similar wind action takes place also on areas of finer and better soil types. In general, wind erosion increases as the percentage of sand in the soil rises and is most dangerous in regions where extensive bodies of fine, dry sand occur. Moving sand dunes are capable of burying and destroying entire forests, and conversely the establishment and maintenance of forests upon areas of shifting sands constitute the only method of rendering such areas productive and preventing injury to adjacent property including forests. Wholesale erosion of soil by wind may start even within a forest where mismanagement has destroyed the litter covering the soil. Wind erosion is a potential source of danger to the forest, principally in regions of light sandy soils where the precipitation is relatively scanty during at least part of the year. Soil materials cast up by the sea and not yet clothed with vegetation are particularly susceptible to wind erosion and threaten adjacent forests and property. Mismanaged agricultural lands suffer enormous losses of soil from wind erosion each year, but consideration of this problem, except as the wind-blown soil threatens to overwhelm forests in their paths, is outside the scope of the discussion.

3.10.1. Effects upon the Forest Atmosphere

For perfect functioning of the forest community the air within the forest should be calm, moist and relatively warm. When these conditions prevail excessive evaporation and transpiration are avoided and the humid atmosphere enables the trees to elaborate food materials to greatest advantage. Particularly is the supply of carbon dioxide, so necessary for plant activity, abundantly available. Where wind is admitted into the inner part of the forest this favorable condition is changed. The carbon dioxide is rapidly carried away, and the forest atmosphere may be cooled by the influx of colder air. Thus the warmth secured from the sun's rays and held within the forest may be lost. Or the wind may be excessively hot and dry and then it will raise temperatures too high and decrease moisture within the forest. From whatever angle the subject is approached it remains a fact that the free movement of wind inside the forest affects the forest atmosphere unfavorably and should be pre- vented.

A. **Direct Physiological Injury to Trees**: The physiological effect of the wind is expressed in a variety of ways. It deforms the crown, changes the character of the root system and stunts the height of the stand. Trees along the border of a stand exposed for long periods to strong winds coming from one direction have deformed crowns and root systems especially developed to hold fast against these winds. The strongest will be developed on the leeward side of the tree to furnish resistance to bending (Fritzsche 1933). The height of the trees will be less on the outer exposed edge, and normal heights will be attained only after going 60 to 200 feet inside the border (Munch 1923). Wind action sometimes causes excessive development of the root system at the expense of the growth of the portion above ground. Eccentric and crooked stems frequently result from continuous wind action. Wind often is responsible for the drying out of tops of trees, creating what is known as a stag-headed condition. In fact, much of the injury to trees left isolated on cutover areas and attributed to changed site condition is caused by wind action in drying out the soil and increasing the loss of water from the tree. From the physiological side the wind question is in many instances a water-supply question. The most important injurious physiological effect comes from an increase in the transpiration from leaves and twigs. It is sometimes claimed that a stimulation in growth may result from a reasonable increase in transpiration and that light winds may even be of benefit in this respect. However, strong winds soon raise the rate of transpiration beyond the point most favorable for tree growth. This, combined with the water shortage for the roots, which may be brought about by heightened evaporation from the soil, has serious consequences for the growth and health of the forest. The wind often turns the leaves into positions unfavorable for assimilation. They may also be cooled by the wind, and this results in interference with normal nutrition. Wind movement may cause the closing of the leaf stomata and thereby hinder entrance of carbon dioxide into the leaves. All in all, the wind is of distinct physiological importance in deforming the trees and in reducing the growth of the stand (Barth 1934). These physiological influences of the wind are in progress even with winds of low velocity, but mechanical injuries, often spectacular in nature, occur principally in the occasional windstorms of high velocity. Consequently it is possible that the injury of a physiological character suffered by the forest from wind may be greater than that resulting from breakage and wind-throw. In fact, there are places, usually located near the border line between the forest and other types of vegetation, where wind is a sufficiently critical and powerful enough factor to destroy the forest and replace it permanently with other vegetation unless conservative management, directed especially toward minimizing the influence of wind, is practiced.

B. **Mechanical Injuries**: Strong winds have the power to tear out entire trees by the roots, to overthrow whole stands and to snap in two the trunks of large trees. Where occurring in most violent form, as in the tornadoes of the southern United States and tropic countries, the wind cuts a wide swath throughout the forest, knocking down and breaking all the trees in its path. Complete destruction of the forest may result from such violent storms. Winds of lesser intensity, which do not cause overthrow or breakage, lash the small branches against one another, thereby knocking off an appreciable amount of the foliage and small twigs. Tearing and loosening of the roots are frequent wind injuries. Such injury which is often hard to observe above ground may cause a shortage of water supply for the tree, because the fine roots are broken, and thereby result in a lowering of the vitality and in an increased susceptibility of the tree to injury by insects and fungi. Trees of all ages are uprooted and broken by high winds, but on the whole old timber suffers most. The velocity of the wind is the main factor governing extent of the damage. Low-velocity winds cause practically no mechanical damage. Until velocities in excess of 30 miles per hour are reached little mechanical damage is caused by wind. High winds accompanied by rain or wet snow cause the worse injury. Windfall is most likely to occur in seasons when the soil is saturated with water and consequently the holding power of the roots is least effective. Soil texture also influences windfall since it affects the distribution of the roots. On sandy soils there is practically no wind- fall unless the soil is shallow and underlaid with an impervious stratum. On heavy fine-textured soils windfall is more common. Shallow-rooted species suffer most, and conifers particularly in the winter time are more susceptible to damage than broadleaved trees. Trees in uneven aged stands are less likely to be thrown or broken by the wind than those in even aged stands, since the former are better developed as individuals with lower centers of gravity. A peculiar type of mechanical injury by wind has been reported by Moore (1933) and Day (1934). This consisted in the girdling of recently planted Scotch and Corsican pines (*Pinus sylvestris* and *laricio*) by the action of wind swaying the stems against sharp stones lying in the surface soil. The action of wind is felt in every forest in the America. The amount of damage varies tremendously from place to place. In general, regions of relatively low precipitation and high average wind velocity suffer the greatest injury. Forest regions subject to violent wind storms of high velocity show the greatest damage from mechanical breakage and overthrow of timber. Trees growing in isolated position from early youth develop a proper balance between roots and top and accustom themselves to resist the winds normal to their locality. They are in best position to weather the occasional violent storms safely. Trees which are grown from early youth in closed stands have the least resistance to the winds of normal intensity and may suffer complete destruction when their position in reference to adjacent trees is changed by cutting, or when the occasional violent storm occurs.

3.10.2. Methods of Protection against Wind

Complete prevention of injury from wind is impossible, but the damage during the life of a forest crop can be lessened by correct methods of management. The best protection against injury from wind can be secured only by preventing the entrance of the wind into the forest. This can be accomplished in theory by keeping the edges of stands where they abut on open lands completely clothed with dense foliage from the tops to the ground, and by maintaining all through the forest a dense understory which reaches from the ground to the bottom of the dominant crown level. Such a condition is almost impossible to secure and maintain. An uneven aged forest with the ages arranged by single trees or very small groups also constitutes a wind-resistant forest. The uneven aged forest is less susceptible to wind injuries of both the mechanical and physiological character than the even aged forest. For this reason the former type of forest should be developed and maintained on areas where severe injury from wind is anticipated. The uneven aged forest because of its complete vertical closure reduces wind movement and evaporation inside the stand to a minimum. Sometimes entire abandonment of the even aged form of forest may be undesirable. Possibly adequate protection may be secured by maintaining a relatively narrow border of forest in uneven aged form while the main central area remains even aged. Very rarely can such full protection against wind be obtained or justified when considered in relation to management objectives. If the forest products are to be utilized, cuttings must be made and the forest opened up, and wind will be admitted to a greater or less extent. The practical problem is how to combine the production and utilization of timber crops with reasonable protection against wind, an ever-present enemy of the forest. It should be remembered, however, that the degree of departure from the ideal condition of the stand as regards exclusion of wind will be correlated with a gradual decrease in the growth rate of the stand and an increased liability to excessive mechanical injury from the wind. There are areas so dangerously exposed to injury from wind that on them a forest cover of highly wind-resistant character should be developed and maintained by light cuttings. Many other parts of the forest may be so slightly susceptible to damage by wind owing to favorable climate or other factors that special protection against the injurious effects of wind need receive relatively little consideration. This is true particularly as concerns damage from wind to soil, forest atmosphere and physiologically to trees and to lesser degree as regards breakage and overthrow of trees. Injury from windfall and breakage, though occurring in stands of all ages, is of chief importance in mature timber. Such stands have attained their growth, are ready to harvest and will be cut soon. Young and middle-aged stands, on the other hand, must be tended for many years before the time for harvest, and it is essential that they be protected against the entrance of wind with its serious consequences in reduced growth. Windfall and breakage are less common in these immature stands unless a tornado happens to pass through them. Protection against loss to mature timber from windfall and breakage is needed virtually everywhere. In the utilization of the timber, cuttings must be made and when made are likely to leave exposed the sides of forest stands and allow wind to blow against trees which previously have been sheltered by their neighbors. Cuttings of any kind increase the wind damage and in regions where this is serious must be planned so as to minimize the extent of the injury. It is a fact that serious windfall and breakage occur in forests long under management, as well as in unmanaged forests. This is due partly to bad practices and failure to recognize wind as a sufficiently important potential source of injury and partly to the fact that, in the managed forest, cuttings of mature timber are made each year and hence numerous opportunities for wind-throw and breakage exist on areas in the process of being reproduced. Arrangement of the cutting areas so that they progress against the direction of damaging winds is accepted as one of the first principles of protection for mature timber against mechanical injury from wind. In fact, if this arrangement is accomplished it is likely to be of greater protective value than a resistant border zone, since the entire forest is protected throughout. If successive cuttings are made on the leeward side of the stand and advance into the wind, the cut edges of the stand will not be exposed to direct impact of the wind. The windward side of the stand should be developed as a border zone stocked with wind-resistant trees to act as a buffer for the remainder of the area. A long period of years is required to develop such a border, whether it be a single row of trees or a broad belt. Preferably a belt 50 to 100 feet wide should be developed in exposed situations. The trees in this zone must be developed gradually from early youth by repeated thinning so that they possess exceptionally broad crowns and sturdy stems and are thickly rooted to withstand as individual trees the onslaught of the wind. A dense understory of other vegetation and the retention of branches down to the ground on the border trees will add to the wind-resistant value of the border zone. Heavy thinning particularly of the crown-thinning type started early and repeated often are of use as a wind-protective measure, not only in the border zone but throughout the entire forest area, and constitute one of the most effective means at the disposal of the forester for minimizing losses from windfall and breakage.

Thinning made primarily to develop wind-resistant trees will be heavier than is desirable for most other silvicultural purposes and will tend to develop relatively knotty trees with stocky, fast-tapering stems. If thinning are started early, trees can be made wind resistant to all but storms of the tornado type on practically any situation no matter how exposed. Density of stand and the length of time during which the tree has grown under such conditions of close stocking, rather than the degree of exposure of the site, are the determining factors in its ability to resist mechanical injury from wind. Mixed stands in which resistant and non-resistant species are combined will suffer less damage than pure stands of sensitive species. When a species is in itself strong and wind resistant it may be grown in pure stands, but, to grow successfully those species which are easily wind injured, mixed stands must be created and maintained. In managing stands on wind-swept areas some forms of clear cutting or of the strip type of reproduction are often the only methods of regeneration which are possible. This is especially true where the forest is made up of fully stocked even aged stands which have in the past been thinned lightly or not at all. Even aged stands which have been thinned heavily, and several times, may be sufficiently resistant to admit of other reproduction methods than clear cutting. The shelterwood method is likely to heighten the storm damage and is applicable only locally in the best-protected places and in mixed stands. The seed-tree method should not be employed with shallow-rooted species or on areas subject to wind throw. Selection offers the best protection, but is possible of application only if the stands are truly un- even aged or have been so managed from an early age as to make the individual trees wind firm; otherwise selection cuttings may expose the stand to great damage. Cutting in narrow clear-felled strips has advantages from the standpoint of protection against wind as well as other desirable features silviculturally and will be used in many in- stances as forests come under management. Since old timber is more subject to wind-throw than younger stands, shortening the rotation will have the effect of eliminating the serious losses of this character which occur today in areas of virgin timber. Wholesale windfall and break- age in the path of violent storms and tornadoes can never be prevented in stands of any age, irrespective of composition or treatment, although the extent of the loss may be mitigated.

a. **Control of Wind Erosion:** The problem of erosion by wind like that of water erosion has two phases: **first**, the protection of the forest against injury caused by erosion of soil, starting either on areas within the forest or on lands outside and moving into the forest; and **second**, the reclamation of lands ruined by wind erosion. The former is a forest protection problem; the latter is in the field of artificial establishment of forests. Reclamation ordinarily involves the establishment of a vegetative cover, sometimes grasses and shrubs at first but usually ultimately forest trees. In guarding against the start of wind erosion within the forest itself the important principle is to preserve intact the humus, litter and ground cover making up the forest floor. Where this is done the wind has no opportunity to blow away any of the soil. In forests where soil and climate are potentially favorable for the start of wind erosion any little exposure of the soil may be enough to encourage the start of erosion, and a blow hole once started is rapidly enlarged by the wind. Exclusion of the wind from the forest by means of a dense wall of foliage down to the ground and by a thick understory will of course prove effective in preventing erosion without further attention. Wherever the forest has been opened by cuttings, there it becomes important to preserve the floor forest intact if wind erosion threatens. In some regions grazing of domestic animals may be a cause leading to wind erosion. Animals should be excluded or closely regulated to prevent overgrazing. Forest fires should be prevented on all areas liable to injury from wind erosion. Provided that the forest floor is unbroken and reproduction starts promptly on the cutover area, practically any system of cutting may be allowed so far as the danger of wind erosion is concerned. This is evident from experience in the maritime pine region of France, where thousands of acres of sandy soils susceptible to wind erosion have been reclaimed and are managed under a clear cutting method. Shifting sands whose movement originates outside the forest may advance into and destroy a forest, even one which is kept in perfect condition to prevent the start of wind erosion. Once in motion, advancing sand dunes threaten to destroy any forest in their path and can be checked only by establishing and maintaining a vegetative cover upon the wind-blown soil.

Hence for the protection of the forest itself those areas which adjoin it, where the wind is actively eroding the soil, must be reclaimed. Eventually a forest should be developed and permanent control of further movement of sand be sought through maintenance of a thick forest floor. Any disturbance of the forest floor which exposes the mineral soil such as the ruts in a forest road, forest fires or grazing may lead to movement of the soil and ultimate destruction of the forest. Methods of stopping the movement of shifting sands form a special subject in itself to which full consideration cannot be given here. In general, seeding or planting must be undertaken, sometimes supplemented at the worst spots by fences of various types to catch and hold the soil temporarily until a cover of vegetation is established. Lesser forms of vegetation such as grasses may have to be established at first to check temporarily the blowing of the soil, although recent practice appears to indicate that, at least for sand dunes away from the sea, trees may be immediately established with the assistance of a dead brush cover. For example, it has been possible to establish the permanent trees without first obtaining a cover of lesser vegetation. Kroodsma (1937) was successful in developing methods for stopping the movement of sand dunes in Michigan. He states that sand dunes in Michigan move at the rate of 11/2 to 2 feet per year. His methods are summarized in the following paragraphs. An essential step is the spreading of a brush cover laid at right angles to the wind direction over the area on which the soil is to be fixed. This may be done before or just after the trees are planted. Hardwoods are usually planted first, and later conifers can be introduced in spaces left for the purpose. The hardwoods serve as protective cover for the conifers until they become established. The trees considered best for sand-dune planting are black locust, Carolina poplar or cottonwood among the hardwoods, and ponderosa, Scotch, Norway and jack pines. Stock big enough so that it is not covered by blowing sand the first year should be used. This means about 18-inch 1-0 seedlings or cuttings for hardwoods and 2-1 or 3-0 stock for conifers. After the planting is completed and the brush cover laid, sowing of rye in the following fall is advised to furnish a winter mulch. This sowing may be repeated in several succeeding years if needed to prevent soil movement.

The smoke and poisonous gases cast into the atmosphere by industrial plants, railroad locomotives and other sources pollute the atmosphere and injure forest vegetation. Smoke is variable in character, but ordinarily in addition to the soot it contains other materials and is always accompanied by various gases. These gases frequently contain free acids and have a poisoning effect which may even result in killing the entire tree. Those industrial plants where smelting of metals is carried on are the most dangerous type as regards their emission of smoke and gases. The most dangerous gases commonly contained in smoke are those containing sulphur such as sulphur dioxide (SO_2). Sulphur dioxide in very small quantities is sufficient to kill vegetation. Illuminating gas also contains poisonous compounds, but is of little importance as a source of injury to forest trees, although it is a common cause of the death of shade trees in towns and cities growing near gas mains. Another poisonous element is the arsenic which is often emitted in smelter fumes. Even though this arsenic, deposited externally, may not damage the timber, it may be deposited in sufficient quantity on forage so as to poison grazing animals. Injury is caused the forest in a variety of ways. The soot, dust and other impurities settling from the smoke may form a coating over vegetation. Such deposits not only block up the stomata, thus impeding transpiration and absorption of carbon dioxide, but also, by covering the leaves, reduce the intensity of the sunlight as it affects the trees and thus interfere with photosynthesis (Bakke 1913). The deposits may contain substances which are directly injurious to the leaves through corroding or toxic action. The effects of injury by smoke and its accompanying poisonous gases will usually be noted, first, through the discoloration of foliage, later by defoliation and eventually by the death of injured portions or of the entire tree. Where the injury is not serious enough to kill the tree, there will at least be a decided slowing up in the growth rate of forest trees subjected to continuous exposure to smoke and gases. Fortunately most forest areas are not exposed constantly to large volumes of smoke with their poisonous fumes. It is only in the neighborhood of occasional smelters that the damage becomes extreme. The intensity of the attack depends primarily upon the concentration of the poisonous gas and the distance from the smokestack, modified, how- ever, by wind direction and topography. The worst injury is concentrated in the vicinity of smelters such as the one maintained by the Anaconda Copper Company at Anaconda, Montana. In the vicinity of plants of this type forest vegetation unless located in areas sheltered from the smoke stream may be destroyed for miles around the plant. In the neighborhood of the smelter at Anaconda, Mason (1915) states that destruction of lodge pole pine forests occurred in some places 9 miles distant from the smelter and that slight damage was experienced at distances of 30 miles. Conifers suffer more severely than broad-leaved trees, primarily because they retain foliage for more than one year. The older foliage on the conifers, having been affected longer by the poisonous fumes, is likely to show more severe injury than foliage of the current year's growth. Prevention of injury to forest trees from smoke and poisonous gases must come through treatment of the smoke before it leaves the stack. The matter of controlling the emission of poisonous gases and smoke from industrial plants has been investigated quite thoroughly, both by men in this country and by workers abroad, because of the injuries suffered by vegetation in cities and towns and because of the deleterious effect which smoke and its attendant fumes have upon human health. It is now known that the pollution of the atmosphere by the emission of smoke and poisonous gases can be prevented, in entirely practicable ways, by scientific construction and skillful operation of the industrial plants. There is no longer any adequate excuse for the continuation of this type of injury to forest vegetation. The most serious cases of extensive injury to the forests in this country from smoke and poisonous gases occurred several decades ago. Today enlightened sentiment and improved practice, which recovers by-products from the poisonous elements in the smoke stream, should result in preventing further serious losses. Different species of trees show differing degrees of susceptibility to injury from smoke and poisonous gases. In planting areas subject to smoke streams, species of known resistance to such types of injury should be chosen. As yet this information is available to only limited extent. Mason (1915) arranged the Rocky Mountain species occurring in Montana in the following order of susceptibility, the first being the most susceptible: alpine fir (*Abies lasciocarpa*), Douglas fir (*Pseudo-suga taxifolia*), lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea Enqelmanni*),juniper and limber pine (*Pinus* *flexilis*). Since complete elimination of the smoke and gas nuisance should be secured in the manner already described, there should be little if any occasion for restricting forest planting to species non-susceptible to smoke and gas injury.

b. Lightning is a widespread source of injury to forest trees. Trees are excellent conductors for electrical discharges between the clouds and the earth and are frequently struck by lightning. Evidences of lightning injury can be seen in practically within the forests and it varies widely in character. A common type of injury is evidenced by a furrow running down the tree, often from the top to the ground, in which the wood has been splintered and the bark blown off. Sometimes the tree is completely blown to pieces, splinters of wood being scattered for a hundred or more feet in all directions around the tree. In other trees the injury appears to be simply the loss of a strip of bark with minor injury to the tissues immediately beneath the bark. However, such wounds may serve to encourage attack by insects and fungi. Plummer (1912) considers the bolts of lightning which pass upward through trees from the ground to the clouds as particularly explosive in action. Trees may also be killed outright by lightning, which apparently spreads over the entire trunk of the tree, but without causing any splintering or mechanical injury to the stem. This type of injury is not as commonly found in forest trees as the furrowing of the bark and shattering of the wood are. <u>There is no practical method of preventing lightning injury to forest trees</u>. On the whole, the amount of loss suffered from this cause is relatively small, although individual trees injured by lightning can be found scattered through the forest in almost all regions. Lightning causes much more serious damage to the forest indirectly through starting forest fires than it does through direct injury in striking individual trees.

Summary

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Unit 4: Protection against Atmospheric Agencies II

Unit Structure

4.0 Learning Objectives

After going through this unit you shall be able to:

- Know the various atmospheric agencies that harm the forests
- Damage caused by violent rainfall
- Damage caused by floods, frozen water and landslides.
- Control measures for floods violent rainfall, erosion and rainfall.

4.1 Introduction

Precipitation is the process where the local air becomes saturated with vapor and it starts to pour as it no longer can maintain the water vapor in the gaseous form. There are various types of precipitation – Liquid, Freezing, and Frozen. Rainfall can be defined as the precipitation in the liquid form.

4.2 Rainfall

Rainfall is the amount of precipitation, in the form of rain (water from clouds), that descends onto the surface of Earth, whether it is on land or water. It develops when air masses travel over warm water bodies or over wet land surfaces. Atmospheric turbulence and convection carries the moisture, or water vapor, upward into air masses where they form clouds. The clouds eventually release this water vapor, which is dropped as rainfall. Rainfall has been classified into three main types based on the origin:

Convectional Rainfall:

- The air on getting heated becomes light and rises in convection currents.
- As the air rises, it expands and drops the temperature and subsequently, condensation takes place and cumulus clouds are formed.
- Heavy rainfall with lightning and thunder takes place which does not last long.
- Such rain is usually in the summer or the hotter part of the day.
- This type of rainfall generally takes place in the equatorial regions and internal parts of the continents, predominantly in the northern hemisphere.

Orographic Rainfall:

- When the saturated air mass comes across a mountain, it is forced to rise.
- The rising air expands, eventually, the temperature falls, and the moisture gets condensed.
- The principal characteristic of this type of rain is that the windward slopes get more rainfall.
- After giving rain on the windward side, when these winds reach the other slope, they drop away, and their temperature increases. Then their ability to take in moisture increases and hence, these leeward slopes remain dry and rainless.
- The region situated on the leeward side is known as the rain-shadow area.

Cyclonic Rainfall:

- Cyclonic activity causes cyclonic rain and it occurs along the fronts of the cyclone.
- When two masses of air of unlike density, temperature, and humidity meet then it is formed.
- The layer that separates them is known as the front.
- A warm front and the cold front are the two parts of the front.
- At the warm front, the warm lighter wind increases slightly over the heavier cold air.

- As the warm air rises, it cools, and the moisture present in it condenses to form clouds
- This rain falls gradually for a few hours to a few days.

On the basis of Intensity

1. Light rain – Rate of rain varies between 0 to 2.5 millimeters
2. Moderate rain – Rate of rain varies between 2.6 millimeters to 7.6 millimeters
3. Heavy rain – Rate of rain is beyond 7.6 millimeters

4.2.1 Water in excess

Under this subject is included the injurious influence which water in excessive quantities exerts on the forest. The influence of water on the forest is beneficial when present in proper amount. Water is an indispensable element for tree growth and is one of the most important factors in determining the productiveness of the forest site. The harmful effects of water come entirely through an abnormal supply: either there is a deficiency, when injury to the forest results from lack of water (this effect is termed drought and has been covered in a previous section); or there is an excessive amount of water, which is the condition here discussed. Injury from excessive supplies of water will be considered under the following headings:

A. Violent rainfall
B. Floods
C. Erosion (so far as caused by water)
D. Landslides
E. Frozen water in the form of snow, ice or sleet and avalanches.

4.2.1.1 Violent Rainfall

Nature provides precipitation at irregular intervals and frequently supplies it for short periods of time in the form of heavy downpours. Violent rainfall in the act of falling may tear or strip off the tender foliage of trees. However, precipitation itself is rarely so violent as to cause serious mechanical injury of this type. Usually injury from violent precipitation is caused not by the falling of the rain alone, but by the action of wind which is primarily responsible for the injury.

4.2.1.2 Floods

The greatest damage to the forest from water in excessive supply occurs after the water reaches the ground and is made possible by factors which allow and encourage its collection in large volume. Water so collected is designated as a flood. Not every violent rain- storm necessarily results in a flood. The forest floor and soil may be so porous as to absorb all the precipitation as it reaches the ground, thus preventing abnormal surface runoff which is the necessary forerunner of a flood. Storms of exceptional length, or a series of less severe storms or a single cloudburst, may overtax even a dense forest, with the most efficient litter and soil for hastening percolation, so that abundant surface runoff occurs and a flood results. This was the situation in the Vermont flood of 1927. Unfortunately a large share of the precipitation in most forest regions falls on land put to other uses than forest, or upon forest areas not fully effective as stores of water, and consequently heavy surface runoff is the rule and floods of greater or less volume are of frequent occurrence. So far as the forest itself is concerned the damage from floods which originate within forested areas is not of serious injury to these forests unless they have been badly managed. The principal flood damage to forests occurs in forests lying not on the headwaters of streams but on areas farther downstream and especially on watersheds which are to an appreciable extent non-forested on portions of their upstream areas. Ordinarily a flood to cause severe injury to the forest must arise on the watershed above the forest and then sweep down through the forest. The damage to the forest which floods cause is of varied character. Where the movement of water is violent young plants may be destroyed, trees may be torn out by their roots or broken off and they may be wounded by the impact of ice, stones and other materials borne along by the flood. Soil in which the trees grow may be washed away, or conversely, in lowlands where the movement of the water is slow, deposits of soil, rock and debris of various kinds may be spread over the forest floor. Where such deposits are thin and made up of fertile soil of fine texture this effect of the flood may be beneficial. Where coarse material is deposited and the layers are deep the effect is distinctly harmful. One of the most characteristic and most disastrous effects of floods is the erosion of soil. Indeed, it is practically impossible to separate the effects of floods and of erosion. Erosion caused by floods may entirely destroy a forest by carrying away the soil in which the tree anchors its roots and from which its supply of food is obtained. Another type of flood injury occurs on low-lying level lands where flood water ultimately collects and stands for appreciable periods of time at depths covering the root systems of trees. Under such circumstances the trees may be killed through lack of aeration. Swamp lands, as the name implies, are areas which have poor facilities for shedding water and which consequently have an excess of water either permanently or throughout an important part of the year. Floods add to the amount of water standing in swamps and thereby increase the damage suffered by swamp forests. Swamp forests are hindered in growth oftentimes to such an extent that only a stunted forest can be grown. The trees are relatively unhealthy and are constantly exposed to danger from wind throw, owing to the wetness of the soil and the shallowness of the soil layer in which they can develop a root system. Tree roots are most abundant in the zone of soil lying above the level at which water stands during the growing season.

4.2.1.3 Erosion

Erosion is a natural process which has been in operation throughout the past and will continue to operate in the future. The wearing down of land masses by the action of water cannot be pre- vented. Erosion may be either normal or abnormal. Normal erosion is a gradual wearing a way of land surfaces which, although continually in progress, does not seriously affect the use of the land and its productive value until the vegetative cover is broken. Abnormal erosion is an accelerated type which erodes the land surface so fast as to destroy the productive capacity of the soil. It may occur either in the form of sheet or gully erosion. In sheet erosion thin layers of the topsoil are washed away, this process being repeated with each storm until eventually all the fertile soil is removed and unproductive subsoil is exposed. Sheet erosion because the general contour of the surface remains unchanged is frequently overlooked until the land is well on its way to destruction. **Gully erosion** --- more spectacular than sheet erosion --- cuts gullies into the land surface and is evident as soon as it starts. Once under way this type of erosion destroys the land with startling rapidity. Erosion not only ruins the land from which the material is removed but also may destroy the value of other lands by depositing upon them the eroded material. Such deposits are harmful when the material is of coarse texture and sterile nature, but when silt and other fertile soil material is laid down the lands covered may be benefited as in the case of many river bottoms. However, the occasional beneficial effects of erosion are more than counterbalanced by the injury to the lands from which the eroded material came. Erosion varies greatly in character in different parts of the country. The geological formation, particularly the gradient of the land uplift, is a factor influencing erosion. Precipitation itself is a primary factor since water, along with gravity, furnishes the motive power for moving the soil. Severe erosion may occur in relatively level regions which have heavy precipitation and susceptible soils. Soil formation and texture are important factors in determining the extent and amount of erosion. Heavy clays are resistant to erosion, owing to the strong cohesion between soil particles. Coarse sands and gravel are relatively resistant because of the speed with which water percolates through such material. The soils most susceptible to erosion stand midway between these extremes and are of a loamy or silty character. Erosion cannot start in a properly managed forest. It may start in an altitudinal zone above the forest, or in exposed spots within the forest zone such as bare openings and road cuts, or it may start below the forest and work back into it. Although erosion does not start in the well-managed forest, yet there are many ways in which it may start in the forest provided the management is not perfect. Such factors as fire, lumbering, the grazing of livestock, poisonous gases which kill vegetation, agricultural use, rights-of-way for highways, railroad and other transportation lines, all furnish opportunities for erosion starting within or close to the forest. From these starting points, injury to adjoining pieces of well-managed forest may result. It is erosion accelerated beyond the normal rate by such artificial factors as those just named which is responsible for the serious phases of the erosion problem.

4.2.1.4 Landslides

Landslides are a special form of erosion. They are mass movements of soil sliding as a unit rather than the movement of soil as individual particles in a stream or sheet of water. Landslides are caused by masses of soil becoming filled with water or waterlogged. If such portions of soil are located on level land, the excess water simply turns the area into a swamp and no landslide results. Where soil on slopes becomes filled with water, the entire saturated body of soil is likely to slip down to a lower level. Landslides are particularly apt to occur where some stratum either of impermeable soil or rock lies parallel to the slope and prevents deeper entrance of water into the ground. It is easy for the soil above such a stratum to slide downward when saturated with water. Not only the soil but the forest along with it is carried down, leaving a bare exposed slope. The forest in the path of a landslide is destroyed. Either the trees slide with the mass of sojl or if the roots are anchored in firmer unsat- urated strata the landslide passes through and over the forest, smashing the trees and burying the ground under deposits of rock, soil and debris. Injury from landslides may be expected in mountainous regions having abundant rainfall. The area affected by a landslide ordinarily is a long narrow strip running from the top to the bottom of a steep slope.

4.2.1.5 Frozen Water: Snow, Ice or Sleet

In cold climates a portion of the precipitation comes in the form of frozen water, or freezes after it reaches the trees or ground. Under certain circumstances this frozen precipitation may cause serious damage to the forest. The injury results primarily from the weight of the frozen precipitation upon the trees. Snow has a beneficial influence in that it covers the ground like a blanket and prevents deep freezing of the soil as well as the heaving of small plants which often occurs on exposed soil. The snow blanket also assists in lessening injury to reproduction at the time of logging. Since the blanket of snow retards or prevents freezing of the soil, it facilitates percolation of water into the soil. Indeed, as the snow melts on top of the ground the snow water may enter the unfrozen soil. On the whole, the beneficial influence of snow outweighs the damage caused. Snow is particularly injurious under circumstances which cause it to fall in a moist, sticky condition so that it is caught in large proportion upon the trees. A snowstorm of dry, finely divided particles, sifts down through the trees and little is retained on them. The greatest likelihood that a large part of the snowfall will be held on the trees is found in dense stands of conifers where all the crowns are approximately the same height and the branches interlace strongly. Under such circumstances a fall of snow on a calm day may be retained almost in its entirety upon this fiat crown of foliage. Should the snow be somewhat wet as it first falls and the temperature drop enough so that the light cover of snow on the tree tops freezes to the branches and foliage, then an exceptionally strong support may be created to hold up the succeeding snowfall. Thus a heavy sheet of wet, partly frozen snow may be laid upon the trees. The usual damage which results from snow, ice and sleet is classified either as snow-break or snow-crushing. In snow-break the stems of single trees are snapped off and branches are broken. Such injury occurs principally with ice and sleet. In climates where winter rainstorms turn into hail and sleet and freeze on the tree all parts of the foliage, branches and trunk may become coated with a film of ice. After such a storm if the weather is calm the coating of ice may melt and serious breakage be avoided. Should the storm be accompanied or followed by a strong wind before melting can take place disastrous breakage of the heavily weighted and rigid, frozen branches and tree trunks results. On the whole, climatic conditions in the eastern United States from the Southern Appalachians northward lead to greater injuries from this source than elsewhere in the United States. Abell (1934) describes this type of injury in the Southern Appalachians and states that it may be expected to occur periodically. Similar damage occurs in other parts of the country. The wounds caused by breakage afford opportunity for the entrance of fungi. A minor form of ice injury is that caused by hail which mechanically wounds tender twigs and makes holes in the foliage. Snow-crushing is caused primarily by the weight of the snow and is exhibited in the bending of single trees, sometimes way down to the ground, and in the distortion of their crowns in slighter cases of injury.

Trees which have been bent by snow but continue to grow develop crooks in the main stem which may ruin them for lumber. Under the most severe conditions entire groups in the stand may be bent out of an upright position and sometimes crushed to the ground by the weight of snow. The bending of the stems is likely to result in loosening or breaking some of the roots. Severe snow-crushing happens most frequently in young stands. Dense stands of tall, slender saplings are fully a~ susceptible to snow injury as patches of reproduction. Snow-break is most common with weak species: Conifers suffer more from snow-crushing and snow- break than hardwoods do, because their foliage is present during the snow season and there is consequently more surface upon which the snow may stick. As information in a forest region builds up with the passage of time, it probably will be found that there are certain spots or zones where climatic conditions are favorable for creating the special conditions likely to lead to extensive snow injury. Other parts of the same forest may be almost exempt from such injury. Calm weather when the snow is falling is an essential for serious snow-crushing, since when the wind blows, the falling snow, even though wet, is carried in larger part through the trees to the ground. Since wind is a factor in preventing overloads of snow on the trees, it follows that the sites most protected from wind are likely to be those which suffer most from snow. Damage from snow-crushing does not necessarily develop immediately after the snowfall. In fact, the snow may lie on the trees for some time before the injury takes place. Ultimately the dead weight itself or the increase of this weight by more snow or added water content or movement of the trees by wind results in crushing the trees. The distribution of the weight on the tree also is of importance. If the tree is symmetrical and the load of snow well distributed, loss may not be suffered, whereas an unsymmetrical tree or one loaded too heavily on one side may be bent by the same weight of snow. Curtis (1936) working in coniferous plantations found that injury from snow affected trees with one-sided crowns more seriously than those of symmetrical form. Arrangement in small age groups is particularly hazardous when snow damage is expected, since the larger trees in the older age groups may shed their load of snow down upon the groups of younger trees beside them, crushing these groups. A sparsely stocked stand of symmetrical trees appears to be the one safest from snow-crushing. In addition to the direct loss from snow-breakage and snow-crushing there is an indirect loss resulting from snow damage due to the opening up of the stand and its partial destruction.

4.2.1.6 Avalanches

An avalanche is the mass movement of a body of snow motivated by gravity. Where large bodies of snow are involved and the distance traveled by the avalanche is considerable, as down a long slope, serious injury is done to obstacles like a forest stand which may be located in its path. Avalanches when once started may break down and thus destroy the forest through which they pass. They do not start within the properly managed forest, but originate above timberline and on cutover or burned areas. Injury from avalanches is a possibility over only a small fraction of the forest area, which is so situated, on steep mountain slopes, in regions of heavy snowfall and usually adjacent to timberline, as to be threatened by sliding masses of snow from open lands at higher elevations.

4.2.2 Injury by Floods, Erosion, Landslides and Avalanches to Lands outside the Forest

It has already been stated that the forest may be seriously injured and portions even be destroyed by any of these agencies. Hence the forest should be protected against them so far as is practicable. On the other hand, the forest itself has an important part to play in furnishing protection against these agencies to lands and property lying without the forest boundaries, sometimes adjacent thereto and sometimes far distant. The worst effects of floods, erosion, landslides and avalanches are felt outside the forest, either at elevations below the forest zone or on lands which were at one time forested but are now cleared. The agricultural lands and those used for other purposes outside the forest presumably are of greater value than the forest lands. Consequently protection against the effects of water to these lands is more important than the protection of the forest itself. The control of floods, erosion, landslides and avalanches on agricultural, grazing and other types of open land outside the forest is a conservation problem of primary importance but strictly speaking is only indirectly a forest protection problem. Although the forest cannot furnish complete protection from the effects of water to lands outside, yet when properly managed it becomes a most influential agency for this purpose. Adequate forest cover on the headwaters, upper slopes and at critical points on the land of more gentle topography will appre- ciably lessens the injury which may be caused areas outside the forest through excessive concentration and movement of water. The primary factors responsible for floods and soil movement are abnormally high precipitation and unsatisfactory condition of the land area upon which this precipitation falls. The extent and duration of the precipitation cannot be changed, but it is possible to maintain such a good forest cover that the effects, on lands outside the forest, of floods, erosion, landslides and avalanches are minimized. Lands ruined for agricultural purposes by these natural phenomena can best be made productive again by establishing a forest cover. Hence the forester will often be called upon to reforest lands badly eroded or covered with infertile deposits of rock and soil. The large field covering methods of reclaiming and reforesting areas of this character belongs partly under the subject of artificial reforestation and partly under that of forest protection. It is, in the first place, essentially a technique of reestablishing a forest on lands originally forested. The work is made difficult because of the deteriorated condition of the soil under past abuses and because of the possible continuing action of water and soil movement during the early stages of the reforestation. As soon as the plantation is set out, its preservation lies within the field of forest protection and usually presents a difficult problem for the forester. Indeed, it is on the lands already injured by abnormal movement of water and soil that the greatest need for protecting the forest against floods, erosion, landslides and avalanches exists.

4.2.3. Control Measures

In considering methods of control it must be recognized that occasional violent downpours, either cloudbursts or long periods of heavy rain, are to be expected, and the problem in control is how to take care of this excess precipitation without injury to the forest or to lands outside the forest.

4.2.3.1 Floods

The most effective method of controlling floods is by the use of engineering works designed for storage of as large volumes of water as there is reason to believe may be accumulated in single floods. The building of such storage reservoirs is justified only for control of floods outside the forest. An exception to this statement does occur in mountainous regions where engineering works of a simple and inexpensive type above the forest zone may be justified in order to maintain the protective value of the forest. The expense of storage reservoirs is very high, and in some parts of the country the topography is such that adequate reservoirs cannot be provided. And even where adequate storage is developed, the fact remains that the forest will be needed for protection to the reservoirs against their being rapidly filled with silt, as well as for direct protection to the lands outside the forest. Ashe (1926) has shown that, where the life of a reservoir can be prolonged by reforesting the water- shed, thereby preventing or lessening the deposits of silt in the reservoir, this should be done. The forest must be kept in the best condition to absorb water. This means that the forest floor should be as sponge-like as possible, not compacted, nor swept bare of its undergrowth by fire or grazing. This will insure the largest possible amount of water absorption and percolation of water into the soil and at the same time will guarantee that what surface runoff does occur, due to excessive amounts of water falling in a short time, will not cause erosion (Meginnis 1932). To be of the greatest service in preventing floods a forest must have plentiful forest litter and ground cover. Prevention of forest fires and either elimination or close regulation of grazing within forests and on open lands above the forest are essential for the maintenance of a forest litter and ground cover adequate to guarantee satisfactory absorption of precipitation (Bailey, Forsling and Becraft 1934) and prevention of rapid surface runoff. On non-forested slopes, even though protected from fire and grazing, in regions where the danger from floods is great it may be necessary in order to prevent rapid surface runoff and erosion to build terrace like trenches and check dams to hold the water long enough for it to sink into the soil (Bailey 1935). Where the surface runoff carries off soil, quantities of silt are brought down into the storage reservoirs and may fill them up within a relatively short space of time. Even where the water is stored in under- ground reservoirs, namely, deep deposits of gravel and rock strata, as in Southern California, the presence of silt in the water is likely to seal the top layers of these storage gravels and prevent adequate percolation of water into the underground storage basins (Cecil 1932). Keeping the water clear of silt is a stronger argument for retaining a forest cover on the watersheds of storage reservoirs than is the argument that immediate surface runoff is lessened, although ordinarily this also results (Morris 1935). On forest lands periodically subject to floods, species capable of with- standing inundation should be grown. Pollarding which keeps the young shoots above the floods is a suitable method of treatment. Selection and coppice with standards, under both of which methods part of the stand always remains on the area, are better suited for application on lands subject to floods than are other reproduction methods. Drainage, where it is practicable, will lessen damage from excessive water in swamps. Although this action will benefit the forest in the swamp the territory downstream may be injured as a result. Natural swamps often make good storage reservoirs, and indeed the region which has a fairly high percentage of swamp land may be immune from dangerous floods. Draining such swamps decreases the storage capacity of the area for flood waters and tends to increase the height of floods lower down the valley.

4.2.3.2 Erosion

Erosion is best controlled by never allowing conditions favorable for its start to develop. Once started on a large scale, erosion is difficult and expensive to check, particularly on open lands. To reclaim badly eroded lands the reestablishment of a forest cover ordinarily is required. This may have to be obtained artificially. In the worst instances, as for example on the watersheds of the so-called "torrents" in the European Alps, engineering works such as dams and stone walls must first be employed to check movement of the soil before reforestation can be attempted. In many instances in this country badly eroded, mismanaged, agricultural lands must be afforested. If agricultural lands cannot by correct management be prevented from eroding they should be turned back permanently to forest. The object is to prevent abnormal or accelerated erosion. The slow degradation of the land mass as a natural process will continue, but accelerated sheet erosion and all gully erosion should be prevented. Control of erosion is essentially similar to flood control as both hinge upon preventing rapid surface runoff. To accomplish this the natural sod or herbaceous cover above the forest should be kept in good condition to absorb water and to prevent erosion of soil when surface runoff does occur. Erosion above the forest must be controlled by conservative use of the land, particularly the prevention of fires, and avoidance of overgrazing supplemented by simple engineering works. The engineering works appropriate in the zone above the forest are check dams across streamways and incipient gullies and narrow terraces in which water may be held, until it can be absorbed into the soil. In the forest itself the most effective control measure against erosion is to maintain a fully stocked forest with an adequate forest floor. This is done by preventing the occurrence of forest fires, eliminating grazing and on critical sites avoiding heavy cuttings of timber which might be likely to tear up the forest floor and scar the ground, thereby encouraging the start of erosion. Proper maintenance of roads and trails is helpful. Roads must be carefully laid out to shed water without erosion and provided with appropriate facilities such as culverts and ditches, paved when necessary to carry off the water. Cuts and fills are particularly likely to erode and must be kept in condition by sodding, planting trees or other plants and by using correct angles of slope and sometimes by cribwork or retaining walls. Kraebel (1936) shows that the relatively straight, low-grade roads with wide curvature needed for modern fast automobile travel are out of place in mountainous regions subject to erosion, because such roads, on account of their immense cuts and fills, afford opportunities for the start of serious erosion. Mountain roads should be built with a mini- mum amount of cut and fill with the use of retaining walls, cribbing, bridges and tunnels if necessary and with careful attention to drainage. Below the forest zone or on open lands originally forested the control of erosion is a separate problem in itself. Bare lands where erosion is starting or has already occurred can best be reclaimed by establishing a new forest. Sometimes immediate planting with suitable tree species will be successful, but frequently on seriously eroded areas some preliminary treatment is necessary before planting can be done. Trees, vines, creeping plants and grasses may be used in planting eroded lands. Trees furnish the best permanent protection, but they cannot always be made to survive until other plants have become established and have stopped the most rapid erosion. The forest, because of its height and density, is a better protective soil cover than herbaceous plants or shrubs. The forest makes a heavier litter on the soil and over long periods of time is a better upbuilder of the soil than the lesser vegetation. Where gully erosion is actively in progress preparation of the gully before planting ordinarily will be necessary. The heads of actively eroding gullies are the critical points which should be planted first before more land is invaded and ruined by the gully. As described by Meginnis (1933) it is advisable to plow in the upper edges of the gully and catch the fertile topsoil, so distributed, on the slopes or behind wire or brush dams built across the gully. In this way the bad soil conditions of the eroded land are quickly improved and survival of the trees is made possible. In some of the worst cases in gullies or on uplands deeply eroded to the subsoil, where a cover of top soil is not easily provided, it may be necessary to dig holes in the eroded ground large enough for the trees and fill the holes with top soil. Straw, grass or some similar material should be used back of the dams to filter out and hold the silt. Dams should also slope from the ends of the dam toward the center of the gully to prevent water cutting around the ends of the dam.

Experience indicates that only the best grades of nursery stock should be employed for this difficult planting. The planting is relatively costly and is justified not on the basis of the first forest crop which will be produced on the land itself, but rather because this planting will stop further erosion on the area planted and its extension upstream, and prevent injury from deposits of debris on lands further downstream. Engineering works are expensive and should be used in erosion control only to the extent that they are indispensable to supplement the forest, or other plant cover where the forest cannot be grown, or temporarily while a vegetative cover is being established and developed to the point where it will itself prevent erosion. The simple engineering works common in erosion control may be classed as:

(1) Check dams of various types intended to check the velocity of the flowing water. They include brush dams, wire screen dams, wooden dams of logs or planks, crib dams and loose rock, masonry and concrete dams. Brush dams may last only two to three years whereas concrete dams remain useful permanently.

(2) Paving of various types: The principle is to place and maintain a layer of not easily eroded material over critical areas subject to erosion. It is used mostly in stream ways and gullies between check dams or in gullies where there are no check dams. The paving may be made either of brush, staked and wired down, or of loose rock tamped down into the soil or into a grout base. Mulch of straw or grass, placed under the brush, or loose rock pavement may be needed to stop erosion effectively.

(3) Diversion ditches: These are often needed to turn water out of eroding gullies which are being reclaimed. These may also be necessary to afford a permanent outlet for water caught on terraces.

(4) Terraces with retaining walls: On steep slopes above the forest zone it may be necessary to create terraces to check the velocity of the surface runoff and give time for the water to sink in. Stone retaining walls are sometimes needed to maintain these terraces. Best methods of constructing these engineering works vary, depend- ing

upon the soil, topography and climatic conditions encountered and the materials available for construction. Details of construction should be worked out locally.

4.2.3.3 Landslides

Landslides, as previously stated, are examples of a special type of wholesale erosion. Control measures are needed both above the forest zone and within the forest. Above the forest zone, engineering works of the same character as those used to prevent other types of erosion should be built on all slopes in danger of sliding. Grazing should be prohibited and complete fire protection be secured. Inside the forest zone wherever danger from landslides exists complete fire prevention and elimination of grazing should be the rule. Clear cutting of timber should be avoided, and partial cuttings of the selection type, which always retain a large proportion of the stand, should be employed. It will often be necessary not only to maintain a good soil cover, but also to anchor sheets of soil so that they cannot move. This may be done on loose banks by driving in a series of stakes, preferably of live wood which may sprout, and sometimes connecting these stakes with wire. The tree roots form the best insurance for holding large layers of soil once the forest is established.

4.2.3.4 Snow, Ice or Sleet and Avalanches

Control of snow, ice and sleet damage can be secured only through making the individual trees strong and providing room for the snow to fall through to the ground. When snow-damage zones are located, species not easily broken or crushed by snow should be favored and an arrangement of age classes planned which will prevent the dumping of snow on young age groups. Dense, even stocking must be avoided as well as mixtures of species ill suited to resist snow damage. For example, a mixture in which one species outgrows the other usually results in the slow-growing species forming slim stems which are broken or crushed by the snow dropped upon them by the faster-growing species. An ideal mixture for protection against snow is composed of a conifer and a hardwood, the conifer being the faster growing of the two. The conifer sheds its snow upon the hardwood, which species, being without foliage in the winter, allows the snow to fall through to the ground. Skillful thinning is the forester's chief tool for developing strong individuals capable of resisting snow damage. Trees with one-sided crowns should be eliminated from the stand in the thinning unless they are needed in the dominant stand. Curtis (1936) suggests that trees with one-sided crowns should be brought to symmetrical form by artificial pruning and thus be safe-guarded against being bent over by the weight of an unequally distributed load of snow. He also advises that thinning be made after the year's heavy snowfall is completed, so that the remaining trees may have the advantage of a season's growth in this new, more exposed position before being subjected to heavy snowfall. Where snow damage is threatening, thinning of the low thinning type rather than crown thinning may be safer. The subordinate stand maintained in the crown-thinning method is likely to be ruined by the snow sliding down from the trees in the upper canopy. Nothing can be done to prevent the damage caused by sleet storms other than the gradual strengthening of the individual trees by thinning to develop sturdy stems and crowns. Avalanches, or the mass movement of snow on slopes, once started are difficult to stop, hence protective measures should be directed toward preventing their origin. Long grass, ground cover of any kind, brush and reproduction hold the snow and assist in preventing the start of avalanches. Above timberline, protective measures include the encouragement of all woody plant vegetation, the preservation of a grass sod and at the most dangerous points the construction of ditches, walls and fences. Below timberline, protective measures require the maintenance of a protection forest. Munger (1911) mentions four requirements for treatment of such a forest.

(1)Complete fire protection encourages the development of ground cover, underbrush and reproduction.

(2)Exclusion of grazing with the same object in view of keeping the soil densely covered. (3) Careful cutting of timber on steep slopes with a gradient exceeding 50 per cent. Single tree selection is the proper method of reproduction to use. Clear cutting should be prohibited.

(4)Prompt reforestation of denuded areas, in order to reestablish forest conditions.

Summary

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Unit 5: Protection against Atmospheric Agencies III

Unit Structure

5.0 Learning objectives

After learning this you will be able to understand:

- about damage caused by wind
- about effects upon the soil
- about effects upon the forest atmosphere
- about direct physiological injury to trees
- about mechanical injuries
- about methods of protection against wind

5.1 Introduction

Wind affects the forest in a variety of ways but on the whole is injurious. These effects of wind may for our purpose be classified under the following headings: Effects upon the soil; Effects upon the forest atmosphere; direct physiological injury to trees; Mechanical injuries. The beneficial influence of wind is found primarily in the dissemination of seed and pollen (Forbes 1925). Natural regeneration relies largely upon wind-borne seed for stocking cutover areas. Another beneficial influence of wind is the mixing of the soil which occurs as a result of large trees being uprooted. Oftentimes the forest litter is buried and mineral soil exposed, which may afford a favorable seedbed for species not then abundant in the stand. Over a long period of time in the virgin forest an appreciable portion of the forest floor may be disturbed in this way. This action is of more significance in affecting soil conditions and the composition of forests in their natural state than in the managed forest.

5.2 Damage caused by wind

5.2.1 Effects upon the Soil

The wind exerts a distinctly injurious influence upon the soil in two ways --first by blowing it away, which is commonly spoken of as wind erosion, and second by its drying effect upon the soil in place. Accelerated air movements increase the evaporation and tend to exhaust soil moisture. The continued drying action of the wind upon the soil interferes with the building up of the better types of humus, is apt to develop instead a tough, peaty acid humus layer, and also curtails the activity of the soil bacteria and fauna necessary for proper functioning of the soil (Fritzsche 1933). Often- times the entire cover of leaves is blown off, leaving the soil bare, and conversely in other spots these leaves are heaped up thickly, with bad results both for regeneration and for condition of the soil. Wind erosion, the other type of wind action on the soil, results in the movement of the soil particles themselves and their removal from their existing position. Fine earth is continually being blown away from exposed portions of the soil in the forest. This occurs especially on the warmer, drier exposures such as southern-facing slopes. In the long run, this removal by the wind of fine particles of soil results in making the soil shallower and less fertile. Since the fertility of the soil determines the productive power of that area for tree growth, any injury to the soil affects unfavorably the growth rate of the forest. Not only are fine earth particles constantly being removed from exposed spots in the forest, but a most striking type of action occurs where the wind blowing over areas outside the forest causes wholesale movement of soil. This is usually discussed under the head of shifting sand dunes, although similar wind action takes place also on areas of finer and better soil types. In general, wind erosion increases as the percentage of sand in the soil rises and is most dangerous in regions where extensive bodies of fine, dry sand occur. Moving sand dunes are capable of burying and destroying entire forests, and conversely the establishment and maintenance of forests upon areas of shifting sands constitute the only method of rendering such areas productive and preventing injury to adjacent property including forests. Wholesale erosion of soil by wind may start even within a forest where mismanagement has destroyed the litter covering the soil. Wind erosion is a potential source of danger to the forest, principally in regions of light sandy soils where the precipitation is relatively scanty during at least part of the year. Soil materials cast up by the sea and not yet clothed with vegetation are particularly susceptible to wind erosion and threaten adjacent forests and property. Mismanaged agricultural lands suffer enormous losses of soil from wind erosion each year, but consideration of this problem, except as the wind-blown soil threatens to overwhelm forests in their paths, is outside the scope of the discussion.

5.2.2 Effects upon the Forest Atmosphere

For perfect functioning of the forest community the air within the forest should be calm, moist and relatively warm. When these conditions prevail excessive evaporation and transpiration are avoided and the humid atmosphere enables the trees to elaborate food materials to greatest advantage. Particularly is the supply of carbon dioxide, so necessary for plant activity, abundantly available. Where wind is admitted into the inner part of the forest this favorable condition is changed. The carbon dioxide is rapidly carried away, and the forest atmosphere may be cooled by the influx of colder air. Thus the warmth secured from the sun's rays and held within the forest may be lost. Or the wind may be excessively hot and dry and then it will raise temperatures too high and decrease moisture within the forest. From whatever angle the subject is approached it remains a fact that the free movement of wind inside the forest affects the forest atmosphere unfavorably and should be pre- vented.

5.2.3 Direct Physiological Injury to Trees

The physiological effect of the wind is expressed in a variety of ways. It deforms the crown, changes the character of the root system and stunts the height of the stand. Trees along the border of a stand exposed for long periods to strong winds coming from one direction have deformed crowns and root systems especially developed to hold fast against these winds. The strongest will be developed on the leeward side of the tree to furnish resistance to bending (Fritzsche 1933). The height of the trees will be less on the outer exposed edge, and normal heights will be attained only after going 60 to 200 feet inside the border (Munch 1923). Wind action sometimes causes excessive development of the root system at the expense of the growth of the portion above ground. Eccentric and crooked stems frequently result from continuous wind action. Wind often is responsible for the drying out of tops of trees, creating what is known as a stag-headed condition. In fact, much of the injury to trees left isolated on cutover areas and attributed to changed site condition is caused by wind action in drying out the soil and increasing the loss of water from the tree. From the physiological side the wind question is in many instances a water-supply question. The most important injurious physiological effect comes from an increase in the transpiration from leaves and twigs. It is sometimes claimed that stimulation in growth may result from a reasonable increase in transpiration and that light winds may even be of benefit in this respect. However, strong winds soon raise the rate of transpiration beyond the point most favorable for tree growth. This combined with the water shortage for the roots, which may be brought about by heightened evaporation from the soil, has serious consequences for the growth and health of the forest. The wind often turns the leaves into positions unfavorable for assimilation. They may also be cooled by the wind, and this result in interference with normal nutrition. Wind movement may cause the closing of the leaf stomata and thereby hinder entrance of carbon dioxide into the leaves. All in all, the wind is of distinct physiological importance in deforming the trees and in reducing the growth of the stand (Barth 1934). These physiological influences of the wind are in progress even with winds of low velocity, but mechanical injuries, often spectacular in nature, occur principally in the occasional windstorms of high velocity. Consequently it is possible that the injury of a physiological character suffered by the forest from wind may be greater than that resulting from breakage and wind-throw. In fact, there are places, usually located near the border line between the forest and other types of vegetation, where wind is a sufficiently critical and powerful enough factor to destroy the forest and replace it permanently with other vegetation unless conservative management, directed especially toward minimizing the influence of wind, is practiced.

5.2.4 Mechanical Injuries

Strong winds have the power to tear out entire trees by the roots, to overthrow whole stands and to snap in two the trunks of large trees. Where occurring in most violent form, as in the tornadoes of the southern United States and tropic countries, the wind cuts a wide swath throughout the forest, knocking down and breaking all the trees in its path. Complete destruction of the forest may result from such violent storms. Winds of lesser intensity, which do not cause overthrow or breakage, lash the small branches against one another, thereby knocking off an appreciable amount of the foliage and small twigs. Tearing and loosening of the roots are frequent wind injuries. Such injury which is often hard to observe above ground may cause a shortage of water supply for the tree, because the fine roots are broken, and thereby result in a lowering of the vitality and in an increased susceptibility of the tree to injury by insects and fungi. Trees of all ages are uprooted and broken by high winds, but on the whole old timber suffers most. The velocity of the wind is the main factor governing extent of the damage. Low-velocity winds cause practically no mechanical damage. Until velocities in excess of 30 miles per hour are reached little mechanical damage is caused by wind. High winds accompanied by rain or wet snow cause the worse injury. Windfall is most likely to occur in seasons when the soil is saturated with water and consequently the holding power of the roots is least effective. Soil texture also influences windfall since it affects the distribution of the roots. On sandy soils there is practically no wind- fall unless the soil is shallow and underlaid with an impervious stratum. On heavy fine-textured soils windfall is more common. Shallow-rooted species suffer most, and conifers particularly in the winter time are more susceptible to damage than broadleaved trees. Trees in uneven aged stands are less likely to be thrown or broken by the wind than those in even aged stands, since the former are better developed as individuals with lower centers of gravity. A peculiar type of mechanical injury by wind has been reported by Moore (1933) and Day (1934). This consisted in the girdling of recently planted Scotch and Corsican pines (*Pinus sylvestris* and *laricio*) by the action of wind swaying the stems against sharp stones lying in the surface soil. The action of wind is felt in every forest in the America. The amount of damage varies tremendously from place to place. In general, regions of relatively low precipitation and high average wind velocity suffer the greatest injury. Forest regions subject to violent wind storms of high velocity show the greatest damage from mechanical breakage and overthrow of timber. Trees growing in isolated position from early youth develop a proper balance between roots and top and accustom themselves to resist the winds normal to their locality. They are in best position to weather the occasional violent storms safely. Trees which are grown from early youth in closed stands have the least resistance to the winds of normal intensity and may suffer complete destruction when their position in reference to adjacent trees is changed by cutting, or when the occasional violent storm occurs.

5.3 Methods of Protection against Wind

Complete prevention of injury from wind is impossible, but the damage during the life of a forest crop can be lessened by correct methods of management. The best protection against injury from wind can be secured only by preventing the entrance of the wind into the forest. This can be accomplished in theory by keeping the edges of stands where they abut on open lands completely clothed with dense foliage from the tops to the ground, and by maintaining all through the forest a dense understory which reaches from the ground to the bottom of the dominant crown level. Such a condition is almost impossible to secure and maintain. An uneven aged forest with the ages arranged by single trees or very small groups also constitutes a wind-resistant forest. The uneven aged forest is less susceptible to wind injuries of both the mechanical and physiological character than the even aged forest. For this reason the former type of forest should be developed and maintained on areas where severe injury from wind is anticipated. The uneven aged forest because of its complete vertical closure reduces wind movement and evaporation inside the stand to a minimum. Sometimes entire abandonment of the even aged form of forest may be undesirable. Possibly adequate protection may be secured by maintaining a relatively narrow border of forest in uneven aged form while the main central area remains even aged. Very rarely can such full protection against wind be obtained or justified when considered in relation to management objectives. If the forest products are to be utilized, cuttings must be made and the forest opened up, and wind will be admitted to a greater or less extent. The practical problem is how to combine the production and utilization of timber crops with reasonable protection against wind, an ever-present enemy of the forest. It should be remembered, however, that the degree of departure from the ideal condition of the stand as regards exclusion of wind will be correlated with a gradual decrease in the growth rate of the stand and an increased liability to excessive mechanical injury from the wind. There are areas so dangerously exposed to injury from wind that on them a forest cover of highly wind-resistant character should be developed and maintained by light cuttings. Many other parts of the forest may be so slightly susceptible to damage by wind owing to favorable climate or other factors that special protection against the injurious effects of wind need receive relatively little consideration. This is true particularly as concerns damage from wind to soil, forest atmosphere and physiologically to trees and to lesser degree as regards breakage and overthrow of trees. Injury from windfall and breakage, though occurring in stands of all ages, is of chief importance in mature timber. Such stands have attained their growth, are ready to harvest and will be cut soon. Young and middle-aged stands, on the other hand, must be tended for many years before the time for harvest, and it is essential that they be protected against the entrance of wind with its serious consequences in reduced growth. Windfall and breakage are less common in these immature stands unless a tornado happens to pass through them. Protection against loss to mature timber from windfall and breakage is needed virtually everywhere. In the utilization of the timber, cuttings must be made and when made are likely to leave exposed the sides of forest stands and allow wind to blow against trees which previously have been sheltered by their neighbors. Cuttings of any kind increase the wind damage and in regions where this is serious must be planned so as to minimize the extent of the injury. It is a fact that serious windfall and breakage occur in forests long under management, as well as in unmanaged forests. This is due partly to bad practices and failure to recognize wind as a sufficiently important potential source of injury and partly to the fact that, in the managed forest, cuttings of mature timber are made each year and hence numerous opportunities for wind-throw and breakage exist on areas in the process of being reproduced. Arrangement of the cutting areas so that they progress against the direction of damaging winds is accepted as one of the first principles of protection for mature timber against mechanical injury from wind. In fact, if this arrangement is accomplished it is likely to be of greater protective value than a resistant border zone, since the entire forest is protected throughout. If successive cuttings are made on the leeward side of the stand and advance into the wind, the cut edges of the stand will not be exposed to direct impact of the wind. The windward side of the stand should be developed as a border zone stocked with wind-resistant trees to act as a buffer for the remainder of the area. A long period of years is required to develop such a border, whether it be a single row of trees or a broad belt. Preferably a belt 50 to 100 feet wide should be developed in exposed situations. The trees in this zone must be developed gradually from early youth by repeated thinning so that they possess exceptionally broad crowns and sturdy stems and are thickly rooted to withstand as individual trees the onslaught of the wind. A dense understory of other vegetation and the retention of branches down to the ground on the border trees will add to the wind-resistant value of the border zone. Heavy thinning particularly of the crown-thinning type started early and repeated often are of use as a wind-protective measure, not only in the border zone but throughout the entire forest area, and constitute one of the most effective means at the disposal of the forester for minimizing losses from windfall and breakage. Thinning made primarily to develop wind-resistant trees will be heavier than is desirable for most other silvicultural purposes and will tend to develop relatively knotty trees with stocky, fast-tapering stems. If thinning are started early, trees can be made wind resistant to all but storms of the tornado type on practically any situation no matter how exposed. Density of stand and the length of time during which the tree has grown under such conditions of close stocking, rather than the degree of exposure of the site, are the determining factors in its ability to resist mechanical injury from wind. Mixed stands in which resistant and non-resistant species are combined will suffer less damage than pure stands of sensitive species. When a species is in itself strong and wind resistant it may be grown in pure stands, but, to grow successfully those species which are easily wind injured, mixed stands must be created and maintained. In managing stands on wind-swept areas some forms of clear cutting or of the strip type of reproduction are often the only methods of regeneration which are possible. This is especially true where the forest is made up of fully stocked even aged stands which have in the past been thinned lightly or not at all. Even aged stands which have been thinned heavily, and several times, may be sufficiently resistant to admit of other reproduction methods than clear cutting. The shelter wood method is likely to heighten the storm damage and is applicable only locally in the best-protected places and in mixed stands. The seed-tree method should not be employed with shallow-rooted species or on areas subject to wind throw. Selection offers the best protection, but is possible of application only if the stands are truly un- even aged or have been so managed from an early age as to make the individual trees wind firm; otherwise selection cuttings may expose the stand to great damage. Cutting in narrow clear-felled strips has advantages from the standpoint of protection against wind as well as other desirable features silviculturally and will be used in many in- stances as forests come under management. Since old timber is more subject to wind-throw than younger stands, shortening the rotation will have the effect of eliminating the serious losses of this character which occur today in areas of virgin timber. Wholesale windfall and break- age in the path of violent storms and tornadoes can never be prevented in stands of any age, irrespective of composition or treatment, although the extent of the loss may be mitigated.

5.3.1 Control of Wind Erosion

The problem of erosion by wind like that of water erosion has two phases: **first**, the protection of the forest against injury caused by erosion of soil, starting either on areas within the forest or on lands outside and moving into the forest; and **second**, the reclamation of lands ruined by wind erosion. The former is a forest protection problem; the latter is in the field of artificial establishment of forests. Reclamation ordinarily involves the establishment of a vegetative cover, sometimes grasses and shrubs at first but usually ultimately forest trees. In guarding against the start of wind erosion within the forest itself the important principle is to preserve intact the humus, litter and ground cover making up the forest floor. Where this is done the wind has no opportunity to blow away any of the soil. In forests where soil and climate are potentially favorable for the start of wind erosion any little exposure of the soil may be enough to encourage the start of erosion, and a blow hole once started is rapidly enlarged by the wind. Exclusion of the wind from the forest by means of a dense wall of foliage down to the ground and by a thick understory will of course prove effective in preventing erosion without further attention. Wherever the forest has been opened by cuttings, there it becomes important to preserve the floor forest intact if wind erosion threatens. In some regions grazing of domestic animals may be a cause leading to wind erosion. Animals should be excluded or closely regulated to prevent overgrazing. Forest fires should be prevented on all areas liable to injury from wind erosion. Provided that the forest floor is unbroken and reproduction starts promptly on the cutover area, practically any system of cutting may be allowed so far as the danger of wind erosion is concerned. This is evident from experience in the maritime pine region of France, where thousands of acres of sandy soils susceptible to wind erosion have been reclaimed and are managed under a clear cutting method. Shifting sands whose movement originates outside the forest may advance into and destroy a forest, even one which is kept in perfect condition to prevent the start of wind erosion. Once in motion, advancing sand dunes threaten to destroy any forest in their path and can be checked only by establishing and maintaining a vegetative cover upon the wind-blown soil. Hence for the protection of the forest itself those areas which adjoin it, where the wind is actively eroding the soil, must be reclaimed. Eventually a forest should be developed and permanent control of further movement of sand be sought through maintenance of a thick forest floor. Any disturbance of the forest floor which exposes the mineral soil such as the ruts in a forest road, forest fires or grazing may lead to movement of the soil and ultimate destruction of the forest. Methods of stopping the movement of shifting sands form a special subject in itself to which full consideration cannot be given here. In general, seeding or planting must be undertaken, sometimes supplemented at the worst spots by fences of various types to catch and hold the soil temporarily until a cover of vegetation is established. Lesser forms of vegetation such as grasses may have to be established at first to check temporarily the blowing of the soil, although recent practice appears to indicate that, at least for sand dunes away from the sea, trees may be immediately established with the assistance of a dead brush cover. For example, it has been possible to establish the permanent trees without first obtaining a cover of lesser vegetation. Kroodsma (1937) was successful in developing methods for stopping the movement of sand dunes in Michigan. He states that sand dunes in Michigan move at the rate of 11/2 to 2 feet per year. His methods are summarized in the following paragraphs. An essential step is the spreading of a brush cover laid at right angles to the wind direction over the area on which the soil is to be fixed. This may be done before or just after the trees are planted. Hardwoods are usually planted first, and later conifers can be introduced in spaces left for the purpose. The hardwoods serve as protective cover for the conifers until they become established. The trees considered best for sand-dune planting are black locust, Carolina poplar or cottonwood among the hardwoods, and ponderosa, Scotch, Norway and jack pines. Stock big enough so that it is not covered by blowing sand the first year should be used. This means about 18-inch 1-0 seedlings or cuttings for hardwoods and 2-1 or 3-0 stock for conifers. After the planting is completed and the brush cover laid, sowing of rye in the following fall is advised to furnish a winter mulch. This sowing may be repeated in several succeeding years if needed to prevent soil movement.

The smoke and poisonous gases cast into the atmosphere by industrial plants, railroad locomotives and other sources pollute the atmosphere and injure forest vegetation. Smoke is variable in character, but ordinarily in addition to the soot it contains other materials and is always accompanied by various gases. These gases frequently contain free acids and have a poisoning effect which may even result in killing the entire tree. Those industrial plants where smelting of metals is carried on are the most dangerous type as regards their emission of smoke and gases. The most dangerous gases commonly contained in smoke are those containing sulphur such as sulphur dioxide (SO_2). Sulphur dioxide in very small quantities is sufficient to kill vegetation. Illuminating gas also contains poisonous compounds, but is of little importance as a source of injury to forest trees, although it is a common cause of the death of shade trees in towns and cities growing near gas mains. Another poisonous element is the arsenic which is often emitted in smelter fumes. Even though this arsenic, deposited externally, may not damage the timber, it may be deposited in sufficient quantity on forage so as to poison grazing animals. Injury is caused the forest in a variety of ways. The soot, dust and other impurities settling from the smoke may form a coating over vegetation. Such deposits not only block up the stomata, thus impeding transpiration and absorption of carbon dioxide, but also, by covering the leaves, reduce the intensity of the sunlight as it affects the trees and thus interfere with photosynthesis (Bakke 1913). The deposits may contain substances which are directly injurious to the leaves through corroding or toxic action. The effects of injury by smoke and its accompanying poisonous gases will usually be noted, first, through the discoloration of foliage, later by defoliation and eventually by the death of injured portions or of the entire tree. Where the injury is not serious enough to kill the tree, there will at least be a decided slowing up in the growth rate of forest trees subjected to continuous exposure to smoke and gases. Fortunately most forest areas are not exposed constantly to large volumes of smoke with their poisonous fumes. It is only in the neighborhood of occasional smelters that the damage becomes extreme. The intensity of the attack depends primarily upon the concentration of the poisonous gas and the distance from the smokestack, modified, how- ever, by wind direction and topography. The worst injury is concentrated in the vicinity of smelters such as the one maintained by the Anaconda Copper Company at Anaconda, Montana. In the vicinity of plants of this type forest vegetation unless located in areas sheltered from the smoke stream may be destroyed for miles around the plant. In the neighborhood of the smelter at Anaconda, Mason (1915) states that destruction of lodge pole pine forests occurred in some places 9 miles distant from the smelter and that slight damage was experienced at distances of 30 miles. Conifers suffer more severely than broad-leaved trees, primarily because they retain foliage for more than one year. The older foliage on the conifers, having been affected longer by the poisonous fumes, is likely to show more severe injury than foliage of the current year's growth. Prevention of injury to forest trees from smoke and poisonous gases must come through treatment of the smoke before it leaves the stack. The matter of controlling the emission of poisonous gases and smoke from industrial plants has been investigated quite thoroughly, both by men in this country and by workers abroad, because of the injuries suffered by vegetation in cities and towns and because of the deleterious affect which smoke and its attendant fumes have upon human health. It is now known that the pollution of the atmosphere by the emission of smoke and poisonous gases can be prevented, in entirely practicable ways, by scientific construction and skillful operation of the industrial plants. There is no longer any adequate excuse for the continuation of this type of injury to forest vegetation. The most serious cases of extensive injury to the forests in this country from smoke and poisonous gases occurred several decades ago. Today enlightened sentiment and improved practice, which recovers by-products from the poisonous elements in the smoke stream, should result in preventing further serious losses. Different species of trees show differing degrees of susceptibility to injury from smoke and poisonous gases. In planting areas subject to smoke streams, species of known resistance to such types of injury should be chosen. As yet this information is available to only limited extent. Mason (1915) arranged the Rocky Mountain species occurring in Montana in the following order of susceptibility, the first being the most susceptible: alpine fir (*Abies lasciocarpa*), Douglas fir (*Pseudo-suga taxifolia*), lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea Enqelmanni*), juniper and limber pine (*Pinus flexilis*). Since complete elimination of the smoke and gas nuisance should be secured in the manner already described, there should be little if any occasion for restricting forest planting to species non-susceptible to smoke and gas injury.

5.3.2 Lightning

Lightning is a widespread source of injury to forest trees. Trees are excellent conductors for electrical discharges between the clouds and the earth and are frequently struck by lightning. Evidences of lightning injury can be seen in practically within the forests and it varies widely in character. A common type of injury is evidenced by a furrow running down the tree, often from the top to the ground, in which the wood has been splintered and the bark blown off. Sometimes the tree is completely blown to pieces, splinters of wood being scattered for a hundred or more feet in all directions around the tree. In other trees the injury appears to be simply the loss of a strip of bark with minor injury to the tissues immediately beneath the bark. However, such wounds may serve to encourage attack by insects and fungi. Plummer (1912) considers the bolts of lightning which pass upward through trees from the ground to the clouds as particularly explosive in action. Trees may also be killed outright by lightning, which apparently spreads over the entire trunk of the tree, but without causing any splintering or mechanical injury to the stem. This type of injury is not as commonly found in forest trees as the furrowing of the bark and shattering of the wood are. There is no practical method of preventing lightning injury to forest trees. On the whole, the amount of loss suffered from this cause is relatively small, although individual trees injured by lightning can be found scattered through the forest in almost all regions. Lightning causes much more serious damage to the forest indirectly through starting forest fires than it does through direct injury in striking individual trees.

Summary

Unit-6 Protection against Atmospheric Agencies IV

Unit Structure

6.0 Learning objectives.

After studying this unit you will be able to understand:

- General information about pollutants
- Sources of pollutants
- Effects of pollutants
- Protection of vegetation from pollutants
- Lightening and its effects

6.1 Introduction

The main air pollutants are represented by gases forms, particles in suspension, different ionizing radiation and noise. The gases forms are: oxidized and reduced forms of carbon (CO_2, CO, CH_4), of nitrogen (NO_2, NO, N_2O_4, NH_3, NH^{4+}), SO_2, O_3, C_6H_6 vapours, Hg, volatile phenols, Cl_2, etc. The particulate forms are: PM10 and

PM2.5 particulate matter, heavy metals with toxic effect (Pb, Ni, Cd, As), polycyclic aromatic hydrocarbons PAHs, etc.

Atmospheric pollutants have a negative effect on the plants; they can have direct toxic effects, or indirectly by changing soil pH followed by solubilization of toxic salts of metals like aluminum. The particulate matters have a negative mechanical effect. They cover the leaf blade reducing light penetration and blocking the opening of stomata. These impediments influence strongly the process of photosynthesis which rate declines sharply. Also the leaves of the trees have an important role in retention of the particulate matters; they are mostly affected when the wet and dry atmospheric deposition increase. The vegetation plays an important positive role in atmospheric purification and air pollutants reduction. The primary producers represented by plants are an important component in biogeochemical cycles. The vegetation made exchanges with a part of the atmospheric gases by photosynthesis, respiration processes, and the final stage of litter decomposition which mineralization. The plants play an important role in reducing atmospheric CO_2 content, by photosynthesis. This reduction of atmospheric CO_2 content has an important role in reducing of greenhouse gases, participating in reducing greenhouse effect and its consequences on climatic changes. The carbon stored in plants is the result of balance between carbon fixed by photosynthesis and carbon released in the atmosphere by respiration. As the structure of vegetation is more complex, the carbon stock in plants biomass is higher and the period of storage is longer. The most efficient type of vegetation in storing carbon in terms of carbon stored in plants alive is the temperate-continental forest; and in terms of carbon stored in dead organic matter are peat lands. Trees have also been planted to reduce the intensity of ionizing radiation and noise in different urban and industrial areas. The existence of vegetation in an area creates a microclimate where the temperature differentials between day and night are buffered. This prevents the occurrence of warmer temperatures which stimulate the production of volatile pollutants into the atmosphere.

6.1.1 General information about air pollution

Environmental pollution is any discharge of material or energy into water, land, or air that causes or may cause acute (short-term) or chronic (long-term) detriment to the

Earth's ecological balance or that lowers the quality of life. Pollutants may cause primary damage, with direct identifiable impact on the environment, or secondary damage in the form of minor perturbations in the delicate balance of the biological food web that are detectable only over long timeperiods.

Air pollution is the process which the substances and the energy forms are not present in normal atmospheric composition reach the atmosphere, or are present but in much lower concentrations. Air pollution is the introduction of chemicals, particulate matter, or biological materials that cause harm or discomfort to humans or other living organisms, or cause damage to the natural environment or built environment, into the atmosphere. More than 3,000 substances that are not part of the atmospheric composition, falling in the atmosphere can be considered air pollutants. Some substances that are normally present in the atmosphere in a certain concentration can be considerate pollutants because their concentration is much higher than usual concentration. Also certain substances that are normally present in certain layers of the atmosphere (e.g. ozone in the stratosphere), once arrived in the troposphere is pollutant. Some gases, such as oxides of nitrogen may have beneficial effect on vegetation, after hydration may affect the leaf fertilizer. The air pollutants factors can be chemical (chemicals), mechanics (particles in suspension) physical (ionizing radiation) and acoustic (noise). Pollutants describe a global circuit; they are produced by different sources, are transported and transformed into atmosphere, some of them being removed, another part is reaching the earth having different effects on different biocoenosis of ecosystems (Fig. 1).

An analysis done at the global level revealed a diversification of pollutants agents and sources of air pollution. This diversification and

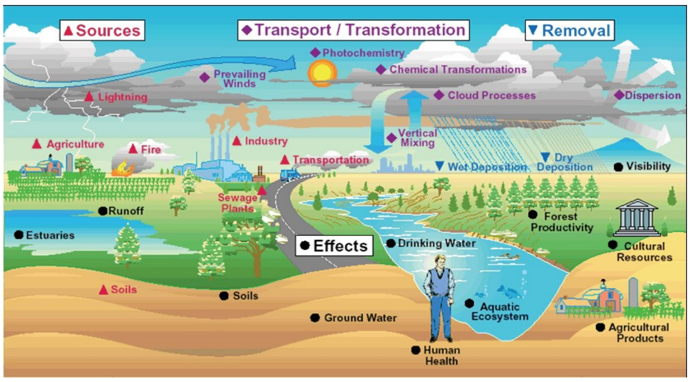

Fig. 1 Global pollutants circuit (www.cleartheair.nsw.gov.au, 2011)

increasing concentrations are in strict correlation with industrialization and the increasing of amounts use as fossil energy (non- renewable sources). At the beginning, the pollution has been felt in urban areas and the forms of relief that favored the accumulation of pollutants and long stay (depressions, closed valleys, etc.). Currently, air pollution has become a larger area, sometimes to disperse across multiple continents.

Air pollution can be analyzed on three spatial scales: global pollution, regional pollution and local pollutants. The global pollution is the result of cumulative effects of various sources, located on the entire surface of the globe, manifested by global effects: the stratospheric ozone depletion; greenhouse effect - emission of greenhouse gases (CO_2, methane, CFCs, etc.); formation of aerosols (pollutant clouds which suspended particles and chemical compounds). The regional pollution is in part the result of local air pollution--including that produced by individual sources, such as automobiles - that has spread out to encompass areas of many thousands of square kilometers. Meteorological conditions and landforms can greatly influence air-pollution concentrations at any given place, especially locally and regionally. For example, cities located in bowls or valleys over which atmospheric inversions form and act as imperfect lids are especially likely to suffer from incidences of severe smog. Oxides of sulfur and nitrogen carried long distances by the atmosphere and then precipitated in solution as acid rain, can cause serious damage to vegetation, waterways, and buildings. The local pollutants (smog) can be loosely defined as a multi-source, widespread air pollution that occurs in the air of cities. Smog, a contraction of the words smoke and fog, has been caused throughout recorded history by water condensing on smoke particles, usually from burning coal.

In terms of the effects of pollutants can be acidifying agents - sulphur dioxide (SO_2), nitrogen oxides (NOx) ammonia (NH_3) fluoride and Cl_2, hydrogen chloride (HCl) - and oxidizing agents - carbon monoxide (CO), PAN (peroxyacetylnitrate-$CH_3CO.O_2.NO_2$), ozone (O_3).

6.2 Sources of pollutants

Air pollution comes from natural and anthropic sources; these sources generate pollutants with different effects at global level or on individuals of plants and animals (table. 1).

(i) Natural processes: Natural processes that affect air quality include volcanoes, which produce sulfur, chlorine, and ash particulates. Wildfires produce smoke and carbon monoxide. Cattle and other animals emit methane as part of their digestive process. Even pine trees emit volatile organic compounds (VOCs).

(ii) Man-Made: Many forms of air pollution are man-made. Industrial plants, power plants and vehicles with internal combustion engines produce nitrogen oxides, VOCs, carbon monoxide, carbon dioxide, sulfur dioxide and particulates. In most mega-cities, cars are the main source of these pollutants. Stoves, incinerators, and farmers burning their crop waste produce carbon monoxide, carbon dioxide, as well as particulates. Other human-made sources include aerosol sprays and leaky refrigerators, as well as fumes from paint, varnish, and other solvents. One important thing to remember about air pollution is that it doesn't say in one place. Winds and weather play an important part in transport of pollution locally, regionally, and even around the world, where it affects everything it comes in contact with. The major anthropic sources of air pollution are:

- industry and conventional energies (the mining industry, the energy industry based on fossil fuels - coal, oil, natural gas, central heating, chemical and metallurgical industry, engineering internal combustion machinery industry, industrial waste, noises, etc);
- agriculture (the vegetation fire, denitrification in soils excessively fertilized, paddy field, intensive husbandry, deforestation, etc)

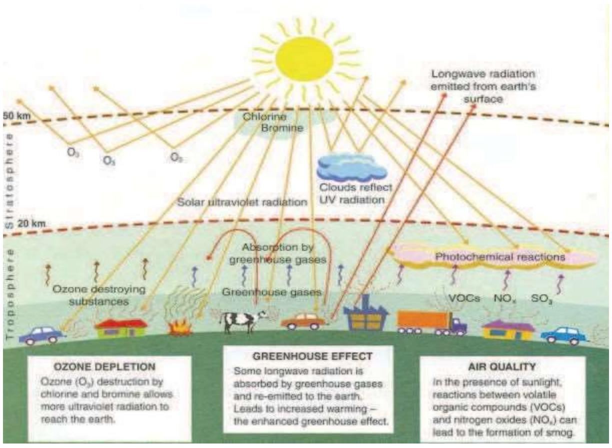

Fig. 2. The major anthropic sources of air pollution (www.cleartheair.nsw.gov.au, 2011)

- transportation (motor vehicle pollution, noises, etc) and urbanization (sewage plans, authorized landfill site, etc) (fig. 2)

Table 1. Type of pollutants, origin and effect at global level or on plants and animals individuals

Name of pollutants	Origin	Effects
Natural sources		
sulfur, chlorine, and ash particulates, smoke and carbon monoxide methane volatile organic compounds (VOCs) Aerosol from deforestation and burning: CO, CO_2, NO, NO_2, N_2O, NH_4	Volcanoes, wildfires, cattle and other animals, pine trees	- acid rain, - smog, - respiratory irritant - increased respiratory - diseases - damage cell membranes of plants - The effects are high only for volcanoes.
Anthropic sources		
Carbon monoxide, carbon dioxide, sulphur dioxide, nitrogen oxides, fluorides and substances with fluorine, chlorine (Cl_2), bromine (Br_2) and iodine (I_2), small dust particles, VOC, methane, ammonia and radioactive radiation.	Industry: the mining industry, oil and natural gas extraction, the energy industry based on fossil fuels - coal, oil, natural gas, the production of brick, tile, enamel frit, ceramics, and glass; the manufacture of aluminium and steel; and the production of hydrofluoric acid, phosphate chemicals and fertilizers. central heating, chemical and metallurgical industry, engineering internal combustion machinery industry, industrial waste, noises	- respiratory irritant, - acid rain, - smog, - increased respiratory - formation of secondary pollutants (PAN, O_3) - effect on soilfertilizer - Respiratory diseases - toxic effects on living cells - greenhouse gas effect - toxic effects - carcinogenic proprieties - accumulation in tissues - blocking of different processes - stratospheric ozone depletion
CO, CO_2, NO, NO_2, NH_3, CH_4, SO_2, oxides of heavy metals, H_2SO_4, SPM, HC, VOC, background aerosols: sea salt oxidation of sulphur containing gases, same organics, nitrous oxide (N_2O) pesticides	Agriculture: the vegetation fire, the denitrification process, in soils excessively fertilized and excessive use the pesticides , paddy field, intensive husbandry, deforestation	- formation of secondary pollutants (PAN, O_3) - effect on soilfertilizer - respiratory diseases - greenhouse gas effect - toxic effects - acid rain, - stratospheric ozone depletion
Aerosols from transport and constructions NOx, CO, HCl, Lead and other heavy metals , SPM	The motor vehicle pollution, noises	- smog - increased respiratory diseases - damage cell membranes of plants - carcinogenic proprieties - accumulation in tissues - blocking of different processes - stratospheric ozone depletion

Domestic aerosols CFC, HC, FC, H_2S, CH_4 CO_2	sewage plans, authorized landfill site	- carcinogenic proprieties - accumulation in tissues - blocking of different processes - stratospheric ozone depletion

6.3 The most important atmospheric pollutants

The air pollutants are represented by gases forms, particles in suspension, different ionizing radiation and noise.

6.3.1 Major gaseous pollutants

Sulphur dioxide (SO_2): It is the most important and common air pollutant produced in huge amounts in combustion of coal and other fuels in industrial and domestic use. It is also produced during smelting of sulphide ores. Sulphur dioxide concentrations in air have decreased in the past two decades, mainly because we use more non-sulphur-containing fuels for the generation of energy. Sulphur dioxide is a stinging gas and as a result it can cause breathing problems with humans. In moist environments, sulphur dioxide may be transferred to sulphuric acid. This acid causes acidification and winter smog.

Nitrogen oxides (NO_x) and nitrous oxide (N_2O): The Nitrogen oxides (NO_x) and nitrous oxide (N_2O) using catalysers in car exhausts can prevent emissions of nitrogen oxides. Nitrogen oxides are gasses that react with other air pollutants when they are present in air. For example, nitrogen oxides play an important role in the formation of ozone in the lower atmosphere, and in acidification and eutrophication processes. They can deeply penetrate the lungs and damage human lung functions.

Fluorides: Common gaseous fluoride pollutants are HF, SiF_6, CF_4 and F_2. Particulate fluoride pollutants include Ca_3AlF_6 (Cryolite), CaF_2, NH_3F, AlF_6, CaSiF, NaF and Na_2SiF_6. Aerosols are often formed from NaF, $NaAlF_6$ and AlF_6. Chief sources of fluoride pollutants are brickworks, aluminium factories, glassworks, steelworks, ceramic factories, phosphate fertilizer plants and uranium smelters. Some fluorine pollution also occurs during combustion of coal. Most injurious fluoride pollutant is gaseous hydrogen fluoride (HF). Fluoride is released into the air in large quantities by aluminum reduction plants, phosphate processors, steel mills, coal burning operations, brick and tile manufacturers, and various less significant sources [1]. It can cause adverse effects when ingested by domestic animals or absorbed by plants. There are also reports that fluoride air pollution can adversely affect human health, though these are less well documented than those concerning sensitive animals and plants. Fluorides are released into the air in both a gaseous state (as hydrogen fluoride and silicon tetra-fluoride) and in solid particles. The particles fall on, and the gases are absorbed by, vegetation near the polluting industry. If this vegetation includes forage crops which are fed to cattle, sheep, horses, or pigs, serious problems may ensue, since these animals, particularly the cattle are vulnerable to fluoride [2]. In fact, according to the U.S. Ninety-six percent of the ingested fluoride that accumulates in the bodies of animals is incorporated into the crystal structure of bone and tooth mineral [3], [4]. When fluoride is ingested with food or water, most of that which is not deposited in the bones, teeth, and other calcified tissue is excreted in the urine within hours of ingestion [5]. Thus it is not surprising that fluoride mainly affects the bones and teeth. Teeth are more markedly affected by ingested fluoride than are bones, but their high sensitivity is limited to the period of their formation. Thus a cow that has not been exposed to excessive fluoride before the age of two and one-half to three years will not develop the severe dental lesions which would occur in the same animal exposed at a younger age [6]. The developing tooth exposed to small amounts of fluoride may experience color variations ("mottling") that have little or no effect on the animal's ability to eat. Higher levels of fluoride result in more serious dental abnormalities, ranging from small, brittle, chalky areas on the tooth surface to pitting of enamel and easily eroded teeth [2]. Even more serious effects, including severe pain and the wearing down of the tooth right to the gum, can prevent the cattle from drinking cold water or eating. Localized or generalized enlargement of certain bones in the legs (metacarpals and metatarsals) and the lower jaw (mandible) of cattle are common symptoms of excessive fluoride ingestion [7]. As highly abnormal bone tissue replaces normal bone, [8] overall enlargement occurs, and the normally smooth bone surfaces take on a chalky, white, irregular appearance [2]. Hard ground can cause fluorotic hoof (pedal) bones to fracture, resulting in severe lameness [6]. Cattle with advanced fluorosis may also be crippled by mineralization of ligaments, tendons, and the structures surrounding the joints [9]. Enlargement of the joints themselves may also contribute to lameness.

Fluoride- induced tooth destruction, lameness, and stiff joints affect the animal's ability to stand, eat, and graze, and all tend to lower the milk yield of dairy cattle or the weight of beef cattle.

Chlorine (Cl_2): Although chlorine concentrations change very rapidly in the atmosphere due to atmospheric chemistry and light rain can remove all the chlorine from the air in a very short time, chlorine injury can occur to plants near the source of pollution. The impact of chlorine pollution increases in bright sunlight, decreases in drought and low temperature. Many particulate and gaseous fluorides are produced when ores containing fluorine are processed and used in industries. Common gaseous fluoride pollutants are HF, SiF_6, CF_4 and F_2. Particulate fluoride pollutants include Ca_3AlF_6 (Cryolite), CaF_2, NH_3F, AlF_6, CaSiF, NaF and Na_2SiF_6. Aerosols are often formed from NaF, $NaAlF_6$ and AlF_6. Chief sources of fluoride pollutants are brickworks, aluminium factories, glassworks, steelworks, ceramic factories, phosphate fertilizer plants and uranium smelters. Some fluorine pollution also occurs during combustion of coal. Most injurious fluoride pollutant is gaseous hydrogen fluoride (HF).

Hydrogen chloride (HCl): HCl gas is released in large quantities in combustion of PVC and all chlorinated hydrocarbon material in large fires or incinerators. The HCl gas is very hygroscopic and quickly changes to hydrochloric acid by reacting with atmospheric moisture and forms aerosol droplets.

Ammonia (NH_3): Continuous releases of ammonia from the sources are rarely high enough to cause acute injury but occasional high release or spillage may cause ammonia pollution. High concentrations of ammonia are sometimes found around intensive farm units e.g. chicken batteries. Extent of injury reduces rapidly with increase in distance from the source. Under certain conditions the ammonia may remain as a cloud above ground level causing more injury to trees than to the ground flora. Injury symptoms may take up to 9 days to develop. In most plant species, recovery may occur in about 2 weeks after exposure is stopped. Ammonia forms during agricultural activities. EEA-32 emissions of NH_3 have declined by 24% between the years 1990 and 2008. Agriculture was responsible for 94% of NH_3 emissions in 2008. The reduction in emissions within the agricultural sector is primarily due to a reduction in livestock numbers (especially cattle) since 1990, changes in the handling and management of organic manures and from the decreased use of nitrogenous fertilizers. The reductions achieved in the agricultural sector have been marginally offset by the increased emissions which have occurred during this period in sectors such as transport and to a lesser extent the energy industry and other (non-energy) sectors. In context to environment NH_3 contributes to acid deposition (plays an important role in acidification) and eutrophication. The subsequent impacts of acid deposition can be significant, including adverse effects on aquatic ecosystems in rivers and lakes and damage to forests, crops and other vegetation. Eutrophication can lead to severe reductions in water quality with subsequent impacts including decreased biodiversity, changes in species composition and dominance, and toxicity effects. NH_3 also contributes to the formation of secondary particulate aerosols, an important air pollutant due to its adverse impacts on human health.

VOC (Volatile Organic Compounds): VOC can be a range of different contaminants, such as carbohydrates, organic compounds and solvents. These compounds usually derive from petrol and gasoline reservoirs, industrial processes and fuel combustion, paint and cleanser use, or agricultural activities. VOC play an important role in ozone shaping in the lower atmospheric layer, the main cause of smog. VOC can cause various health effects, depending on the kind of compounds that are present and their concentrations. Effects can vary from smell nuisance to decreases in lung capacity, and even cancer.

Organic gases (Ethylene) and Methane (CH_4): Among organic gaseous pollutants, ethylene is most common. Other organic gases are propylene, butylenes and acetylene. Ethylene is continuously emitted from many sources involving combustion or processing of petroleum or its products or burning of organic materials e.g. straw burning. Other organic gases are also produced in various chemical industrial processes.

Ethylene is a natural plant growth substance so the injury effects produced by it on plants are very similar to growth abnormality symptoms. Other organic gases also produce symptoms similar to those of ethylene pollution. However, the sensitivities of species to different gases are variable.

Ethylene is a byproduct of automobile exhaust and can be a noticeable problem in urban environments.

Chlorofluorocarbons (or CFCs): It is an organic compound that contains carbon, chlorine, and fluorine, produced as a volatile derivative of methane and ethane.

Hydro-chlorofluorocarbons (HCFCs): A common subclass is the hydro-chlorofluorocarbons (HCFCs), which contain hydrogen, as well. They are also commonly known by the DuPont trade name Freon. The most common representative is dichlorodifluoromethane (R-12 or Freon-12). Many CFCs have been widely used as refrigerants, propellants (in aerosol applications), and solvents. The manufacture of such compounds is being phased out by the Montreal Protocol because they contribute to ozone depletion.

Minor gaseous pollutants: Many other air pollutants which are highly injurious to animals and human beings also cause damage to plants. However, plants are affected by these gases at quite higher concentrations than the animals. Common such gaseous pollutants are CO, H_2S, Br_2, I_2 and Hg - vapors.

Hydrogen sulphide (H_2S): It is a colorless, very poisonous, flammable gas with the characteristic foul odor of rotten eggs at concentrations up to 100 parts per million. It often results from the bacterial breakdown of organic matter in the absence of oxygen, such as in swamps and sewers (anaerobic digestion). It also occurs in volcanic gases, natural gas, and some well waters. The human body produces small amounts of H_2S and uses it as a signaling molecule.

Carbon monoxide (CO) carbon dioxideCO_2): Carbon monoxide (CO) carbon dioxide in excess (CO_2), this gas consists during incomplete combustion of fuels. When we let a car engine run in a closed room, carbon monoxide concentrations in the air will rise extensively. Carbon monoxide contributes to the greenhouse effect, smog and acidification. The gas can bind to hemoglobin in blood, preventing oxygen transport through the body. This results in oxygen depletion of the heart, brains and blood vessels, eventually causing death. It is highly toxic to humans and animals in higher quantities, although it is also produced in normal animal metabolism in low quantities, and is thought to have some normal biological functions. Carbon monoxide consists of one carbon atom and one oxygen atom, connected by a triple bond which consists of two covalent bonds as well as one dative covalent bond. It is the simplest ox-carbon. In coordination complexes the carbon monoxide ligand is called carbonyl. Carbon monoxide is produced from the partial oxidation of carbon-containing compounds; it forms when there is not enough oxygen to produce carbon dioxide (CO_2), such as when operating a stove or an internal combustion engine in an enclosed space. In the presence of oxygen, carbon monoxide burns with a blue flame, producing carbon dioxide [10]. Coal gas, which was widely used before the 1960s for domestic lighting, cooking and heating, had carbon monoxide as a significant constituent. Some processes in modern technology, such as iron smelting, still produce carbon monoxide as a byproduct [11]. Worldwide, the largest source of carbon monoxide is natural in origin; due to photochemical reactions in the troposphere which generate about 5×10^{12} kilograms per year [12], other natural sources of CO include volcanoes, forest fires, and other forms of combustion.

In biology, carbon monoxide is naturally produced by the action of heme oxygenase 1 and 2 on the heme from hemoglobin breakdown. This process produces a certain amount of carboxyhemoglobin in normal persons, even if they do not breathe any carbon monoxide. Following the first report that carbon monoxide is a normal neurotransmitter in 1993, as well as one of three gases that naturally modulate inflammatory responses in the body (the other two being nitric oxide and hydrogen sulfide), carbon monoxide has received a great deal of clinical attention as a biological regulator . In many tissues, all three gases are known to act as anti- inflammatory, vasodilators and promoters of neo-vascular growth [13]. Clinical trials of small amounts of carbon monoxide as a drug are on-going.

Bromine (Br_2) and Iodine (I_2): At high temperatures, organo-bromine compounds are easily converted to free bromine atoms, a process which acts to terminate free radical chemical chain reactions. This makes such compounds useful fire retardants and this is bromine's primary industrial use, consuming more than half of world production of the element. The same property allows volatile organo-bromine compounds, under the action of sunlight, to form free bromine atoms in the atmosphere which are highly effective in ozone depletion. This unwanted side- effect has caused many common volatile brominated organics like methyl bromide, a pesticide that was formerly a large industrial bromine consumer, to be abandoned. Remaining uses of bromine compounds are in well-drilling fluids, as an intermediate in manufacture of organic chemicals, and in film photography.

Iodine and its compounds are primarily used in nutrition, the production of acetic acid and polymers. Iodine's relatively high atomic number, low toxicity, and ease of attachment to organic compounds have made it a part of many X-ray contrast materials in modern medicine. Like the other halogens, iodine occurs mainly as a diatomic molecule I_2, not the atom. In nature, iodine is a relatively rare element, ranking 47th in abundance. It is the heaviest essential element utilized in biological functions. Its rarity in many soils has led to many deficiency problems in land animals and inland human populations, with iodine deficiency affecting about two billion people and being the leading preventable cause of mental retardation [14]. As a component of thyroid hormones, iodine is required by higher animals. Radioisotopes of iodine are concentrated in the thyroid gland. This property of thyroid- concentration, along with its mode of beta decay, makes iodine-131 one of the most carcinogenic nuclear fission products.

Hg and Mercury vapors Pre-industrial deposition rates of mercury from the atmosphere may be about 4 ng/ (1 l of ice deposit). Although that can be considered a natural level of exposure, regional or global sources have significant effects. Volcanic eruptions can increase the atmospheric source by 4–6 times [15]. Natural sources, such as volcanoes, are responsible for approximately half of atmospheric mercury emissions. The human- generated half can be divided into the following estimated percentages:

- 65% from stationary combustion, of which coal-fired power plants are the largest aggregate source (40% of U.S. mercury emissions in 1999).
- This includes power plants fueled with gas where the mercury has not been removed. Emissions from coal combustion are between one and two orders of magnitude higher than emissions from oil combustion, depending on the country [15].

- 11% from gold production. The three largest point sources for mercury emissions in the
- U.S. are the three largest gold mines. Hydro-geochemical release of mercury from gold- mine tailings has been accounted as a significant source of atmospheric mercury in eastern Canada [16]
- 6.8% from non-ferrous metal production, typically smelters.
- 6.4% from cement production.
- 3.0% from waste disposal, including municipal and hazardous waste, crematoria, and sewage sludge incineration. This is a significant underestimate due to limited information, and is likely to be off by a factor of two to five.
- 3.0% from caustic soda production.
- 1.4% from pig iron and steel production.
- 1.1% from mercury production, mainly for batteries.
- 2.0% from other sources [15], (EPA report, 2007).

The above percentages are estimates of the global human-caused mercury emissions in 2000, excluding biomass burning, an important source in some regions [15]. Current atmospheric mercury contamination in outdoor urban air is (0.01–0.02 µg/m3) indoor concentrations are significantly elevated over outdoor concentrations, in the range 0.0065–0.523 µg/m3 (average 0.069 µg/m3) [17]. Mercury also enters into the environment through the improper disposal (e.g., land filling, incineration) of certain products.

6.3.2 Particulate pollutants

(i) Particles in suspension: Dust particles. Dust particles form a complex of organic compounds and minerals. These can derive from natural sources, such as volcanoes, or human activities, such as industrial combustion processes or traffic. Particles are categorized according to particle size. The smallest particles have the ability to transport toxic compounds into the respiratory tract. Some of these compounds are carcinogenic. The upper respiratory tract stops the larger dust particles. When they are released into the environment, dust particles can cause acidification and winter smog.

(ii) **Cement-kiln dust:** Cement factories are the chief source of cement dust pollution. The composition of such dust varies with the source. Main component of cement dust is CaO and varying amounts of K_2O, Na_2O and KCl and traces of Al, Fe, Mn, Mg, S and silica. Dust with more than 24% CaO is more injurious to plants. Fine particles cause more damage than larger particles. Cement-kiln dust is alkaline in nature and dissolves in atmospheric moisture forming a solution of pH 10-12.

(iii) **Lime and gypsum:** Lime and gypsum processing industries and mining deposits are chief sources from where fine particles of these substances are blown away to great distances.

(iv) **Soot:** Burning of fossil fuels, organic matter or natural forest fires produce huge quantities of fine carbon particles which form the soot pollution. Soot can be dispersed over a quite wide area and transported to great distances by blowing winds.

(v) **Magnesium oxide:** Magnesium roasters are the chief sources of such pollution.

(vi) The magnesium oxide dust may be carried by winds and deposited even at a distance of 5 km from the source. In the atmosphere, magnesium sulphate ($MgSO_4$) combines with carbon dioxide and water to form $Mg(CO_3)_2$. Both these compounds are alkaline and slightly soluble in water.

(vii) **Boron:** Boric acid and borax are common raw materials in many industries. Oven and refrigerator manufacturing industries are chief sources of boron pollution.

(viii) **Chlorides of sodium, potassium and calcium:** Sodium and calcium chlorides are commonly used in cold countries on the roads during winters to melt ice and snow. Potash industry produces aerial emission of KCl and NaCl in ratio of 3:1. All such chlorides are carried away by winds and deposited on the soil and plants.

(ix) **Sodium sulphate:** Sodium sulphate with an annual production of 6 million tones, it is a major commodity chemical and one of the most damaging salts in structure conservation: when it grows in the pores of stones it can achieve high levels of pressure, causing structures to crack. Sodium sulfate is mainly used for the manufacture of detergents and in the Kraft process of paper pulping. About two-thirds of the world's production is from mirabilite, the natural mineral form of the decahydrate, and the remainder from by-products of chemical processes such as hydrochloric acidproduction.

(x) **Pesticides, insecticides and herbicides:** Pesticide use in the agricultural industry began in earnest in the early 1940s. Although pesticide use had been

(xi) quite popular for more than twenty years, government officials first became aware of the potential danger of pesticide runoff to humans in the early 1960s when Rachel Carson's famous and influential *Silent Spring* was published. Though this book warned mainly of the detrimental effects of DDT (a popular insecticide developed in the early 1940s) for birds and other non-human victims, Carson's work inspired health officials to speculate about the effects of pesticide runoff on humans. Recently, exposure to DDT was linked to Parkinson's disease. Because of concern over DDT's adverse effects on the environment and on people, this pesticide was banned in 1972. Despite the ban of DDT, pesticide use continues, and the effects of some modern insecticides and herbicides can be just as debilitating. Even through careful use, runoff from pesticides continues to makes its way into drinking water sources.

6.3.3 Secondary pollutants

(i) **Photo-oxidants:** In presence of strong sunlight and in hot weather a series of complex chemical reactions involving nitrogen oxides and hydrocarbons may produce certain photo- oxidant chemicals. These chemicals do not have any specific anthropogenic source but are formed over wide areas in which suitable environmental conditions are prevailing. Two such photo-oxidants that can reach ambient concentrations toxic to plants are PAN (Peroxyacetylnitrate) and ozone.

(ii) PAN (Peroxyacetylnitrate-$CH_3CO.O_2.NO_2$) Impact of this secondary pollutant is not affected by humidity. However, the impact decreases with lowering of temperature and increasing drought conditions. The impact also increases in the morning and in bright sunlight. Young plants and young rapidly expanding leaves are more sensitive to this pollutant. PAN interacts with SO_2 and O_3 in complex manner producing variable impact conditions.

(iii) Ozone (O_3): Ozone is the main pollutant in the oxidant smog complex. It is formed

(iv) in the troposphere when sunlight causes complex photochemical reactions involving oxides of nitrogen (NOx), volatile organic hydrocarbons (VOC) and carbon monoxide that originate chiefly from gasoline engines and burning of other fossil fuels. Woody vegetation is another major source of VOCs. NOx and VOCs can be transported long distances by regional weather patterns before they react to create ozone in the atmosphere, where it can persist for several weeks. Seasonal exposures at low elevations consist of days when ozone concentrations are relatively low or average, punctuated by days when concentrations are high. Concentrations of ozone are highest during calm, sunny, spring and summer days when primary pollutants from urban areas are present. Ozone concentrations in rural areas can be higher than in urban areas while ozone levels at high elevations can be relatively constant throughout the day and night. Middle aged leaves and young plants are more sensitive to ozone. This pollutant interacts with SO_2, NO_2, PAN and heavy metals in complex manner. Ozone is created through photochemical transfer of oxygen. This process takes place under the influence of ultra violet sunlight (UV), aided by pollutants in the outside air (fig. 2). Ozone causes smog and contributes to acidification and climate change. Ozone is an aggressive gas. This can easily penetrate the respiratory tract, deeply. When humans are exposed to ozone, the consequences may be irritation of the eyes and the respiratory tract.

(v) Acid deposition: Various acid gases, aerosols and other acidic substances released into the atmosphere from the industrial or domestic sources of combustion of fossil fuels eventually come down to the ground. These substances are deposited directly on the water bodies. In addition, these substances also reach the water bodies along with run-off rainwater from the polluted soil. Deposition of acidic substances causes acidification of water by lowering its pH below 6.0. The sulphates, nitrates and chlorides have been reported to make water bodies like lakes, rivers and ponds acidic in many countries. Acid deposition is not merely characterized as acid rain; it can also be snow and fog or gas and dust. Acid deposition mainly forms during fossil fuel combustion. When emissions of sulphur dioxide and nitrogen oxides come in contact with water, they will become sulphuric acid and nitric acid. When acidifying agents, such as sulphur dioxide, nitrogen oxides and ammonia, end up in plants, surface water and soils, this has a number of consequences: availability of nutrients and metal spores is likely to decrease when acidity is high more metals will dissolve in water. This can cause surface water to become polluted, which has serious health effects on aquatic plants and animals. For example, high aluminum (Al) concentrations can complicate nutrients uptake by plants. This makes aluminum one of the prior causes of forest decay. Mercury can be dispersed by transport through surface water, causing it to accumulate in fish. Mercury can bio magnify up the food chain, to be taken up by humans eventually. Buildings and monuments may be damaged through erosion. Sulphur dioxide breaks down limestone by reacting with calcium carbonate, causing limestone to absorb water during rainfall. Limestone will than fragment

(vi) Noise pollution: Noise pollution has a relatively recent origin. It is a composite of sounds generated by human activities ranging from blasting stereo systems to the roar of supersonic transport jets. Although the frequency (pitch) of noise may be of major importance, most noise sources are measured in terms of intensity, or strength of the sound field. The standard unit, one decibel (dB), is the amount of sound that is just audible to the average human. The decibel scale is somewhat misleading because it is logarithmic rather than linear; for example, a noise source measuring 70 dB is 10 times as loud as a source measuring 60 dB and 100 times as loud as a source reading 50 dB. Noise may be generally associated with industrial society, where heavy machinery, motor vehicles, and aircraft have become everyday items. Noise pollution is more intense in the work environment than in the general environment, although ambient noise increased an average of one dB per year during the 1980s. The average background noise in a typical home today is between 40 and 50 decibels. Some examples of high-level sources in the environment are heavy trucks (90 dB at 15 m/50 ft), freight trains (75 dB at 15 m/50 ft), and air conditioning (60 dB at 6 m/20 ft).

(vii) **Radiation pollution:** Radiation pollution is any form of ionizing or no ionizing radiation that results from human activities. The most well-known radiation results from the detonation of nuclear devices and the controlled release of energy by nuclear-power generating plants (see nuclear energy). Other sources of radiation include spent-fuel reprocessing plants, by- products of mining operations, and experimental research laboratories. Increased exposure to medical x rays and to radiation emissions from microwave ovens and other household appliances, although of considerably less magnitude, all constitute sources of environmental radiation.

(viii) **Radioactive radiation:** Radioactive radiation and radioactive particles are naturally present in the environment. During power plant incidents or treatments of nuclear waste from a war where nuclear weapons are used, radioactive radiation can enter the air on account of humans. When humans are exposed to high levels of radioactive radiation, the chances of serious health effects are very high. Radioactive radiation can cause DNA alteration and cancer.

6.4 Flow of atmospheric pollutants at global level

The air pollutants are produced by different sectors of the economy like: industry, agriculture, transports and urbanization. The burning of hydrocarbons in motor vehicle engines gives rise to CO_2, CO, SO_2 (sulfur dioxide), NO_x (NO [nitrogen monoxide]) and NO_2^-- in varying proportions-and C_2H_4 (ethylene), as well as a variety of other hydrocarbons. Additional SO_2 originates from domestic and industrial burning of fossil fuels. Industrial plants, such as chemical works and metal-smelting plants, release SO_2, H_2S, NO_2, and HF (hydrogen fluoride) into the atmosphere. Tall chimney stacks may be used to carry gases and particles to a high altitude and thus avoid local pollution, but the pollutants return to Earth, sometimes hundreds of kilometers from the original source.

Photochemical smog is the product of chemical reactions driven by sunlight and involving NO_x of urban and industrial origin and volatile organic compounds from either vegetation (*biogenic* hydrocarbons) or human activities (*anthropogenic* hydrocarbons). Ozone (O_3) and peroxyacetylnitrate (PAN) produced in these complex reactions can become injurious to plants and other life forms, depending on concentration and duration of exposure. Hydrogen peroxide, another potentially injurious molecule, can form by the reaction between O_3 and naturally released volatiles (terpenes) from forest trees. The concentrations of polluting gases, or their solutions, to which plants are exposed are thus highly variable, depending on location, wind direction, rainfall, and sunlight. Experiments aimed at determining the impact of chronic exposure to low concentrations of gases should allow plants to grow under near-natural conditions. One method is to grow the plants in open-top chambers into which gases are carefully

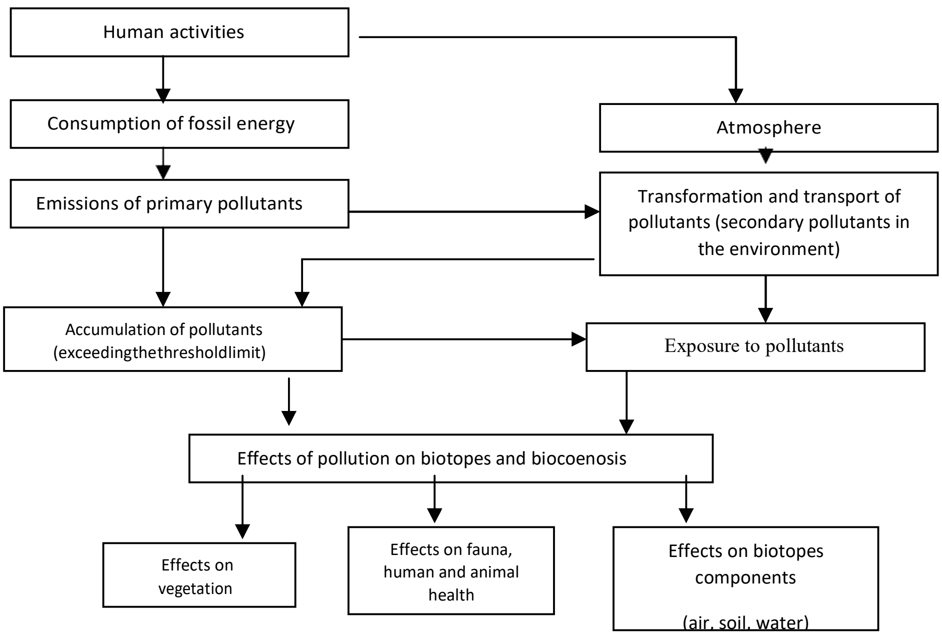

Fig. 3. The air pollutants flow diagram

metered, or where plants receiving ambient, polluted air are compared with controls receiving air that has been scrubbed of pollutants. These pollutants emitted into the atmosphere can react with components of the atmosphere and transform into more or less aggressive or toxic compounds. The air pollutants can accumulate and manifest directly effects in the atmosphere (greenhouse effect, ozone layer depletion, etc) or can to transform in other pollutants and manifest indirectly effects on ecosystem biocoenosis, plants, animals and human health (fig. 3)

6.5 Effect of pollutants on vegetation, direct effects, and indirect effect, gas toxicity, wet and dry deposition, and deposition mixtures

Dust pollution is of localized importance near roads, quarries, cement works, and other industrial areas. Apart from screening out sunlight, dust on leaves blocks stomata and lowers their conductance to CO_2, simultaneously interfering with photosystem II. Polluting gases such as SO_2 and NO_x enter leaves through stomata, following the same diffusion pathway as CO_2. NO_x dissolves in cells and gives rise to nitrite ions (NO_2^-, which are toxic at high concentrations) and nitrate ions (NO_3^-) that enter into nitrogen metabolism as if they had been absorbed through the roots. In some cases, exposure to pollutant gases, particularly SO_2, causes stomatal closure, which protects the leaf against further entry of the pollutant but also curtails photosynthesis.

In the cells, SO_2 dissolves to give bisulfite and sulfite ions; sulfite is toxic, but at low concentrations it is metabolized by chloroplasts to sulfate, which is not toxic. At sufficiently low concentrations, bisulfite and sulfite are effectively detoxified by plants, and SO_2 air pollution then provides a sulfur source for the plant. In urban areas these polluting gases may be present in such high concentrations that they cannot be detoxified rapidly enough to avoid injury. Ozone is presently considered to be the most damaging phytotoxic air pollutant in North America [18], [19]. It has been estimated that wherever the mean daily O_3 concentration reaches 40, 50, or 60 ppb (parts per billion or per 10^9), the combined yields of soybean, maize, winter wheat, and cotton would be decreased by 5, 10, and 16%, respectively. Ozone is highly reactive: It binds to plasma membranes and it alters metabolism. As a result, stomatal apertures are poorly regulated, chloroplast thylakoid membranes are damaged, rubisco is degraded, and photosynthesis is inhibited. Ozone reacts with O_2 and produces reactive oxygen species, including hydrogen peroxide (H_2O_2), superoxide (O_2^-), singlet oxygen ($^1O_2^*$), and the hydroxyl radical ($^{\cdot}OH$). These denature proteins and damage nucleic acids (thereby giving rise to mutations), and cause lipid peroxidation, which breaks down lipids in membranes. Reactive oxygen species form also in the absence of O_3, particularly in electron transport in the mitochondria and chloroplasts, when electrons can be donated to O_2. Cells are protected, at least in part, from reactive oxygen species by enzymatic and nonenzymatic defense mechanisms [20], [21]. Defense against reactive oxygen species is provided by the scavenging properties of molecules, such as ascorbic acid, α-tocopherol, phenolic compounds, and glutathione. Superoxide dismutases (SODs) catalyze the reduction of superoxide to hydrogen peroxide.

Hydrogen peroxide is then converted to H_2O by the action of catalases and peroxidases. Of particular importance is the ascorbate-specific peroxidase localized in the chloroplast. Acting in concert, ascorbate peroxidase, dehydroascorbate reductase, and glutathione reductase remove H_2O_2 in a series of reactions called the *Halliwell–Asada pathway*, named after its discoverers. Glutathione is a sulfur-containing tripeptide that, in its reduced form, reacts rapidly with dehydroascorbate and becomes oxidized in the process. Glutathione reductase catalyzes the regeneration of reduced glutathione (GSH) from its oxidized form (GSSG) in the followingreaction:

$$\mathbf{GSSG + NADPH + H^{+} \rightarrow 2\ GSH + NADP^{+}}$$

Exposure of plants to reactive oxygen species stimulates the transcription and translation of genes that encode enzymes involved in protection mechanisms. In Arabidopsis, exposure for 6 hours per day to low levels of O_3 induces the expression of several genes that encode enzymes associated with protection from reactive oxygen species, including SOD, glutathione S- transferase (which catalyzes detoxification reactions involving glutathione), and phenylalanine ammonia lyase (an important enzyme at the start of the phenylpropanoid pathway that leads to the synthesis of flavonoids and other phenolics) [22].

In transgenic tobacco transformed with a gene from *Escherichia coli* to give additional glutathione reductase activity in the chloroplast, short-term exposure to high levels of SO_2 is much less damaging than for wild-type tobacco [23]. Environmental extremes may either accelerate the production of reactive oxygen species or impair the normal defense mechanisms that protect cells from reactive oxygen species. In water-deficient leaves,for example, greater oxygen photoreduction by photosystems I and II increases superoxide production, and the pool of glutathione, as well as the activity of glutathione reductase, increase-presumably as part of the cell defense mechanism. In contrast, levels of ascorbate, another antioxidant, generally decline with mild water stress. Transgenic plants overexpressing mitochondrion superoxide dismutase (Mn-SOD), the isozyme localized in the mitochondrial matrix, show less water-deficit damage and, significantly, improved survival and yield under field conditions [24]. In other experiments, transgenic alfalfa overexpressing Mn-SOD was found to be more tolerant of freezing. Conversely, winter rye, wheat, and barley acclimated at 2 °C for several weeks, were found to have developed resistance to the herbicides, paraquat and acifluorfen, which generate reactive oxygen species. Such investigations support the hypothesis that tolerance of oxidative stress is an important factor in tolerance to a wide range of environmental extremes. Many deleterious changes in metabolism caused by air pollution precede external symptoms of injury, which appear only at much higher concentrations. For example, when plants are exposed to air containing NO_x, lesions on leaves appear at a NO_x concentration of 5 ml/l, but photosynthesis starts to be inhibited at a concentration of only 0.1 ml/l.

These low, threshold concentrations refer to the effects of a single pollutant. However, two or more pollutants acting together can have a synergistic effect, producing damage at lower concentrations than if they were acting separately. In addition, vegetation weakened by air pollution can become more susceptible to invasion by pathogens and pests. Unpolluted rain is slightly acidic, with a pH close to 5.6, because the CO_2 dissolved in it produces the weak acid, H_2CO_3. Dissolution of NO_x and SO_2 in water droplets in the atmosphere causes the pH of rain to decrease to 3 to 4, and in southern California polluted droplets in fog can be as acidic as pH 1.7. Dilute acidic solution can remove mineral nutrients from leaves, depending on the age of the leaf and the integrity of the cuticle and surface waxes. The total annual contributions to the soil of acid from acid rain (*wet deposition*) and from particulate matter falling on the soil plus direct absorption from the atmosphere (*dry deposition*) may reach 1.0 to 3.0 kg H^+ per hectare in parts of Europe and the northeastern United States [25]. In soils that lack free calcium carbonate, and therefore are not strongly buffered, such additions of acid can be harmful to plants. Furthermore, the added acid can result in the release of aluminum ions from soil minerals, causing aluminum toxicity. Air pollution is considered to be a major factor in the decline of forests in heavily polluted areas of Europe and North America. There are indications that fast-growing pioneer species are better able to tolerate an acidifying atmosphere than are climax forest trees, possibly because they have a greater potential for assimilation of dissolved NO_x, and more effective acid buffering of the leaf tissue cell sap. Air pollution injury to plants can be evident in several ways. Injury to foliage may be visible in a short time and appear as necrotic lesions (dead tissue), or it can develop slowly as a yellowing or chlorosis of the leaf. There may be a reduction in growth of various portions of a plant. Plants may be killed outright, but they usually do not succumb until they have suffered recurrent injury.

Major primary air pollutants gases are sulphur dioxide, oxides of nitrogen particularly NO_2, HF, HCl, chlorine, ammonia, ethylene and other organic substances. Particulate air pollutants are soot, dust, fine particles of cement and various other substances. Various fertilizers, pesticides and insecticides used in aerial spray are also important air pollutants. The common sources of the pollutants, factors affecting the effect of pollutant and the injury symptoms produced in plants are discussed below.

6.6 Major gaseous pollutants

(i) Sulphur dioxide (SO_2): Sulfur dioxide is a major component in acid rain. One of the byproducts of sulfur dioxide is sulfuric acid, and both can be extremely damaging to plants that are exposed to these chemicals. Exposed leaves can begin to lose their color in irregular, blotchy white spots. Some leaves can develop red, brown or black spots. When the pigments in enough tissue are damaged or killed, plants can begin to lose their leaves. Crop output is greatly reduced and growth can be stunted. This is especially noticeable in young plants. It is the most important and common air pollutant produced in huge amounts in combustion of coal and other fuels in industrial and domestic use. It is also produced during smelting of sulphide ores. Major sources of sulfur dioxide are coal-burning operations, especially those providing electric power and space heating. Sulfur dioxide emissions can also result from the burning of petroleum and the smelting of sulfur containing ores.

SO_2 effects increase in high humidity, windy conditions, in the early morning, in the deficiency of K and Cl_2 and excess of sulphur in the soil. It interacts with ozone, NO_2 and HF. The nature of interaction depends on the relative proportion of gases. The impact of SO_2 decreases in low soil moisture, low temperature, deficiency of nitrogen, sulphur and phosphorus and sometimes in excess of nitrogen also.

In angiosperms, young leaves and in conifers, needles are most sensitive to SO_2 pollution. In general, seedlings are more sensitive than older plants. The effect of the gas usually decreases with age of the plant and lesser morphological and physiological symptoms appear in older plants.

Injury symptoms: The gas is a strong reducing agent. In low concentration, it is oxidized and used in protein synthesis of the plant. However, in high concentration, it causes swelling of thylakoids and interferes with electron transport chain. In SO_2 pollution, plants show initial reduction of photosynthesis and increased respiration. The gas reduces stomatal opening and thus causes general water stress in plants. SO_2 replaces oxygen in cellular materials and changes their nature. It affects structural proteins in the cell membrane and thus changes the membrane permeability. High concentration of the gas causes accumulation of sulphydril and decrease of sulphides in plants. SO_2 interferes with amino acid metabolism and reduces the synthesis of proteins and enzymes. It stimulates the oxidation of PGA and increases the pentose phosphate cycle activity. It reduces the level of keto acids, ATP, sucrose and glutamate in plants and increases the level of glucose, fructose and glycolate. It inactivates many enzymes either by breaking their S-S bonds or by changing their stereo structure. In lichens, the gas induces photooxidation in the phycobiont part. Most common visible

Fig. 4. Acute sulfur dioxide injuries to raspberry [26].

symptom of SO_2 injury is water-soaked appearance of leaves which later become necrotic changing into brown spots. Color and shape of necrotic spots is characteristic in different species and NO_2 concentrations. In some species, characteristic intraveinal chlorosis is caused. In general, SO_2 pollution results in abscission of older leaves and tip necrosis in flower and sepals.

Sulfur dioxide enters the leaves mainly through the stomata (microscopic openings) and the resultant injury is classified as either acute or chronic. Acute injury (fig. 4) is caused by absorption of high concentrations of sulfur dioxide in a relatively short time. The symptoms appear as 2-sided (bifacial) lesions that usually occur between the veins and occasionally along the margins of the leaves. The colors of the necrotic area can vary from a light tan or near white to an orange-red or brown depending on the time of year, the plant species affected and weather conditions. Recently expanded leaves usually are the most sensitive to acute sulfur dioxide injury, the very youngest and oldest being somewhat more resistant.

Chronic injury is caused by long-term absorption of sulfur dioxide at sub-lethal concentrations. The symptoms appear as a yellowing or chlorosis of the leaf, and occasionally as a bronzing on the under surface of the leaves. Different plant species and varieties and even individuals of the same species may vary considerably in their sensitivity to sulfur dioxide. These variations occur because of the differences in geographical location, climate, stage of growth and maturation. The following crop plants are generally considered susceptible to sulfur dioxide: alfalfa, barley, buckwheat, clover, oats, pumpkin, radish, rhubarb, spinach, squash, Swiss chard and tobacco. Resistant crop plants include asparagus, cabbage, celery, corn, onion and potato. Plants damaged by sulfur dioxide can be as far as 30 miles from its source, but the most severe damage, defoliation and discoloring is typically found within five miles. For some plants, it can take exposure of only four hours to suffer damage. A wide variety of plants are vulnerable, from alfalfa and carrots to crab apple and fir trees.

(ii) Nitrogen dioxide (NO_2): NO_2 mostly affects the leaves and seedlings. Its effects decrease with increasing age of the plant and tissue. Conifers are found to be more sensitive to this gas during spring and summer than in winters. Older needles are more sensitive to the gas than young ones. Injury symptoms: The gas causes formation of crystalloid structures in the stroma of chloroplasts and swelling of thylakoid membrane. As a result the photosynthetic activity of the plant is reduced. Most common visible injury symptoms are chlorosis in angiospermic leaves and tip burn in conifer needles. In angiosperms, most of the species produce water-soaked intraveinal areas that later become necrotic. Tip burn is common symptom in bracts, sepals and awns.

(iii) Fluorides: Fluirides in general, are accumulated in the plant tissues over long times. They are first accumulated in the leaves and then are translocated towards tips and margins of the leaves. The injury symptoms are produced only after a critical level of fluoride is attained. Due to such accumulation over long times, flurides generally and HF particularly can induce injury at very low atmospheric concentrations. Critical concentration for fluoride injury is 0.1 ppm for several days. Toxicity of particulate fluorides depends upon the particle size, their solubility and humidity of the atmosphere. HF gas is much lighter than air and so can cause damage in plants even at a distance of 30 km from the source. It is a hygroscopic gas and forms acidic cloud near the source. Generally the impact of HF pollution increases with humidity and excess of P in soil while decreases in low temperature, drought and deficiency of N and Ca in the soil.

In some species, impact of HF has been reported to decrease with excess of N and Ca in the soil. In most of the species, recovery from moderate fluoride injury can occur within few days if exposure to pollutant stops. However, some highly sensitive species e.g. pine and spruce can never recover fully. HF generally affects immature leaves in angiosperms and needles in conifers. Injury symptoms: Fluorides combine with metal components of proteins or inhibit them otherwise and thus interfere with the activity of many enzymes. As a result the cell wall composition, photosynthesis, respiration, carbohydrate synthesis, synthesis of nucleic acids and nucleotides and energy balance of the cell are affected. In the leaves subjected to HF exposure, endoplasmic reticulum is reduced, ribosomes are detached from ER, number of ribosomes is reduced and mitochondria become swollen. Chlorophyll synthesis and cellulose synthesis are inhibited. Activities of UDP-glucose-fructose transglucosylase, phosphoglucomutase, enolase and polyphenol oxidase are reduced. On the other hand activities of catalase, peroxidase, pyruvate kinase, PEP-carboxylase, glucose-6-phosphate dehydrogenase, cytochrome oxidase and pentose phosphate pathway are stimulated. In conifer needles common visible injury symptoms are chlorosis later turning into red/brown discolouration, tip burn later turning into necrosis of whole needle, formation of sharply defined red/purple bands between healthy and injured tissue. Similar symptoms are common in angiospermic leaves also. In addition, the angiospermic leaves in many species also show zonation of necrotic areas, leaf cupping, curling of leaf edges and ragged leaf margins. In sepals, petals, bracts and awns, water-soaked margins and later tip and marginal necrosis are observed. Fluorides absorbed by leaves are conducted towards the margins of broad leaves (grapes) and to the tips of monocotyledonous leaves (gladiolus).

Little injury takes place at the site of absorption, whereas the margins or the tips of the leaves build up injurious concentrations. The injury (fig. 5) starts as a gray or light-green water-soaked lesion, which turns tan to reddish-brown. With continued exposure the necrotic areas increase in size, spreading inward to the midrib on broad leaves and downward on monocotyledonous leaves.

Fig. 5. Fluoride injuries to plum foliage [26].

The fluoride enters the leaf through the stomata and is moved to the margins where it accumulates and causes tissue injury. Note, the characteristic dark band separating the healthy (green) and injured (brown) tissues of affected leaves. Studies of susceptibility of plant species to fluorides show that apricot, barley (young), blueberry, peach (fruit), gladiolus, grape, plum, prune, sweet corn and tulip are most sensitive. Resistant plants include alfalfa, asparagus, bean (snap), cabbage, carrot, cauliflower, celery, cucumber, eggplant, pea, pear, pepper, potato, squash, tobacco and wheat.

(iv) Chlorine (Cl_2): Older plants are more sensitive to chlorine than seedlings. The age of tissue has little effect on the sensitivity and older as well as young tissues are almost equally afected by chlorine pollution. Injury symptoms: Chlorine injury symptoms can appear from 18 hours to 8 days after exposure. In most plant species, recovery from chlorine injury can occur 3 to 4 days after exposure is stopped. Chlorine injury symptoms are quite variable in different species. Most common visible symptoms in conifers are chlorosis, tip burn and necrosis is needles. In angiosperm leaves, marginal or intraveinal necrosis, water-soaked appearance, leaf cupping and abscission are common.

(v) Hydrogen chloride (HCl): The HCl injury can be caused to plants even at a distance of 800 meter from the source. Like fluorides, the chloride from HCl is accumulated in the leaves and translocated towards their margins and tips. Symptoms of HCl injury appear after a critical concentration is reached, usually between 24 and 72 hours after the exposure.

Impact of HCl pollution decreases with increase in humidity, deficiency of Mg and excess of Ca. Mature plants are more sensitive to HCl than seedlings. Similarly, young fully expanded leaves are more sensitive than immature unexpanded leaves.

Injury symptoms: Most common visible injury symptoms in conifer needles are red or brown discolouration and tip burn. In angiosperm leaves, common symptoms are intraveinal water-soaked streaks, yellow or brown necrosis, tip necrosis, bleached areas around the necrosis and shot-holing. Tip burn, necrotic stipple and discolouration in sepals and petals are also observed.

(vi) Ammonia (NH_3): Impact of ammonia on plants generally increases with humidity and decreases with drought. Effect of darkness on ammonia sensitivity is highly variable among species. Some species are more sensitive to low concentrations of ammonia than to its high concentration. Age of

Fig. 6. Severe ammonia injuries to apple foliage and subsequent recovery through the production of new leaves following the fumigation [26].

tissue has little effect on sensitivity and both young and old tissues are equally sensitive to ammonia.Injury symptoms: Most common visible symptoms in conifers are black discolouration, usually sharply bordered tip burn and abscission of needles. In angiosperm leaves, common symptoms are water-soaked appearance later turning black, intercostal necrosis, slight marginal and upper surface injury, glazong/bronzing of upper surface, desiccation and abscission. Ammonia injury to vegetation has been observed frequently in Ontario in recent years following accidents involving the storage, transportation or application of anhydrous and aqua ammonia fertilizers. These episodes usually release large quantities of ammonia into the atmosphere for brief periods of time and cause severe injury to vegetation in the immediate vicinity. Complete system expression on affected vegetation usually takes several days to develop, and appears as irregular, bleached, bifacial, necrotic lesions. Grasses often show reddish, interveinal necrotic streaking or dark upper surface discolouration. Flowers, fruit and woody tissues usually are not affected, and in the case of severe injury to fruit trees, recovery through the production of new leaves can occur (fig. 6). Sensitive species include apple, barley, beans, clover, radish, raspberry and soybean. Resistant species include alfalfa, beet, carrot, corn, cucumber, eggplant, onion, peach, rhubarb and tomato.

(vii) Organic gases (Ethylene): Ethylene injury symptoms develop in plants only in exposure to high concentrations and take several days to develop. After exposure to the gas is stopped, level of recovery is variable in different species. Generally, younger plant parts recover but older parts do not. Much 'acute' damage to plants is caused on the fringes of polluted area or by a steady leakage of gas in low concentration.

Injury symptoms: In injuriously high concentrations of ethylene, growth of plants is stopped. In low concentrations, growth abnormalities appear. In conifers, yellow tips in needles and abscission of branches and cones are common. In angiosperms, common symptoms are epinasty or hyponasty, loss of bark, abscission of leaves and flowers, premature flower opening and fruit ripening. Ethylene affects the growth hormones and regulatory process that takes place in the plant and results in a number of outward manifestations of infection. Leaves can begin to curl and die; ethylene causes the leaves of plants to curl down and fold under as they shrivel and are stuck with necrosis. On flowering plants, buds can stop opening or flowers can begin to show signs of discoloration or die and drop sooner than expected. Even in more resistant plants like evergreen conifers, growth of the plant will be stunted, needles will be small and few pine cones will be produced. Plants such as peach trees, marigolds, blackberries and tomatoes are extremely vulnerable to damage from exposure toethylene.

6.7 Minor gaseous pollutants

(i) Hydrogen sulphide (H_2S): Plants show wilting on exposure to this gas but the symptoms develop after about 48 hours. No injury occurs below the exposure of 40 ppm for 4 hours.

(ii) Carbon monoxide (CO): Like ethylene this gas produces epinasty, chlorosis and abscission. However,concentration of over 1000 times that of ethylene is needed to produce same degree of damage. No injury to plants occurs below exposure of 100 ppm for 1 week.

(iii) Bromine (Br_2) and Iodine (I_2): Studies show these gases are highly toxic to plants. HI and I_2 are readily absorbed and accumulated by plants producing visible injury symptoms similar to those of SO_2. Injury occurs at exposure of 0.1 ppm for 18 hours.

(iv) Common injury symptoms of bromine in angiosperms are necrosis of leaf margins, leaf tips and tendrils; brown discoloration and black spots later spreading to entire leaf. In conifers, yellow/white needle tips or red/brown discoloration later becoming grey/brown are common symptoms.

(v) Mercury vapors (Hg): Unlike other pollutants, flowers are more sensitive to Hg than leaves. Injury symptoms usually appear within 24 hours of Hg exposure but often go on increasing up to 5 days.

(vi) Common injury symptoms due to Hg-vapors pollution are abscission of oldest leaves, interveinal necrosis, chlorosis around veins, flower abscission, loss of petal colors, buds remaining closed and later becoming necrotic, blackening of stamens, pistils and peduncles.

(vii) Particulate pollutants: Different types of solid particulate materials are also important air pollutants. Each of these affects the plants in characteristic manner. Some common particulate air pollutants have been discussed below.

(viii) Cement-kiln dust: In generals, plants having hairy surface of leaves trap more dust and are, therefore, damaged more than the plants with shiny leaf surface. The cement dust forms crusts on the surface of leaves, twigs and flowers. This inhibits gaseous exchange from the surfaces of plant parts. Such crust on the leaves also inhibits light penetration and consequently reduces photosynthesis. Such crusts are especially thicker in conditions of dew, mist or light rains. In dry conditions, dust blowing with wind is highly abrasive and damages the cuticle of leaves. Cuticle is also damaged due to alkalinity of cement dust. Due to damaged cuticle plants become more susceptible to infection by pathogens.

(ix) Lime and gypsum: Lime and gypsum deposited on the soil from the air, these change the pH of the soil and thus affect the nutrient availability to plants. Such deposition usually causes appearance of various nutrient deficiency symptoms in the plants. Lime and gypsum are less adhering as compared to cement-kiln dust. However, these are also trapped and deposited on the surface of plant parts particularly the leaves with hairy surfaces and produce injury symptoms similar to cement dust. Lime and gypsum particles blowing with wind are also highly abrasive for cuticle.

(x) Soot: Soot deposited on the surface of leaves may be washed away by rains so its damage may be reduced. However, in bright sunlight and high temperature, the damage is increased.

(xi) Soot deposited on the surface of leaves inhibits light penetration, increased surface temperature due to absorption of heat and clogging of stomata. The result of these is reduced gaseous exchange, reduced photosynthesis and general weakening of the plant growth. Necrotic spots also develop in many species due to soot deposition.

(xii) Magnesium oxide: Deposited on the soil these compounds can soon increase the soil pH to levels injurious to plants. Deposition of these substances on the soil prevents germination of seedlings. The seedlings that are able to emerge usually have yellow/brown tips of leaves and their roots are stunted. In areas of heavy pollution, composition of the vegetation changes completely.

(xiii) Boron: Severe injury to plants is observed even at a distance of 200 meters from the source and mild injury may be observed up to 500 meters in all the directions from the source. Impact of boron pollution is more severe on older leaves than on younger leaves. Boron is also accumulated in the leaves and produces injury symptoms quite similar to fluoride pollution.

(xiv) Chlorides of sodium, potassium and calcium: Injury symptoms produced by these chlorides in plants are very similar to those produced by SO_2 and fluoride pollution.

(xv) Sodium sulphate: Dust can cause necrosis of leaves of the plants. The damage increases in moist condition.

(xvi) Pesticides, insecticides and herbicides: A large variety of such chemicals are sprayed on the crops these days. These substances may drift with wind to nearby areas. Generally, these chemicals are deposited on the soil and form important soil pollutants. However, in frosty conditions when crops and other plants damaged by early frost are quite susceptible to foliar spray of these chemicals, these may also be injurious air pollutants. Injury symptoms vary with the plant species and the type of chemical. Generally, the symptoms are produced on foliage and are quite similar to those produced when these substances act as soil pollutants.

6.8 Secondary pollutants and plants

Many of the primary pollutants under specific environmental conditions may interact with each other and produce secondary environmental pollutants or certain complex environmental conditions that are injurious to plants. Such secondary pollutants and pollution conditions are discussedbelow.

Fig. 7. Ozone injuries to soybean foliage [26].

(i) **Photo-oxidants PAN (Peroxyacetylnitrate- $CH_3CO.O_2.NO_2$):** The common visible symptoms of exposure to PAN are chlorosis and necrosis in leaves. It also interferes with photosynthesis, respiration and absorption and synthesis of carbohydrates and proteins. It inhibits photorespiration, NADP reduction, carbon dioxide fixation, cellulose synthesis and the enzymes associated with photosynthesis and respiration.

(ii) **Ozone (O_3):** It is released into the atmosphere from the burning of fossil fuels and is one of the most harmful pollutants to plants. It can be carried for long distances and is readily absorbed as a part of the photosynthetic process. Plants exposed to large amounts of ozone can develop spots on their leaves. These spots are irregular and often tan, brown or black. Some leaves can take on a bronze or red appearance, usually as a precursor to necrosis. Depending on the concentration of ozone in the environment, plants can show different amounts of discoloration before the leaves begin to die. Studies by the National Crop Loss Assessment Network show that ozone in the environment also has a detrimental effect on crop production. While crops such as cotton, soybeans and other dicots are more sensitive than monocot crops, all crops sampled over the decades-long studies show significant loss of productivity when exposed to ozone. Cotton crops show significantly less yield when exposed to levels of ozone in the atmosphere. Middle aged leaves and young plants are more sensitive to ozone. This pollutant interacts with SO_2, NO_2, PAN and heavy metals in complex manner.

(iii) Common symptoms of ozone pollution are yellowing, flecking and blotching in leaves, premature senescence and early maturity. It interferes with pollen formation, pollination, pollen germination and growth of pollen tubes. Increase in the level of RNA, starch, polysaccharides and number of polysomes is observed in ozone pollution. Ozone stimulates respiration, inhibits oxidative phosphorylation and changes membrane permeability. In some species, it inhibits the synthesis of glucon and cellulose and reduces the level of reducing sugars, ascorbic acid and ATP while in other species the effect is opposite to it. The impact of ozone, on plants increases with humidity and decreases with drought, darkness, low temperature, high soil salinity, deficiency of soil phosphorus and excess of soil sulphur. Throughout the growing season, particularly July and August, ozone levels vary significantly. Periods of high ozone are associated with regional southerly air flows that are carried across the lower. Localized, domestic ozone levels also contribute to the already high background levels. Injury levels vary annually and white bean, which are particularly sensitive, are often used as an indicator of damage. Other sensitive species include cucumber, grape, green bean, lettuce, onion, potato, radish, rutabagas, spinach, sweet corn, tobacco and tomato. Resistant species include endive, pear and apricot. Ozone symptoms (fig. 7) characteristically occur on the upper surface of affected leaves and appear as a flecking, bronzing or bleaching of the leaf tissues. Although yield reductions are usually with visible foliar injury, crop loss can also occur without any sign of pollutant stress. Conversely, some crops can sustain visible foliar injury without any adverse effect on yield. Susceptibility to ozone injury is influenced by many environmental and plant growth factors. High relative humidity, optimum soil-nitrogen levels and water availability increase susceptibility. Injury development on broad leaves also is influenced by the stage of maturity. The youngest leaves are resistant. With expansion, they become successively susceptible at middle and basal portions. The leaves become resistant again at complete maturation

Ground-level ozone causes more damage to plants than all other air pollutants combined. This web page describes the ozone pollution situation, shows classical symptoms of ozone injury and shows how ozone affects yield of several major crops. Ozone enters leaves through stomata during normal gas exchange. As a strong oxidant, ozone (or secondary products resulting from oxidation by ozone such as reactive oxygen species) causes several types of symptoms including chlorosis and necrosis. It is almost impossible to tell whether foliar chlorosis or necrosis in the field is caused by ozone or normal senescence. Several additional symptom types are commonly associated with ozone exposure, however. These include flecks (tiny light-tan irregular spots less than 1 mm diameter), stipples (small darkly pigmented areas approximately 2-4 mm diameter), bronzing, and reddening. Ozone symptoms usually occur between the veins on the upper leaf surface of older and middle-aged leaves, but may also involve both leaf surfaces (bifacial) for some species. The type and severity of injury is dependent on several factors including duration and concentration of ozone exposure, weather conditions and plant genetics. One or all of these symptoms can occur on some species under some conditions, and specific symptoms on one species can differ from symptoms on another. With continuing daily ozone exposure, classical symptoms (stippling, flecking, bronzing, and reddening) are gradually obscured by chlorosis and necrosis.

Studies in open-top field chambers have repeatedly verified that flecking, stippling, bronzing and reddening on plant leaves are classical responses to ambient levels of ozone. Plants grown in chambers receiving air filtered with activated charcoal (CF) to reduce ozone concentrations do not develop symptoms that occur on plants grown in non-filtered air (NF) at ambient ozone concentrations. Foliar symptoms shown on this web site mainly occurred on plants exposed to ambient concentrations of ozone (either in NF chambers or in ambient air).

(iv) Yield Loss Caused by Ozone: Field research to measure effects of seasonal exposure to ozone on crop yield has been in progress for more than 40 years. Most of this research utilized open-top field chambers in which growth conditions are similar to outside conditions. The most extensive research on crop loss was performed from 1980 to 1987 at five locations in the USA as part of the National Crop Loss Assessment Network (NCLAN). At each location, numerous chambers were used to expose plants to ozone treatments spanning the range of concentrations that occur in different areas of the world. The NCLAN focused on the most important agronomic crops nationally. The strongest evidence for significant effects of ozone on crop yield comes from NCLAN studies [18] (fig. 8). The results show that dicotyledonous species (soybean, cotton and peanut) are more sensitive to yield loss caused by ozone than monocot species (sorghum, field corn and winter wheat).

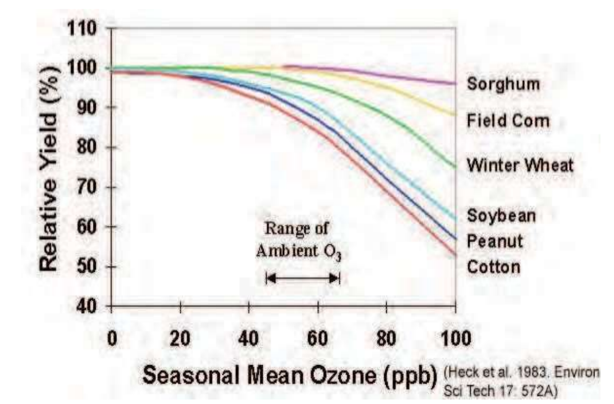

Fig. 8. Effect of ozone on yield of crops [18]. cotton image by arklite06 from.

(v) Particulate Matter: Particulate matter such as cement dust, magnesium-lime dust and carbon soot deposited on vegetation can inhibit the normal respiration and photosynthesis mechanisms within the leaf. Cement dust may cause chlorosis and death of leaf tissue by the combination of a thick crust and alkaline toxicity produced in wet weather. The dust coating (fig. 9) also may affect the normal action of pesticides and other agricultural chemicals applied as sprays to foliage. In addition, accumulation of alkaline dusts in the soil can increase soil pH to levels adverse to crop growth.

6.9 Effects of atmospheric pollutants on vegetation monitoring system

Because the crop plants are mostly annual plants they cannot show the long-term effects produced by air pollutants. Therefore to monitor the effects of air pollution are recommended the trees, the changes in forest structure highlight the harmful effects of different air pollutants.The evident decline of the health state of the forest in Europe since the beginning of the 1980 due to the negative impact of air pollution were illustrated by numerous publication from this period (see litt.). In the efforts to obtain objective and comparable data concerning the health of the European forests were developed a common methodology for the assessment of the forest state under the influence of air pollution. This network is known under the short term ICP- Forest (International Cooperative Programme for the investigation of the trans-boundary Pollution Influence on the Forests). The poor health status of the forests in Central Europe concerns all the Europe. The pictures of the forests on large area were dominated by tree with defoliated crowns and an increasing rate of the death trees (fig 10). The assessment of the causes of the “new damages“- neuartiges waldschaden, in germ– is not easy

Fig. 9. Cement dust coating on apple leaves and fruits. The dust had no injurious effect on the foliage, but inhibited the action of a pre-harvest crop spray [26].

because the symptoms of the decline were different from the symptoms of the damages caused by natural (biotic and abiotic) and anthropiccauses.

Under the umbrella of ICP Forest Programme, were developed and implemented an European network of plots for the assessment of the parameters of the trees crowns condition known as Level I plots. The grid of the European Level I plots were established at 16 * 16 km, arranged on a transnational unified grid over Europe. In comparison with the national grids used by each country the obtained data were relevant for the evaluation of the forest health state at European level. After 1996 were put in function the Level II monitoring plots used for the intensive monitoring and collection of comparable data related to the changes in forest ecosystems which are directly connected to specific environment at factors such as atmosphere pollution and acid deposition. Such data can help in a better understanding at the relation causes and effects in the forests decline.

The monitoring results contribute to the scientific basis of air pollution control policies of UN/ECE and the European Commission (EC). Fifteen years of monitoring forest condition and two decades of forest damage research have shown, however, that the discussion of recent forest damage must not be confined to the effects of air pollution alone. The comprehensive monitoring programme corresponds to the complex interrelations between natural and anthropogenic factors in forest ecosystems. Infrastructure and data of the programme are thought to be relevant for other processes of international forest policies, e.g. those on biodiversity, climate change and sustainable forest management. In this respect the monitoring pursues the objectives of Resolution SI of the Strasbourg, Resolution HI of the Helsinki and Resolution, L2 of the Lisbon

Fig. 10. General aspects of silver fir crowns affected by decline in the border of the northern Carpathians (Forest District Solca).

Ministerial Conference on the Protection of Forests in Europe, and contributes to global forest policies such as the United Nations Forum on Forests (ICP- Report 2007).

6.10 Protection

The effects of injury by pollutants and its accompanying poisonous gases will usually be noted first through the discoloration of foliage, later by defoliation, and eventually by the death of injured portions or of the entire tree (Tourney 1921). Where the injury is not serious enough to kill the tree, there will at least be a decided slowing-up in the growth rate of forest trees subjected to continuous exposure to smoke and gases. Fortunately most forest areas are not exposed constantly to large volumes of smoke with their poisonous fumes. It is only in the neighborhood of occasional smelters that the damage becomes extreme. The intensity of the attack depends primarily upon the concentration of the poisonous gas and the distance from the smokestack, modified, however, by wind direction and topography. The worst injury is concentrated in the vicinity of smelters such as the one maintained by the Anaconda Copper Company at Anaconda, Montana. In the vicinity of plants of this type, forest vegetation unless located in areas sheltered from the smoke stream may be destroyed for miles around the plant. Mason (1915) states that destruction of lodgepole pine forests occurred in some places 9 miles distant from the Anaconda smelter and that slight damage was experienced at distances of 30 miles. Conifers suffer more severely than broad-leaved trees, primarily because they retain their foliage for more than 1 year. The older foliage on the conifers, having been affected longer by the poisonous fumes, is likely to show more severe injury than foliage of the current year's growth.

Prevention of injury to forest trees from Pollutants (smoke and poisonous gases) must come through treatment of the smoke before it leaves the stack. The matter of controlling the emission of poisonous gases and smoke from industrial plants has been investigated quite thoroughly, both by men in this country and by workers abroad, because of the injuries suffered by vegetation in cities and towns and because of the deleterious effect, which smoke and its attendant fumes have upon human health. It is now known that the pollution of the atmosphere by the emission of smoke and poisonous gases can be prevented, in entirely practicable ways, by scientific construction and skillful operation of the industrial plants. There is no longer any adequate excuse for the continuation of this type of injury to forest vegetation. The most serious cases of extensive injury to the forests in this country from smoke and poisonous gases occurred several decades ago. Today enlightened sentiment and improved practice, which recovers by-products from the poisonous elements in the smoke stream, should result in preventing further serious losses.

Different species of trees show differing degrees of susceptibility to injury from smoke and poisonous gases. In planting areas subject to smoke currents, species of known resistance to such types of injury should be chosen. As yet this information is available to only a limited extent. Mason (1915) arranged the Rocky Mountain species occurring in Montana in the following order of susceptibility, the first being the most susceptible: alpine fir, Douglas-fir, lodgepole pine, Engelmann spruce, western juniper and limber pine. Since complete elimination of the smoke and gas nuisance should be secured in the manner already described, there should be little if any occasion for restricting forest planting to species nonsusceptible to smoke and gas injury.

9.11 Lightning

Lightning is a widespread source of injury to forest trees. Trees are excellent conductors for electrical discharges between the clouds and the earth and are frequently struck by lightning. Evidences of lightning injury, varying widely in character, can be seen in practically all parts of this country. Lightning injures trees first by shattering the tree either in whole or in part, with a wide variation in the extent of the damage, and second by killing the tree without any splintering or mechanical injury. Sometimes an entire tree is literally blown to pieces with splinters scattered in radii of a hundred or more feet. In other cases pieces of bark may be knocked off with minor injury to the tissues immediately beneath the bark. A common type of shattering is a furrow opened up in the bark and cambium layer often running nearly the entire length of the tree. Where such a groove follows a spiral grain the tree may be girdled.

When trees are killed without external evidence, the lightning apparently spreads over the entire trunk of the tree or kills the root system. Occasionally a small group of trees are killed by lightning without external sign, rendering it difficult to determine the cause of death.It is believed that lightning strokes from clouds to ground shatter trees, while discharges from earth to clouds often injure roots and sometimes kill trees without external evidence (Dodge 1936). Damage to the forest from lightning is usually considered of minor importance as compared to other sources of injury. However, individual trees struck by lightning can be found scattered through the forest in most forest regions. Reynolds (1940) lists lightning as the chief cause of loss of volume through mortality in selectively cut stands of loblolly and shortleaf pines. In ponderosa pine stands in Arizona, Wadsworth (1943) reported that the trees struck by lightning amounted to about one-third of the total timber mortality. There is no practical method of preventing lightning injury to forest trees. Lightning causes much more serious damage to the forest indirectly through starting forest fires than it does through direct injury in striking individual trees. Lightning is, in fact, one of the chief causes of forest fire in the United States. The consideration of lightning as a fire cause and of the control of fires originating from this cause belongs more properly under the head of forest fires

Summary

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Unit 7: Protection against injuries by plants

Unit Structure

7.0 Learning Objectives

After going through this unit you shall be able to:

- Know the various plants harmful for forest growth and development
- Damage caused by weeds, fungi and mistletoes
- Control measures from harmful plants

7.1 Introduction

There are many plants which may pose threat to forest species in various stages of their life., i.e., seedling, sapling or even at mature stages. Such plants directly or indirectly have impacts on the growth and development processes. Plants injurious to forests may be weeds, climbers, parasitic phanerogams or fungi. In this unit, we will discuss about the various plants which are injurious to forests. We will also discuss their control measures.

7.2 Injury to Forests by Plants

From the standpoint of forest protection all plants which in one way or another cause injury to the growing forest crop are the matter of discussion under this chapter. Injurious plants can be dividing in general into three classes:

- fungi,
- mistletoes and
- forest weeds

Plants which cause damage to cut forest products are not considered here as they fall outside the scope of forest crop production. Preservation from decay and other injuries of wood after being cut is an important problem for the wood anatomist but not for the silviculturist. Protection against injurious plants has often been regarded as synonymous with the subject of forest pathology, and this in turn with tree diseases. Hubert (1931) gives the following definition of tree diseases: "A tree disease maybe defined as any interference with the normal functioning of a sound tree resulting in disturbed or abnormal physiological action or the deterioration of any of its parts." This is an exceedingly broad definition, so comprehensive as to take in injurious activities of practically all agencies affecting forests such as fire, insects, animals, atmospheric factors and man in so far as they interfere with the normal functioning of trees. In other words, protection against tree diseases if carried to the logical conclusion becomes practically synonymous with forest protection as a whole. This conception is too allinclusive to be advantageously used in a general study of all the agencies against which the forest needs protection. As a matter of fact, forest pathologists have never extended their consideration of tree diseases to the full limits which this definition makes possible. For our purpose the term tree diseases will be used in a relatively narrow sense as applying only to the plants which directly attack trees. The present chapter is devoted to consideration of the injuries to the growing forest caused by injurious plants which include principally fungi, mistletoes and forest weeds. The effects of the first two of these classes of plants may be spoken of as diseases, but the effect of the latter class is not usually classified as a disease.

Every part of the tree both above and below ground (the roots, the trunk, including bark, cambium layer, sapwood and heartwood, the branches, needles, buds and seeds) is susceptible to injury by other plants. Some of the tree diseases are of epidemic character, and those caused by certain plants imported from foreign countries such as the chestnut blight (*Endothia parasitica*) may be so virulent continuously as to accomplish commercial extermination of the hosts. Other tree diseases may become epidemic periodically as the result of favoring environ- mental conditions. Still others though always present in the forest and a constant source of loss rarely if ever develops in epidemic form. Both insects and fire usually are rated more destructive in their effects upon the forest than the plants covered in this chapter. Yet individual plants have the capacity for inflicting injury on a large scale. Witness the chestnut blight, which already in a period of about forty years since its introduction into this country has exterminated the chestnut (*Castanea dentata*) as a commercial species over at least two-thirds of its range and is still advancing. The rapidity of this attack and the completeness of the destruction over a large region are not characteristic of the work of most injurious plants. On the average they work more slowly than fire and insects, are disseminated unnoticed, may exist within their tree hosts for many years before revealing their presence and often take several decades to accomplish the death and destruction of a single tree. The extent of the damage caused annually by plants has not as yet been even approximately estimated. The individual species are so numerous, the damage caused is so varied, both as to character and amount on individual trees in the same stand, and so much of the damage is invisible occurring inside the tree that it is practically impossible to make such an estimate.

The injury from plants may be classified under one of two types- the first is physiological in nature, resulting in interference with the life processes of the tree. Such interference may be so severe as to kill the tree or cause deformation of a part or of the whole tree. Sometimes the result may be simply a reduction in the growth rate of the tree.

The second type of injury is of a technical character resulting in injury to the commercial products of the tree. Injury of this type may be invisible externally like some heart rots and cause no interference with the life processes, at least until the technical value of the tree is practically destroyed. In other cases external deformation or decay may lessen or ruin the value of certain portions of the tree for commercial use.

A well-managed forest is one which is stocked with healthy plants of a number of desired species occupying various storey of the forest. In order that the desired species grow without undue competition for space and nutrients, and do not suffer casualty due to suppression by unwanted species, they should be protected from damage caused by:

(1) Excessive congestion of the desired species and

(2) Presence of unwanted species

7.2.1 Damage due to excessive number of desired species

At the initial stage, number of plants per unit area of a forest – natural or plantation– remains quite high. For example, a plantation normally starts with 1500 to 2500 plants per ha. Transplanting in large number per unit area is done to take care of natural mortality that will take place. However, excessive crop density even of the desired species is not sustainable or desirable for the forest to grow healthy. Each plant, for its survival and growth, demands space, food, water and light, which are all limited in a given site. As the plants grow, the demand of each plant increases and soon a stage is reached when the site cannot afford to meet the increasing demand. The plants therefore enter into competition for the essentials and with time the competition becomes fiercer. The dominant individuals which suppress the weaker ones are also denied of optimum growth because the weaker plants still continue to share the limited food and water the site can afford. If the situation is not intervened, the resulting crop of the desired species will consist of under-nourished, under-sized and disease prone trees/plants with little utility.

The management intervention that is necessary is to progressively reduce the number of plants per unit area, as the demand of each plant for food and water increases with its age. The objective is to restrict the total demand of the entire stock for essentials within the limit that the site can provide. It is done by carrying out cleanings in the sapling stage and regular thinning at pole stage and thereafter. This will result in a mature crop of the desired species which would consist of healthy individuals of optimum growth and vigour.

7.2.2 Damage or Injuries by unwanted species

Forests are damaged by the following unwanted species.

a) **Damage by Forest Weeds and its Protection:** The term forest weed usually comprises plants which by their vigorous growth in masses more or less retard the development of young forest plants. By extending the meaning of the term, shrubs, and even many otherwise useful trees, may be included, which injure the growth of the principal local forest species.

Weeds are undesirable and troublesome plants that grow profusely in forest floor, particularly in the blanks, cleared lands and in young plantations. The weeds may be shrubs, herbs or grass. If left unchecked, the weeds will suppress the seedlings of the desired species, retard their growth and, in extreme circumstances, can annihilate them. Certain weeds also act as host to insect pests and rust diseases. When weeds infest open areas and blanks of forests and plantations in their infancy, regeneration of desired species becomes extremely difficult. In the process of creation of plantations, shoots that come up from seeds sown get suppressed before they attain the height and vigour to steer up clear from the reach of weeds. The transplants of species which are slow-growing are also easy victims. In North Bengal forests, the normal method of artificial regeneration of Sal is by sowing, and one major problem being faced is the vigorous attack by weeds. Some of the common weeds that invade forests are *Clerodendron, Mikania, Ageratum conyzoides, Eupatorium, Lantana* etc.

Forest weeds include various kinds of plants - herbs, shrubs, vines and many tree species. They are all alike in one respect, namely, their position with reference to the desirable trees in the forest. This position is a dominating one. The forest weeds overtop the better tree species and threaten by their competition to stunt, deform and kill them. All forest weeds are characterized by the ability to outgrow in height, at least for a short period of time, the desirable crop trees with which they are associated. Thus, the forest weeds obtain a dominant position in the crown canopy early in life and so long as this position is retained exert injurious competition. Oftentimes such competition is hardly suspected, particularly when herbaceous plants, such as grasses, constitute the forest weeds. Grass competition may be very serious for the young crop starting underneath. The encroachment of forest weeds upon the desirable trees frequently starts the very year that the new crop is established.

Weeds may be either woody such as brooms, white-thorn, or herbaceous such as *belladonna, Lentana, Eupatorum, Parthenium, grasses* (except bamboos), *sedges, and reeds*. Weeds may be annuals, biennials, or perennials. Most herbaceous plants, except some grasses, are annuals whereas belladonna is biennials, but this class is rare among forest weeds, and all woody plants are perennials. Further, the weeds may be of indigenous origin or exotics.

Weeds may overtop young trees and deprive them of light and dew, they may constrict them, as in the case of the woodbine, or completely stifle them by growing all over them, like the bindweed; they may smother and bend them down when pressed on them by snow, as dead bracken ; or cause swamps like the peat-moss, Sphagnum.

The damage done by forest weeds is either direct or indirect however; many of the weeds cause harm directly as well as indirectly. Poisonous plants, such as *Daphne* spp. Or belladonna is harmful to grazing animals in the forests. A dense growth of thorny species put great hindrance during felling operations and may, therefore, be considered as directly harmful. The indirect harms of weeds is due to the following causes:

- The matted roots of many weeds increase the difficulty of reproduction of the forest, as in the case of heather, bilberry and couch-grass
- The removal of valuable mineral matter from the soil, which thus becomes impoverished, for instance, of potassium phosphate in grass-seeds
- Mechanical injury to young forest plants owing to deprivation of light, heat, air, dew, or rain
- Injuries by smothering or constricting plants
- excessive moisture in the surface-soil during wet weather, and formation of swamps, consequent increase of damage by frosts

- A dense growth of grass or weeds may prevent dew or light rains, which merely dry off the surface of the weeds, from penetrating the soil, and is thus very hurtful to plantations and sowings during droughts. This may be easily proved by digging up a sod and examining the soil beneath it. Besides excluding moisture from the soil, the grasses draw up the soil moisture from below and transpire it into the air, so that the denser the growth of grass, the drier the soil becomes.
- Certain plants produce sour or dry humus which is unsuitable for most forest trees.
- Shelter is afforded by grass and herbage to mice and insects
- Weeds increase danger from forest fire
- Some weeds serve as hosts to injurious fungi, which may afterwards spread to forest trees or to agricultural crops. Many parasitic fungi are either most frequently found on weeds, or attack agricultural crops only after passing one stage of their existence on a weed.
- The amount of damage done to forests by weeds depends on their wide dissemination and on the vigour and special nature of their growth. These are determined by the locality, the prevailing system of forest management, and the state of the weather during the growing season.

Weeds are chiefly disseminated by winds which carry light seeds and fruits by millions, as for instance, the fruits of Composite; many birds, especially disseminate seeds either by pecking atthe ripe fruit heads and causing the wind to disperse the seeds, or by eating the fruits and voiding the indigestible seeds. This is especially the case with white-thorn. Other birds seat the seeds of many weeds. Hares, deer, and other animals also carry seeds in their fur. The seeds of many water-side plants are carried down by streams and inundations.

Damage to trees also depends upon its kind. Slow-growing species are more easily injured by the growth of weeds than fast-growing ones, and of these, light-demanding species suffer most.

Habit of weeds is also important. Perennial weeds, and especially those which produce root suckers, are much worse than annuals. Also those with dense foliage and those which are gregarious in nature, injure forest plants more than scantily foliaged and solitary growing weeds. Weeds which by their decomposition yield dry or acid humus are also harmful, as they produce soil unsuitable for forest vegetation. Dry humus formed of lichens, contains little carbon dioxide, easily crumbles, decomposes with difficulty and absorbs very little water. Acid humus, on the other hand, does injury by exhaling marsh-gas, and by containing certain organic acids which are detrimental to tree life.

The objective should be to prevent the forest weeds from obtaining a dominant place in the stand. If this can be accomplished the crop trees will be relieved of serious overhead competition and will develop unhampered by forest weeds. When treatment is started too late to prevent the forest weeds from growing into a dominant position overtopping the crop trees, then the elimination of this competition should be undertaken as soon as it is discovered. Methods of preventing or controlling damage from forest weeds consist in killing or removing those plants which either is going to obtain or have already obtained a dominating position over the trees which it is intended to develop into the ultimate crop. A variety of methods exist for accomplishing this purpose. The forest weeds can be managed by following certain rules as described below-

- **Maintenance of the Density of the Forest:** Care is needed particularly in shelter-wood systems in which soil is liable to become weedy.

- Long rotations should be avoided and woods of light-demanding species (oak, pine etc), should be under-planted at the right time with shade-bearers (silver fir, spruce). If a soil-protection-wood is to serve its proper purpose, it must be introduced before grasses have sprung up and helped to dry the soil.

- Clear-cuttings should be rapidly re-stocked with strong transplants planted closely.

- The natural soil-covering of dead leaves, needles or moss should be maintained, by keeping up a dense cover, and by preventing the removal of litter.
- The secondary felling should be carried out gradually. All blanks should be filled in with strong transplants.
- Nursery-beds should be weeded before the weeds blossom, and during rainy weather. Burned sods should be used as manure, as this destroys the seeds of weeds.
- Spaces between plants may be covered with moss, dead leaves or sawdust. This prevents the soil from caking and retains moisture near the surface, and thus replaces completely the expensive processes of working the soil, weeding and watering.
- Cutting the forest weeds is the simplest and usually the method first tried. Such work often proves to be expensive unless the forest weeds have a sale value. Hence a cheaper method is sought. Modifications of the usual cutting method include treatment of the forest weeds with applications of poison or by girdling the stems. The effect of girdling is to cause the gradual death of the plant, thereby removing its competition. In order to be effective the girdling must go through the bark and preferably through the sapwood. Even though the plant may not die during the first season, the girdling results in a lessening of the competition and ordinarily in the death of the plant within one to three years. Girdling is adapted only for use in disposing of the larger forest weeds. Any stems below 3 to 5 inches in diameter can be felled more cheaply than girdled.

Sometimes poisoning will prove more effective than either girdling or felling. Poison is best introduced by cutting a ring of incisions around the stem and introducing the poison solution through these cuts into the sapwood. The cutting is done usually with an axe or hatchet, although a special tool has been devised by Cope and Spaeth (1931) for the purpose of introducing poison solution in the tree. The choice between poisoning and girdling will often be made on the basis of the relative freedom from sprouts arising from the roots of the treated forest weeds.

One disadvantage of the poisoning method is the fact of having to buy and handle dangerous chemicals, usually solutions of sodium arsenite. The livestock are expected to eat the grass and other palatable forest weeds and leave the crop trees not only uninjured but freed of the overtopping weeds. This method is of value only when the animals prefer to browse upon the forest weeds instead of upon the crop trees which need release. The operation of treating forest weeds overtopping crop trees is known in silviculture as a cleaning, weeding or release cutting.

b) **Injuries from Fungi:** The fungi are parasitic and saprophytic in nature. It is the parasitic fungi which attack the growing forest. Fungi cause a number disease in forest trees. Parasitic fungi prey upon living trees and directly affect the yield and quality of forest crops. Under favorable conditions some fungi generally classed as saprophytic attack living though usually weakened trees. They then become parasitic in nature. The two most destructive classes of fungi attacking forest trees are the wood-destroying heart rots and the epidemic diseases which are virulent enough to cause rapid death of their host over wide areas of country. Where a fungus of this epidemic type becomes established it causes more widespread and wholesale loss than the heart rots. Decay fungi, in contrast, work very slowly, and though ultimately they may totally destroy the timber value of the stand, they require decades to accomplish this result. Furthermore, most of these decay fungi do not attack the trees while young, but develop only after the trees are fairly well along in life since they attack the heartwood which is not formed in youth.

- Saprophytic fungi obtain their nourishment from dead and dying wood and not from living trees. Silviculturists are least concerned with for forest crop as they do not attack their forest crops. Indeed, the saprophytes have a beneficial effect on forest growth as they hasten the decay process and enrich the soil with nutrients.
- There are a great many species of decay fungi, and practically every important timber tree is susceptible to attack by one or more species. Types which work principally in the heartwood and those which work in the sapwood are both found. Some of the fungi which cause decay in the sapwood work with far

greater rapidity than the typical heart rots and may ruin the sapwood zone in the tree within a relatively few years. They can attack young as well as old trees since the sapwood forms as soon as the tree begins life. The cumulative destruction of timber by these fungi is enormous in the virgin forest, for here the fungi may have been growing within the old trees for several hundred years and have rotted the entire tree except a relatively thin shell on the outside. The second growth forest which follows present-day cuttings in old-growth timber will in its turn be harvested on a shorter rotation and will not afford time for the heart rots to develop so extensively. Thus, once the virgin forest is utilized, heart rots will be of relatively lesser importance among the injurious fungi than they are today. The root rots are one of the most threatening types of fungi because of the fact that they work and spread underground. Hence, infected trees cannot be removed as sources of further infection as can those infected with species of decay fungi whose spread is restricted to the above-ground portion of the tree. Another serious feature of the root rots is that, unlike the heart rots, they are not restricted to older trees which have heartwood but may be prevalent in stands of all ages and may kill even young trees. The action of root-destroying fungi may be a large factor in accounting for losses. Other types of fungi among which may be mentioned stem and branch cankers and rust diseases on foliage result at least in loss of increment. Serious cankers of the nectria and strumella canker type may destroy the tree. The strumella canker (*Strumetla coryneoidea*) attacking oaks and the nectria canker attacking many hardwoods, because the formation of cankers on the main stem and branches. These cankers gradually spread, and several occurring in a short space along the stem or even a single one may girdle the trunk. If the tree is not girdled it may be broken over at the point of attack. Although single scattered trees may be attacked the damage in the aggregate is very large. It is particularly bad because the best dominant trees in the stand may be attacked. Fungi other than the heart rots are prevalent in stands of all ages, often attacking young trees and causing serious loss in middle-aged stands. In second-growth timber they are likely to assume a role of major importance as compared to the heart rots. Many of the fungi which are prevalent in stands past the reproduction stage kill or severely injure only occasional trees throughout the stand. These trees may be widely scattered or too poor quality to pay to salvage.

- Fungi are particularly destructive in forest nurseries because of the favorable conditions prevailing for their development. Here, the trees are small and tender and grow in densely stocked beds containing only individuals of a single species.
- A variety of fungi attack the young trees including damping-off fungi, root rots, diseases of the needles, stem rusts and molds on stock buried under snow (Hartley, Boyce and others 1933). One of the commonest types of disease is caused by damping-off fungi which attack only the newly established seedlings soon after they have started and when uncontrolled cause extensive losses in coniferous seedbeds. Such seedlings quickly wilt and perish within a very short period of time. Fungi causing root rots, stem rusts, infesting needles and mold may cause death of the seedlings in the nursery. Fungi may get access inside young trees before cork formation in the bark even through the uninjured bark under favourable climatic conditions, whereas in mature wood it is possible only through a wound or opening in bark. Such wounds may be created in a variety of ways, as for example by fires, lightning, frost, storms, insects, branch stubs left by natural pruning or wounds caused by logging. Some fungi enter through leaf stomata. Contact between roots of neighboring trees may result in infection of a sound tree by an adjoining diseased tree. The presence of fungi is revealed readily by the appearance of the fruiting bodies springing from the soil or parts of the tree above the ground. Sometimes other parts of the fungi such as the mycelium can also be seen. Where sporophores or other parts of the fungi are not in evident there may still be fungi within the trees. Although the fungi themselves, if sporophores are lacking, often are difficult to detect without dissection of the suspected diseased portion and sometimes microscopic examination, yet there are numerous external signs of diseased condition which indicate their presence. Unusual swellings of the butt

section of the tree or around branch whorls, exudation of pitch from branch stubs or wounds, dead and dying leaves, twigs and larger portions of the tree, deformities or unusual growth forms and wilting of young plants are among the numerous indications of tree disease. Environmental factors such as temperature, light and moisture are of fundamental importance in keeping the trees themselves in a thrifty, vigorous state and in establishing conditions which will be favorable or unfavorable for the development of tree diseases, however, the effect of climatic factors apparently is not the same for all groups of fungi. There are always abundant opportunities for a fungus to enter a tree through wounds, such as fire scars or abrasions of the branch, dead branch stubs resulting from natural pruning and leaf stomata.

- Some fungi are of value in forming mycorrhiza over the small tree roots which carry on absorption from the soil. Any solutions taken into the roots from the soil must pass through the mycorrhiza fungi. Hartley, Boyce and others (1933) state that it is questionable whether mycorrhiza is always beneficial to the trees, although the right species of fungus will be helpful. Nitrogen fixing bacteria, which for our purpose may be included among the fungi, are of great importance in maintaining soil fertility.

Methods of Controlling Fungi

- Under ordinary circumstances indirect methods must be used in preventing the inception of tree diseases and in controlling those already started.
- The damping-off fungi are controlled directly by the application of various chemicals, either in solution or as dusts, which act to disinfect the soil or render it more acid. The chemicals are usually applied before the seeds are sown although sometimes treatment is given after the seedlings are up. Sulphuric acid, Bordeaux mixture, formaldehyde and aluminum sulphate are some of the chemicals which are effective against damping-off (Hartley 1921).
- Various needle diseases of coniferous nursery stock may be controlled by means of chemical sprays.

- The remedy advised was reduction of density by thinning especially on the sites most subject to drought. Silvicultural measures for general use should be directed toward keeping the stands in thrifty condition since trees in full vigor have the best chance of escaping attack.
- Among the measures particularly recommended is the prevention of forest fires because of the part which fire scars play in affording points of entrance for fungi.
- Other silvicultural measures include the systematic use of thinning, the avoidance of wounding trees in logging or at other times and the elimination of infected trees, even if un-merchantable. In making thinning in young and middle-aged stands containing trees of sprout origin the question frequently comes up as to whether or not some of the individuals in a sprout clump can be safely cut, because of the danger that decay will enter the heartwood of the cut stub and thus pass into the remaining stems of the clump. As a general rule stems 3 inches or less in diameter contain little or no heartwood and if cut low should heal over before decay develops. Stems more than 3 inches in diameter offer a greater hazard, particularly where the union between members of the sprout clump is so high above the ground that direct connection exists between the heart rot of the several stems. All stems having high unions should be cut or all should be left. Where the union is low and consequently no above-ground connection occurs between the individual stems some may safely be cut and others left (Hepting 1933). Age of the stand and the relative resistance to decay fungi of the species involved may warrant modifying this treatment. In theory it would be desirable to extend work of this character over all the forest area, thereby disposing promptly of all infected trees, rather than restricting such disposal to trees on timber sale areas. Ordinarily the removal of infected trees can be justified under present economic conditions only on timber sale areas where the return from the stumpage encourages a small investment for sanitation.
- Sanitation cutting is the best method of controlling the canker diseases such as **Nectria** and **Strumelta**. The best method of treating trees attacked by

Nectria canker is to use them for cordwood and burn the remaining slash. If this is impracticable either girdling or felling will assist in reducing spore production (Spaulding, Grant and Ayers 1936). Strumella cankered trees should be felled but not necessarily be removed or burned. They should not be girdled and left standing since the fungus will continue to fruit on the standing dead tree (Hepting 1933).

- Where a choice can be made, naturally reproduced stands should be preferred to those established by planting, since the former are considered more secure against tree diseases than planted stands. This is particularly true when root rots are feared since planted trees are liable to injuries in planting which may encourage the development of root rots.
- It is important that only seed from suitable localities and of species native to the region be used in artificial regeneration. Unfortunately, this rule is generally not followed.
- Where the danger is serious of infecting planted stock with root rots through wounds on the roots it may be safer to employ direct seeding rather than planting in reforesting an area.
- Pathologically, mixed stands as contrasted to pure stands and many aged stands as contrasted to even-aged are preferable for minimizing the danger from tree diseases. Mixtures of hardwoods and conifers are especially desirable, since the two groups are not attacked by the same fungi.
- One possible method of control, in theory at least, namely the development of resistant strains of trees immune to the dangerous tree diseases, has as yet received little attention in connection with the production of forest tree crops.
- Heart rots can be prevented in the timber crops succeeding the present one by use of a rotation sufficiently short, so that the decay fungi do not have the opportunity to destroy more than a small percentage of the timber. The earliest age at which heart rots will cause appreciable loss in second-growth timber is above the rotations which will ordinarily be used when forest crop production is undertaken. This will minimize without any expense whatever future damage

from the dangerous group of heart rots which today are the most destructive fungi in virgin timber.

- Prevention of infection to the new crop during feeling of old crop infected from Heart rots should be well taken care off. Treatment of felled timber as well as the infected slash should be done in such a manner as to prevent the production of sporophores. For this purpose the larger pieces of slash (which are the only portions in which heart rots occur) should be charred by fire or be otherwise so treated as to insure their drying out and thus check development of the fungi. The use of a short rotation is so effective in eliminating serious losses from heart rots that special treatment of slash should be unnecessary.
- In theory, the retention of uninfected trees for seeding purposes is the wisest plan, particularly from the genetic standpoint.
- The trees which are still largely sound but rapidly becoming defective should be harvested if practicable, starting first with the stands which are decaying fastest. A stand of old defective timber may be making no net growth whatever and even be decreasing in volume each year. The greater the amount of cull material in the stand the more it needs treatment to remove or destroy the defective trees and enable healthy young trees to become established and occupy the area.

c) **Grasses:** Grasses are equally harmful as shrub/herbaceous weeds. The effect is very menacing when the root system forms a mat on the forest floor. It prevents germination of seeds and kills most of those which manage to germinate. Moreover, it remains a permanent source of fire hazard, particularly in dry season.

d) **Climbers:** Climbers by their nature use other plants (forest trees) as support and climb up, and cause damage to desired plants. At any stage of their growth the plants can be harmed by the climbers. Sometimes the slender climbers get on to the top of young saplings, enclose them and either kill those saplings or badly affect their growth. When thicker climbers twine round the pole crop, they get grooved into the tender bark as the poles grow in diameter. Woody climbers (example: Bauhinia vahlii), by their sheer weight, bend the trees and may even kill them by total suppression.

e) **Parasites:** In some parasitic plants like species of Cuscuta (Swarnalata), small adventitious root-like structures, i.e rootlets called haustoria or sucking roots develop from stems of the parasites. These roots penetrate the tissues of the host plant and suck the latter. The parasite thus lives by sucking the host plant with the help of sucking roots. They weaken the host plant, cut into the stem of host plant as they twine up and may even kill the host plant. Given below is an extract of tour note of A Basu Ray Chaudhuri, IFS (Retd) relating to his inspection as CCF Research and Monitoring of an experimental 2001 Sal plantation at Beliatore (Bankura) in November 2006. The serious infestation of the plantation by *Cuscutare flexa* (Swarnalata). Invading from north, the weed has attacked a large number of Sal saplings climbing and twining up to the crown. It has created a kind of mesh on the floor suppressing medicinal plants that were planted as intercrop in 2004. The weed is known for its power of vigorous growth and habit of killing its hosts. …"

7.3 Preventive and remedial measures

7.3.1 Preventive measure

Preventive measure against the unwanted species, in man-made forests, is to deny these species space to emerge and establish. It is the open space between sowing strips and transplant lines where the weeds/unwanted species easily emerge fast and profusely. As they get established they spread and try to cover the young seedlings of the forest crop lines. Thus an effective preventive measure is to grow some crop, generally annuals or short-lived perennials, in the interspaces and thus prevent the emergence of the unwanted species in such space. Leguminous agricultural crop like *Cajanus cajan* (Arhar) or suitable vegetable crop may be raised in the interspaces during the first couple of years since creation of a plantation. In fact, Taungiya system of cultivation adopted in Sal regeneration in North Bengal comes in good stead to contain and suppress the weeds in the interspaces and help the Sal seedlings grow healthy in profuse numbers. The procedure is to allow the dwellers to raise agricultural crop or vegetables in the intervening spaces between the strips of Sal in the first year. Regular weeding and cleaning undertaken by the villagers to raise the agricultural crop automatically keep the weeds away from the forest crop. Preventive measure described above applies to man-made forests. In primary forests, such measure of raising agricultural or vegetable crop cannot be adopted and is not permissible. Even in plantations, despite taking all good preventive measures, emergence of weeds or unwanted species cannot be stopped altogether.

7.3.2 Remedial measure

The remedial measure upon emergence of unwanted species is to remove them physically as early as possible. This is done by carrying out cutting, weeding, cleaning in the infested area as deemed necessary. These should also be done while carrying out routine cultural operations like marking, thinning etc. In case of plantations, during the first few years the plantation block should be subjected to thorough weeding – cleaning a number of times every year. In an afforestation programme, a plantation generally undergoes four to five cleanings in the first year, that is, year of creation, and further cleanings, fewer in number, in the next few years as part of creation of the plantation. In weed infested areas - most of the forest blocks in North Bengal - the schedule of cleaning followed is often found to be inadequate. The Taungiya system of cultivation turns out to be very essential in such cases. A number of weedicides are available in the market. There are also reports that some of the weedicides have been found to be quite effective in annihilating weeds like Clerodendron, Mikania etc. and liana like Bauhinia vahlii. However, one has to be very careful while applying chemical weedicides because of their toxic effects. Besides weedicides, they may also kill desired species and many other life forms beneficial for the forest ecosystem. It is thus better to avoid application of chemical weedicides. It is rather worthwhile to explore for suitable organic weedicides. But before deciding to use any particular organic weedicide, it is necessary to assess its efficacy and economics by conducting trial over sample plots.

Summary

Unit 8: Protection against Injuries by Diseases

Unit Structure

8.0 Learning objectives.

After studying this unit you will be able to understand:

- What are the different forest tree diseases?
- Timing of disease control measures
- Identification of forests trees disease
- Disease management of some important tree species.

8.1 Introduction

Diseases of forest trees are responsible not only for tree death, but also for reductions in growth and growth abnormalities, and can be caused either by abiotic agents, e.g. climatic and edaphic factors, chemical pollutants, or by biotic infectious agents. Diseases operate in many ways to reduce the yield and quality of timber and other values of trees. Losses begin with seed abortion and deterioration in the germinability of seeds and the survival of seedlings. Root pathogens, e.g. *Phytophthora ramorum*, *Fomes annosus* and *Poria weirii*, kill or decrease tree growth. Bark and cambial parasites, e.g. *Nectria galligena* and *Botryodiplodia theobromae*, can girdle and kill trees, or produce lesions that lead to decay. Wood-discoloring and rotting fungi, e.g. *Fomes pini* and *Ganoderma lucidum,* decrease the merchantability of wood in conifers and hardwoods. Foliage pathogens, such as *Phanerochaete salmonicolor, Ravenelia hobsoni and Elytroderma deformans* decrease the ability and quality of the economical trees and decrease the amenity value of trees, decrease their growth, and sometimes kill them.

The term “tree disease” covers a wide range of pathogenic infections, abnormalities, and disturbances of the normal structure and growth of a tree. Many different species of organisms and non-living agents can cause diseases that may reduce growth, lower quality, kill outright, or predispose a tree to attack by other pests. By definition, “tree disease” refers to the deleterious effects resulting from injurious agents other than fire, insect damage or other types of wounding (e.g. animals or hail). The causes of tree disease are usually classified as non-infectious or infectious. However, disease symptoms usually develop as a result of a complex interaction between the susceptible tree, predisposing environmental conditions, or a living, infectious agent such as a fungus. An awareness of this interaction of living and non-living agents enables greater insight into the dynamics behind disease outbreaks.

When a plant cannot function normally, it is diseased. The primary causes of disease in trees are pathogens and environmental factors. Trees have many disease pathogens: viruses, bacteria, fungi, nematodes, mycoplasma-like organisms, and parasitic higher plants. Fungal pathogens are the most prevalent. They cause seed rots, seedling damping-off, root rots, foliage diseases, cankers, vascular wilts, diebacks, galls and tumors, trunk rots, and decays of aging trees. Unfavorable weather and environmental factors such as temperature and moisture extremes, high winds, or ice can damage trees directly and predispose the trees to pest attack. The major objective of disease management is to prevent or minimize losses while preserving tree quality. Absolute disease control is rarely achieved or even attempted. More often, management efforts are directed toward preventing disease or reducing it to the status of a tolerable nuisance. In most instances, forest disease management requires preventive methods over a long period of time and considers the stand as whole rather than specific diseased individuals. Management measures must be economically feasible - expenditures must not exceed the expected benefits. Direct control of disease in the forest is limited by many factors, including:

- **(i)** The vast areas involved
- **(ii)** The inaccessibility of many stands.
- **(iii)** The long life cycle of trees.
- **(iv)** The relatively low per acre or per individual tree values.

Thus, spraying, dusting, or other direct control procedures commonly employed with high-value crops such as Christmas trees, forest nursery crops, and valuable seed orchards are rarely applicable in the forest. Occasionally, however, disease epidemics of introduced forest pests warrant drastic and costly direct control measures to meet the emergency

Impacts of Forest Diseases

The adverse effects of forest tree diseases may be either obvious or subtle. These are listed here without any order of relative importance:

- **(i)** **Mortality:** trees killed by any disease.
- **(ii)** **Destruction of wood already formed:** meaning essentially the losses from heartrots that destroy or disintegrate wood. The decays of living trees are hence a type of loss distinct from all others.
- **(iii)** **Reduction in growth increment:** decreased height and/or diameter growth which adds up to volume loss.
- **(iv)** **Delayed regeneration:** years lost in getting a new crop started.
- **(v)** **Deficiencies in stocking:** too few stems, uneven spacing, or holes in the stand. Site not fully occupied and, hence, not up to full production potential.
- **(vi)** **Degeneration of species composition:** disease of preferred species permitting volunteer inferior or weed species to take over the area.
- **(vii)** **Deterioration of site:** soil erosion, compaction, leaching, etc.
- **(viii)** **Reduction in wood quality:** incipient decay, stain, cracks, excessive knots, pitch pockets, and other responses to disease. No change in volume of production but loss in value of products.

Most of these eight types of impact are not too difficult mentally to visualize. Except for mortality, however, they are difficult ocularly to observe in the field, and are extremely difficult to measure or otherwise evaluate in quantitative terms. Also, it is obvious that any given disease may induce more than one type of loss. Reduction in growth increment eventually followed by mortality is an especially common sequence of events.

8.2 Timing of disease control measures

When chemical disease control application is economically feasible, as in the case of forest nursery stock, it is essential that the pest manager understand the life cycle of the disease to be controlled. For many diseases, only one short window of control may be available in a calendar year, or the control spray may have to be applied preventively—before any signs or symptoms of disease are present. Chemical control measures must be applied to the plant when infection is most likely to occur or it will be a waste of time, effort and money. By understanding the life cycle of the disease organism, you will be able to make proper and timely management decisions.

8.3 Forest disease management

The most important principle in forest protection is that preventing attack by an insect or disease pest and/or preventing further development of the pest problem is far more effective than attempting to stop the damage after it is underway. The wise application of forest management practices ultimately has more enduring and less expensive results than more direct methods of protection. Most forest disease control is achieved through adjustments in forest management practices. General methods of silvicultural control may include:

- Decay reduction through rotation
- Fire prevention and care when logging
- Reductions of disease through timber stand improvement operations and the use of partial cutting methods.

- Use of prescribed burning.
- Maintenance of high stand densities where applicable.
- Salvage to reduce losses.

Planted stands are particularly liable to disease. The impact of disease will become increasingly important as more planting is done and as plantations become older. The critical period for most stands is from about 20 to 40 years of age, the period when the stands make the greatest demands on the site. Vigorous early growth is no assurance of satisfactory long-term development. The major effort toward disease control in plantations is through avoidance. Selecting a site with favorable growing conditions and then a species suited to that site is of primary importance. Planting stock must be free of disease. Pure stands are at more risk than mixed stands, as are large areas of even-aged trees. Spacing, thinning and weed control are also important for maintaining stand vigor.

8.4 Disease surveys

Disease surveys are important and are the first step in application of control measures. Detection, appraisal, and control surveys are made for early recognition of disease; for information on scope of attack, extent of damage, possibilities for control, estimates of costs, and delimitation of control areas; and for assessing the effectiveness of control programs.

8.5 Disease management of important tree crops

8.5.1 Neem (*Azadirachta indica*)

Earlier reports show that a few fungi are known to cause diseases in nurseries and plantations of neem. They are fungi like species of *Alternaria, Cercospora, Colletotrichum, Fusarium, Oidium, Ganoderma* and *Corticium*. A brief description of the various diseases and their control measures in nursery is given below:

(A) Damping off:

- Among the nursery diseases, damping-off is the most prevalent and highly destructive disease and cause heavy loss of seedlings. It is referred to a group of disease namely preemergence and post-emergence damping off depending on the stage of growth of seedlings when they are attacked.

- This disease is caused by various soil fungi such as Pythium, Phytophthora, Fusarium and Rhizoctonia of which the last two fungi are quiet prevalent in forest nurseries in India.
- High soil temperature, excessive soil moisture, high soil pH (alkaline), high nitrogen content, low light intensity due to shading, stiffy or clayey soil with poor drainage, dense sowing are the conditions which favour the disease development in serious proportion. In case of Neem seedlings, the disease was caused by *Fusarium oxysporum* (Mehrotra and Pandey, 1992).
- Control Measures: The disease has been managed through: Cultural practices aimed at favouring plant growth and discouraging the growth of plant pathogen; Use of chemicals like formalin and suitable fungicides. Formalin is applied as soil fumigant and the fungicides can be applied either as soil drench or soil mix. Also, seed dressing with fungicide (Bavistin) in certain cases found very effective. Potting media should be properly sterilized by solar heating before use.

(B) Leaf Web Blight

- It is caused by *Rhizoctonia solani.* The disease appears in the nursery after the regular monsoon rains set in (Mehrotra, 1990; Sankaran *et al.,* 1986).
- ***Symptoms:*** Development of greyish brown blotches which increase in size with the advancing fungal hyphae and ultimately engulf the entire leaf blade. The infected adjoining leaves get joined together by the fungal hyphae as if caught in a spider's web, hence the name web blight. The leaflets or the entire pinnae become detached prematurely. The disease spreads through contact of the overlapping foliage.
- ***Control Measures:*** The disease has been managed through interacted approach which includes measures such as sanitation and cultural practices. Application of fungicide (Bavistin 0.1% a.i.) is found effective.

(B) *Colletotrichum* Leaf spot and blight:

- It is caused by *Colletotrichum gloeosporioides.* It has been recorded in a serious form at New Forest, Dehra Dun. It appears in nursery at the end of the September or first week of October (Mehrotra and Pandey, 1992).
- **Symptoms**: The fungus causes leaf spots which increase rapidly in size covering large leaf areas. The infected leaves present a blighted appearance and are eventually shed. Severely infected seedlings show premature defoliation.
- **Control Measures:** Application of Blitox fungicide (0.2% a.i.) twice at weekly intervals is found effective in controlling the disease.

***(C) Alternaria* Leaf spot and blight:**

- It is caused by *Alternaria alternata*. It is a destructive pathogen. It appears late in the growing season in the last week of October or early November. It attacks the leaves when the leaves become old and contain less soluble sugars.
- Control Measures: Application of Blitox fungicide (0.2%) at fortnightly intervals is found very effective.

(D) *Pseudocercospora* Leaf spot:

- It is caused by *Pseudocercospora subsessilis.* The disease occurs throughout the natural distribution of neem.
- **Symptoms:** The infection spots are brown in colour interspersed with white patches. The fungus sporulates on the under surface of the leaf and produces conidia which appear grayish in mass. The heavily infected leaves turn pale and are shed prematurely.
- **Control Measures:** Application of Mancozeb in combination with Brestan is found effective in controlling the disease.

(E) Powdery Mildew:

- This disease is caused by *Oidium azadirachtae.*

- **Symptoms**: White patches seen on the surface of the leaves. These patches coalesced and covered the whole leaf lamina giving greyish white appearance. Severely infected leaves and leaflets defoliated prematurely.
- **Control Measures:** Foliar spray of Bavistin fungicidal solution (0.01%) is found to be effective in minimizing the disease.

(F) Other Foliar Diseases:

- Bacterial leaf spot: Bacterial leaf spot is caused by a bacterium, *Xanthomonas azadirachtii* and *Pseudomonas viticola*.
- Leaf spot and Blight: Leaf spot is caused by *Colletotrichum capsici*. Leaf Blight and stem rot are caused by Sclerotium rolfsii.
- Seedling wilt: Seedling wilt is caused by *Fusarium solani*. Twig canker and shot hole in leaves are caused *Phoma* sp.

8.5.2 Diseases of *Albizia spp.*

(A) Leaf spot and blight:

- Different pathogens such as *Cercospora* albizziae, Colletotrichum sp., Alternaria alternata, Camptomeris albizzia, Pleiochaeta setosa and Epicoccum sp. have recorded to attack of leaves of Albizia lebbeck in nurseries (Mehtrotra et al., 1992).
- **Symptoms:** The disease manifests on older leaves of seedlings as small water soaked yellowish spot which later develops into a circular light brown lesion with a distinct yellowish margin. The spot hole develops in the advanced stages of infection causing premature defoliation. The disease is aggravated under high humid conditions. The tender shoots of seedlings are also infested and damaged.
- **Control measures:** Application of Captaf (0.2%) fungicide solution as foliar spray is found effective in controlling the disease problem.

(B) Seedling wilts:

- It is caused by the fungal pathogen, *Fusarium oxysporum*.
- Symptoms: The lower leaves initially turn yellow and then fall off. The yellowing proceeds towards the growing shoot and within a month the seedling dies. The roots of affected seedlings get discoloured.
- Control Measures: Application of Dithane M-45 (0.3%) or Bavistin (0.2%) fungicidal solution is found effective in controlling the disease problems. Also, treating the seed beds with 0.2% Bavistin solution before sowing prevents the occurrence of disease pathogens.

(C) *Rhizoctonia* Leaf Web Blight

- It is caused by *Rhizoctonia solani*. The disease has been reported for the first time in Assam (Mehrotra, 1989; 1990). This disease was also reported on other broad leaved trees.
- Symptoms: It first appears on leaves close to the ground, as water soaked silvery grey blotches.The infected adjoining leaves become joined together by the fungal hyphae if caught in a spider's web hence the name web blight.The fungal invasion of foliage is rapid over the wet leaf surface during rains (Mehrotra, 1990).
- Control Measures: It can be managed through an integrated approach involving measures such as sanitation, cultural practices and use of fungicides. Sanitary measures recommended are disposal of leaf litter by burning and segregation of diseased seedlings soon after such seedlings are spotted. This will help in preventing lateral spread of the disease through contact of the overlapping foliage of the adjoining seedlings thereby minimizing the disease incidence. Cultural practices include raising of seedlings in poly bags instead of beds; keeping seedlings in lots of 250-300 seedlings instead of 1000 seedlings in nurseries. Application of Bayleton (0.1% a.i.) as foliar spray is found very effective in controlling the disease.

(D) Leaf Rust:

- It is caused by *Ravenalia clemensiae*. The pathogen attacks leaflets of the seedlings.
- Profuse development of pustules takes place on the leaf surface adversely affecting the metabolic activity of the plants resulting even in death.
- Control Measures: The disease is controlled by application of 0.2% Dithane M-45 or Sulfax fungicide.

(E) Little leaf disease:

- The disease caused by Pytoplasma like organisms is often observed in seedlings after the germination of seeds.
- The cotyledons and first pair of leaves turn yellow.
- Later, the foliage becomes bunchy with much reduced sized of leaves.

8.5.3 Diseases of *Gmelina arborea*

Most of the diseases on *G. arborea* have been recorded from nurseries and plantations raised in different parts of the country. A brief description of various nursery diseases recorded in *G. arborea* is given below:

(A) Foot rot:

- This is caused by *Fusarium oxysporum*. It has been recorded from Madhya Pradesh on 1-month old seedlings.
- Symptoms: Infected portion exhibits water-soaked depression which late turns dark brown causing wilt and subsequent death of plants.
- Control Measures: Soil drenching with 0.2% Bavistin or Dithane M-45 at monthly intervals effectively controls the disease (Jamaluddin et al., 1988).

(B) Poria root-rot:

- Poria rhizomorpha has been recorded as a root parasite of Gmelina arborea in part of India in north Bengal and Assam (Bagchee, 1953).

- Symptoms: The severity of the disease has been noticed more on clayey sites where the soil becomes periodically waterlogged. The fungus perennates in the forest on woody debris in the soil and humus from which it spreads to the host through white coloured cord-like rhizomorphs often to a distance of 30 meters, disseminating the disease from one tree to another. It causes brown cuboidal rot in the root resulting in death of root cambium followed by die back and death of affected trees both in natural regeneration and plantations. The sporophores of the fungus effused thin, brittle, poroid, crust, inseparable from the substrate, or white to pinkish cinnamon, pores round to angular, basidiospores hyaline, ellipsoid in shape.

(C) Root rot and Collar rot:

- The diseases are caused by Sclerotium rolfsii and recorded in 1-2 months old seedlings in Kerala (Florence and Sankaran, 1987).
- Symptoms: Paling of foliage and leaf shedding and subsequent death of the seedlings. In Kerala, the disease causes premature defoliation and is reported to be in mild form.
- Control Measures: Soil drenching with 0.2% Bavistin or Dithane M-45 at monthly intervals effectively controls the disease.

(D) Leaf spot:

- Leaf spot is caused by Pseudocercospora ranjita and reported from Assam and Kerala.
- Deptoshaeria gmelinae causing leaf spot and die-back of twigs has been reported from Madhya Pradesh.
- Other leaf spot fungi recorded from Madhya Pradesh are Phoma tropica, Alternaria laternata and Macrophomina phaseolina (Jamaluddin et al., 1988) and Corynespora cassicola is from Kerala (Sharma et al., 1985).
- Symptoms: Paling of foliage and shedding of leaves are the common symptoms.

- Control Measures: Application of Bavistin (0.1%) and Dithane M-45 (0.1%) are found effective against the diseases in nursery.

(E) Leaf and shoot blight:

- Colletotrichum state of Glomerella cingulata in association with Fusarium solani has been reported from Kerala causing severe blight disease in 5-6 month old seedlings during May and June.
- Symptoms: The disease spreads rapidly after initial appearance in patches, causing large scale mortality of nursery stock. Infected plants exhibit blighting of shoots and leaves. Subsequent colonization by Fusarium solani hastens blighting.
- Control Measures: The disease has been effectively controlled by two applications of Bavistin at weekly interval (Sharma et al., 1985).

(F) Powdery Mildew:

- It is caused by *Phyllactinia suffulta* var. *gmelina* and recorded from Maharashtra.
- Symptoms: The pathogen produces infection spots on the lower surface of the leaves with corresponding pale yellow colour on the upper surface (Patil, 1961).

(G) Phoma stems rot:

- Stem rot disease caused by *Phoma nebulosa* is recorded in 3-4 months old seedlings from Kerala (Sharma et al., 1985). The disease flares up under warm and humid conditions especially in overcrowded seedlings.
- Symptoms: The infected seedlings wilt and eventually die. Numerous pycnidia develop on dead stem, and spore masses ooze out from them on maturity.
- Control Measures: It can be effectively controlled by removing the affected seedlings from the seed beds, regulating the water to bare minimum and applying 2-3 foliar sprays of Dithane M-45 (0.05% a.i.) at weekly intervals.

(H) Canker disease:

- Stem canker disease caused by conidial state of *Thyronectria pseudotricha* and *Hendersonula toruloidea* has been recorded from Kerala.
- Symptoms: The pathogen causes depressions and necrosis of the bark on which numerous conidia (imperfect state) are produced resulting in formation of perennial cankers which increase in size due to fungal invasion to the surrounding healthy tissues. The bark later splits and peels-off exposing the dead wood (Sharma et al., 1985).

***(I) Phomopsis* Die back**

- Twig blight caused by *Phomopsis* sp. and stem canker caused by P. gmelinae has been reported from Madhya Pradesh and Kerala respectively (Jamaluddin et al., 1988; Sankaran et al., 1987).

8.5.4 Diseases in *Pongamia pinnata*

Pongamia is attacked by few diseases. A brief description of the nursery diseases is given below:

(A) Leaf spot and blight:

- Leaf spot and blight diseases caused by *Fusicladium pongamiae* on *Pongamia pinnata*.
- The pathogen causes severe leaf deformities.
- *Microstroma pongamiae* causes white to cream-coloured spots giving a yellowish appearance to the leaves.
- Other fungi such as *Phyllochora pongamiae, Robillarda makatii* and *Urohendersonia pongamiae* cause leaf spot disease.
- *Cercospora pongamiae* and *Sphaceloma pongamiae* cause anthracnose spots on leaves, tender shoots and pods resulting in severe damage and early defoliating in young seedlings and trees.
- Control Measures: Foliar spray of Bavistin fungicidal solution (0.1%) is found to be effective in minimizing the disease.

(B) Leaf Rust:

- The rust fungus, *Ravenelia hobsoni* infects the leaves and produces numerous chest-nut brown teliospore heads on the lower surface of the leaves.
- Another rust fungus, *R. stictica* is also known to attack the leaves.
- Control Measures: Dusting or foliar spray of sulphur based fungicide (0.05%) is found to be effective in minimizing the disease.

(C) Powdery mildew:

- Powdery mildew disease caused by *Oidium* sp. was also reported on *Pongamia* seedlings.
- Symptoms: The pathogen formed irregular white patches, consisting of mycelium and asexual conidia on the surface of the leaves. These patches coalesced and covered the whole leaf lamina giving grayish white appearance. Severely infected leaves and leaflets defoliated prematurely.
- Control Measures: Foliar spray of Bavistin fungicidal solution (0.01%) is found to be effective in minimizing the disease.

8.5.5 Disease in Teak *(Tectona grandis)*

Different disease problems of Teak were recorded in nursery. The symptoms, causative organisms and their management are as follows:

(A) Leaf blight:

- This is caused by *Rhizoctonia solani.*
- Symptoms: The infected plants show water soaked grayish brown patches that enlarge rapidly and cover a large part or the entire lamina. The blighted leaves often show holes in the infected portion as a result of shedding of infected tissues during heavy rains. The infected leaves dry

up and are eventually shed. The disease spreads laterally in the nursery through overlapping foliage of the adjoining seedlings often resulting in group blighting of seedlings. In each case of severe infection, defoliation is high.

- Control Measures: Immediate removal of infected plants helps to prevent the disease spread. Application of Dithane M-45 (0.1%) is found effective in controlling disease.

(B) Leaf rust:

- This disease is caused by *Olivea tectonae.*
- Symptoms: The infected leaves are almost plastered with yellowish brown fruit bodies of the fungus. The upper leaf surface presents a grey appearance due to the formation of fleeks, which correspond to the position of sori on the lower surface. Infected leaves fall off prematurely resulting in retardation of plant growth. The disease is common in nursery and young plantations.
- Control Measures: The infected seedlings can be segregated and kept in isolation. Severely infected and dead seedlings can be burnt away from the nursery to prevent the spread of the disease. The disease may be controlled in the nursery by the application of sulphur based fungicide (Sulfax) on both sides of the leaves.

(C) Leaf spots:

- Leaf spot diseases are caused by different fungal and bacterial pathogens on teak.
- Symptoms: The symptoms are brown to greyish brown, which develop near the tip and along the margin of the leaves. The disease spreads laterally in the nursery through overlapping foliage of the adjoining

seedlings often resulting in group blighting of seedlings. In each case of severe infection, defoliation is high.

- Control Measures: Immediate removal of infected plants helps to prevent the disease spread.

(D) Powdery mildew:

- Members of the family Erysiphaceae have been recorded to cause mildews in teak. *Phyllactinia corylea* is recorded to attack teak laves (Bagchee, 1952). *Phyllactinia guttata* is also recorded to attack teak from other countries. *Uncinula tectonae,* widely occurs in nurseries and forests in central and southern India.

- Symptoms: The fungus forms white powdery coating on the undersurface of teak leaves and later develops dark coloured cleistothesia over the white fungus weft (Spaulding, 1961). *Uncinula tectonae* is restricted to the upper leaf surface and the infected leaves are coated with a dull white mycelium and conidia borne on conidiophores. Conidia are air-borne which are produced abundantly and cause fresh infection. The metabolic changes in plants take place which lead to drying of infected leaves.

- Control Measures: Sulphur dust was most effective in controlling powdery mildew in two year old seedlings followed by Baycor, Mortesan and Calixin (Kulkarni and Siddaramaiah, 1979).

8.5.6 Disease in Shisham *(Dalbergia sissoo)*

Dalbergia sissoo is attacked by a number of diseases and the details are given below:

(A) Leaf spot:

- Different fungi viz., *Cercospora sissoo, Colletogloeum sissoo, Phyllachora dalbergiae, Phyllachora spissa, Phyllosticta sissoo, Mycosphaerella dalbergiae, Myrothesicum roridum* and *Alternaria* *alternata* causing leaf spots on this tree species and recorded from the region this tree species grows.

- Symptoms: The pathogen, *Cercospora sissoo* attacks the leaves mostly on the lower surface, producing yellowish to grayish-green discoloration. Pustules are mostly intra-epidermal. Stomata are brown with simple or forked conidiophores (Sydow and Mitter, 1933).
- The pathogen, *Colletogloeum sissoo* causes imperceptible leaf spots and is recorded from Varanasi, Uttar Pradesh (Pavgi and Singh, 1971).The pathogen, *Phyllachora dalbergiae* attacks the upper leaf surface and produces shining black cushion-like stromata which may occur scattered or in clusters (Saccardo, 1883).
- The pathogen, *Phyllachora spissa* attacks the leaves and forms densely aggregated dot-like dark stromata on irregular brownish infection spots and recorded from Wynaad, Kerala and Meghalaya (Bakshi, 1976); Khandala, Maharashtra (Ananthanarayanan, 1964).
- The pathogen, *Phyllosticta sissoo* causes infection on leaves. The spots are round to irregular, greyish-brown which sometimes cover the entire leaf surface. Dark brown pycnidia are produced on lower leaf surface in densely aggregated groups (Saccardo, 1931).
- The pathogen, *Myrothecium roridum* causes leaf spots in seedlings of sissoo from Bareilly and Dehra Dun (Uttar Pradesh) and Ambala (Haryana). Infection spots appear in June or eearly July. They are grey or light brown with dark brown margin on the concentric sones, coalescing to form larger leaf spots. The necrotic tissues usually fall off resulting in formation of shot holes (Tivari *et al.,* 1991).
- The pathogen, *Alternaria alternata* appears in July continues throughout humid months and declines after September in Dehra Dun. The disease

incidence is reported be as high as 100 per cent and almost 80-100 per cent leaflets are infected. Infection spots are dark brown, vary in size and shape and coalesce to form larger spots. The fungus sporualtes on the lower surface of the leaves. The heavily infected leaves are shed prematurely (Mehrotra, 1992a).

(B) Leaf Blight:

- Rhizoctonia web blight of sissoo caused by *R. solani* an anamorph of *Thanatephorus cucumeris* was recorded from Dehra Dun (Mehrotra (1992b).
- Symptoms: The disease first appears on leaves close to the ground as water soaked grayish brown blotches which increase in size with the advancing fungal hyphae and ultimately the entire leaf blade is invaded by the fungus.
- The leaflets show stromatid aggregates on the under surface and eventually turn brown. The infected adjoining leaflets often join together by the fungal hyphae as if caught in a spider's web hence the name web blight. Leaflets or entire leaf become detached prematurely but they remain clinging to the stem for a considerable period as they are invariably joined together by the fungal hyphae.
- There is a cluster of hyphae at the base of the petiole or petiole. The disease spreads laterally through contact of overlapping foliage of the adjoining seedlings resulting in group infection of seedlings in the nursery.Control Measures: The disease can be effectively managed through proper sanitation, weeding and foliar application of fungicide solution (Bayleton – 0.1% at fortnightly intervals).

(C) Powdery Mildew:

- *Phyllactinia dalbergiae* causes powdery mildew on sissoo seedlings and recorded from Dehra Dun and Allahabad (Uttar Pradesh), Pusa (Bihar), Poona, Bombay and Nagpur (Maharashtra) and Chichrauli and Seonti (Haryana) (Pirozynski, 1965; Mukerji, 1969; Singh, 1973; Mehrotra, 1992c).

- Symptoms: The fungus produces yellowish, persistent, dense mycelium on the lower surface of sissoo leaves.
- Control Measures: Application of sulphur based fungicide was found most effective followed by Baycor, Mortesan and Calixin in controlling powdery mildew disease on *D. sissoo* seedlings in nursery.

(D) Rust disease

- *Maravalia achroa* is recorded on seedling in nurseries from Uttar Pradesh, Bihar, Maharashtra and Assam (Patil and Thirumalachar, 1971; Bakshi, 1976; Mehrotra, 1987). The disease also occurs on young plantations but not in as severe form as in the nurseries.
- Symptoms: The disease appears in February-March on leaves and juvenile twigs and continues attacking the foliage and young twigs up to July-August. The infection declines following monsoon rains. The affected parts are killed resulting in die-back and subsequent death of affected seedlings. Uredinial sori are yellowish and formed on the lower surface of the leaves. Telia are colourless and pulvinate. The infected leaves are often deformed and the infected plants show perceptible retardation in growth and look stunted and weak. The disease incidence is recorded as high as 100% in the nursery at Dehra Dun.
- Control Measures: The disease may be effectively controlled by foliar application of 0.08% Bayleton at fortnightly intervals (Mehrotra and Pande, 1993).

Summary

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Training manual on Forest Management

Unit 9: Protection against insects and pests

Unit Structure

9.0 Learning Objectives

After going through this unit you shall be able to:

- Know about insect and pests
- Injuries caused by insects and pests
- Control measures

9.1 Introduction

The annual loss due to insect depredations is more difficult to estimate accurately. General estimates made by entomologists on the basis of observation and consultation with other experts furnish the best available information. An estimate of the damage by forest insects to standing timber and to forest products before removal from the forest, or while in storage or in use, was published in 1927 by the United States Department of Agriculture (Anonymous 1927-a). The total damage was placed at approximately $147,000,000 annually, of which $100,000,000 was to standing timber. This figure is probably too conservative. Graham (1929, pp. 5-8) stresses the difficulties of obtaining an accurate estimate of losses due to insects. Insects cause comparatively much injury to the forests even sometimes it is more than forest fire does. Spectacular losses from insects occur today in areas of virgin timber located in inaccessible regions where timber of high quality is killed without the possibility of salvage. From the practical standpoint, a much larger proportion of the annual damage caused by insects is unpreventable.

9.2 Injuries due to Insects-pests

Insects bring about severe damage to the plants. The risk of damage due to insect prevails throughout the life span of the plants. In other words, the insects can attack at any stage of growth of the plants. They cause damage to plants:

- **In nurseries** – The seedlings may be damaged by leaf eaters like cutworms and crickets or root-sucking insects like cockchafers.
- **At sapling/ pole stage** – The plants may be damaged by defoliators, bark borers, cambium insects and sap-sucking insects
- **At maturity –** The trees are more vulnerable to attack by insects
- **After death or felling-** Even after the trees die or are felled, they become victim of attack by various beetles and the wood gets deteriorated.

9.2.1 Insect-Pests in nurseries

A prerequisite for good plantation is preparation of healthy planting stock in the nursery. It is therefore necessary to control the pest attack on nursery seedlings. Some common nursery pests and their control are described below.-

a) Cutworms – These are surface caterpillars (larvae) of several species of night flying moths. The larvae are called cutworms because they cut down young plants as they feed on stems at or below the soil surface. (www.extension.umn.edu)

Control measures: The silvicultural method is to remove weeds and plant residue to help reduce egg-laying sites and seedling weeds that nourish small cutworms. The mechanical method that can also be adopted is to catch the larvae and kill them. Although there are chemical insecticides that have been reported to be effective against cutworms, use of chemical insecticides should be avoided as far as possible.

b) Cockchafers – Grubs of cockchafer beetle are root feeders. They consume rootlets and feed on tap roots and thus kill the seedlings. There are several species of cockchafer beetle, and depending on their habits, specific control measures need to be employed. Some general measures are given below.

Control measures – The cockchafer beetles lay eggs in summer or beginning of monsoon. So, one silvicultural control method will be to avoid preparing seed beds during this period, as soil working invites ovipositing. Sowing may also be avoided during this time. If it is unavoidable to do soil working and sowing during oviposition period, the worked soil in the bed may be covered with a layer of charcoal, sand or sulphur; sowing may be done after removing the covering in lines, and the covering material may be put back after sowing. The mechanical method of control is to capture the grubs during the preparation of beds, and destroy them. The chemical method of control, if unavoidable, may be used over small areas where seedlings are found to be affected. In this method, toxic material like carbon disulphide, CACN, acetic acid, or BHC is applied to beds in the prescribed manner.

9.2.2 Insect-Pests of important forest trees

The pest of important forest trees belong to following classes- **Defoliators**. They destroy the tree foliage by eating up, or rolling the leaf, or boring the leaf tissue or by cutting and carrying the leaf for purposes other than food.

a) Feeders - They feed on shoot, cambium or wood. Pests relating to two important trees are described below.

i) Teak Defoliators: *Hyblaea puera* is commonly known as the teak defoliator. It is the most widespread and serious pest in both plantations and natural forests, with as many as 14 generations per year. Defoliation does not kill the trees, but does lead to substantial timber loss. Defoliation by H. puera in plantations four to nine years old has been reported to cause about 44% volume increment loss of the trunk. The larvae directly retard girth increment, reduce timber quality by forking, cause death of the leading shoot and result in formation of epicormic branches.

(Source: http://www.atree.org/sites/default/files/articles/Hyblaea_paper.pdf)

Control measures - The teak defoliator is present the year round in Teak plantations, but in varying population densities. Natural control of this pest to some extent takes place due to a number of parasitoids, predators including wasps, spiders, birds etc., and some pathogens (disease producing agents) that include certain bacteria and fungi. These agents cause mortality to Teak defoliators. (http://en.wikipedia.org/wiki/Hyblaea_puera). Silvicultural method to contain the Teak defoliators is a preventive one. It is advised that Teak plantation should not be created pure over a large area. The maximum size recommended is about 15 to 16 ha. Teak plantations should be separated by strips of natural vegetation. (L S khanna 1998 Forest Protection)

ii) Sal Borer: *Shorea robusta*, is one of the most important timber species of India. The heartwood borer, *Hoplocerambyx spinicornis*, is the most serious pest of Sal throughout its range. Its beetles emerge soon after a few showers of monsoon rains from the third week of June to the end of August. They are attracted to the odour of freshly cut bast and sapwood of sal. Soon after mating, the beetle oviposit white, cream coloured eggs in cracks on the bark. After 3-7 days of egg period, the hatching takes place. The freshly hatched grubs bore the bark and reach to the sapwood, where they form tunnels. After feeding the sapwood, the grub move to heartwood where they form a wider pupal chamber, the grubs start pupation from December onwards, develop to immature beetles between April to May and emerge out from middle June onwards during monsoon. The male has long antennae than their body while the female has short antennae. The incidence of attacked sal trees due to heartwood borer goes upto 24.33 per cent during epidemics. The borer killed more than 26 lakhs of sal trees during the sal borer epidemics in Madhya Pradesh between 1996-02. (Source: K. C. Joshi, N. Roychoudhury, N. Kulkarni, S. Sambath 2006, Sal Heartwood Borer in Madhya Pradesh at http://www.indianforester. co.in/ index.php/ indianforester/article/view/4513/0)

(http://www.cerambycoidea.com/foto.asp)

However, following control measures are generally recommended:

(a) Silvicultural control: Sal crop should not be grown dense. It should be regularly thinned. Felling should be restricted between October and March. (L S.Khanna 1998 Forest Protection)

(b) Mechanical control: In some epidemics in the past following control measures had been adopted:

- **Catching and killing of insects through Trap:** Tree method. In this Operation, one to two trees ha-1 of 60-90 cm girth are felled, cut into 2-3 m long logs and the bark near cut ends is beaten up to provide shelter for the beetle. The beetles get attracted to the smell of sap, get intoxicated after consuming it and become sluggish, rendering their collection and killing easier. Beetles are collected from traps every morning and evening. The heads of beetles are severed and counted for record of daily catches. Trap tree operation starts on the onset of monsoon and that continued till the day the insect catches are nil.
- Felling and removal of affected trees away from the sal forests.
- Burning of debris and stumps after harvesting of trees.
- Stacking of infested timber in depots five km away from sal forests in order to prevent the beetles from flying back to forests.

(Source: http://www.fao.org/docrep/ARTICLE/WFC/XII/0739-B1.HTM)

iii) Galls in Eucalyptus: Plant galls are abnormal outgrowths of plant tissues and can be caused by various parasites, from fungi and bacteria, to insects and mites. Insect galls are more common. In south West Bengal Eucalyptus plantations, on a large scale, were infected by galls in recent past. Galls are also often found in plantations of Emblica officinalis (Amlaki). Insect galls are formed by some herbivorous insects as their own microhabitats. They are plant tissue which is controlled by the insect. Galls act as both the habitat and food source for the insect. (http://en.wikipedia.org/wiki/Gall). Leptocybe invasa, Fisher & La Salle, commonly called Blue Gum Chalcid, is a newly described gall-inducing wasp species currently spreading in many countries and causing damage

Fig. Galls in Eucalyptus (Source:http://en.wikipedia.org/wiki/Gall).

to young eucalypt plantations and nurseries. Galls induced by this wasp can cause serious injuries to trees, thereby weakening them.

Control Measures: No effective control measures are currently available. The following interim measures are recommended to manage the wasp problem:

1) periodic monitoring of infestation in nurseries and plantations;

2) mechanical removal of affected plant parts and subsequent burning; and

3) avoid production and planting of highly susceptible clones.

Application of systemic insecticides like Rogor or Metacid 50 (@ 2ml/1 litre water) on foliage at fortnightly intervals is effective. (http://www.fao.org/forestry/22072-0e774d1f27c87fa48a76b498a3b4bd3b4.pdf)

Unit 10: Protection against injuries by domestic animals

Unit Structure

10.0 Learning Objectives

After going through this unit you shall be able to explain:

- The injuries caused by domestic animals and
- Preventive and remedial measures to control the domestic animals the their harmful effect.

10.1Introduction

Increase in the population of herbivores has a serious impact on forest ecosystem. The herbivores may be domestic or wild. Herbivores in the wild may increase in number through reduction of predators. The domestic animals again grow in number as they are considered as assets or property by men who rear them. The wild herbivores almost totally depend on forest plants for their food. Further, a large portion of domestic herbivores belonging to the villages adjoining to forests graze and browse in the forest lands. Thus the dependence of herbivores, wild and domestic, on forests for food lead to considerable pressure on the forest ecosystem and may turn to be quite destructive of forest regeneration.

Among domestic stock, goats are by far the most destructive of forest regeneration, followed by pigs, sheep, and cattle, in approximately that order. Long-continued overgrazing by livestock will result in the elimination of palatable species from the ground up to the browse line, compaction of forest soil, and eventual conversion of the forest to an open scrub of unpalatable species or grassland (Burton V Barnes et. al, 1998 Forest Ecology John Wiley & Sons, Inc.).

10.2 Domestic Animals and injuries by them

Domestic animals form a part of asset to humans and men, by way of their natural instinct to add to their property, would like to own more number of domestic animals. This is the major reason for increase in the population of domestic animals. It is important to note that even as the livestock population has increased over time, the number of cattle grazing in the forest has risen at a higher rate, since extent of pasture land has decreased. Further, the livestock industry is an important branch of agriculture. As operated in many parts of the country it involves the turning out of the animals into the field and forest for part of the year at least to forage for themselves. The common domestic animals exerting direct influence upon the forest are cattle, horses, mules, asses, swine, sheep and goats. These animals are distributed through all parts of the country.

The adverse impact of domestic animals on forests has been growing due to following factors:

• Increasing population of livestock in the forest fringe villages;

• Paucity of grazing land outside forests;

• Traditional practice of grazing the cattle in the forest land;

• Lack of awareness about the damage being caused by the animals to the growing plants;

• Forest resources are considered as nobody's property and as such forest protection still now receives low priority in rural development.

10.2.1 Classification of domestic animals

On the basis of food the domestic animals are classified into following two classes.

a) **Grazing animals:** Those animals which feed mostly on grass and herbage are categorized as **grazing** animals. Examples are cow, bullock, buffalo, horse etc.

b) **Browsing animals:** Those animals which feed on twigs or shoots, with or without leaves, of shrubs, trees and woody climbers are categorized as **browsing** animals. Examples are goat, camel, elephants etc.

10.2.2 Damage caused by grazing animals

Light controlled grazing does rather good to forests. As grass and herbs are removed, the fire risk goes down. In temperate forests light grazing disintegrates the thick layers of undecomposed needles and facilitates germination of conifers. However, uncontrolled grazing causes the following damage to forests:

- Seedlings of desired species are also grazed along with grass. So regeneration of important tree species is hampered.
- Grazing animals deliver physical damage to desired seedlings by trampling, crushing to earth and dislodging the roots from the soil by their hooves. This leads to mortality of the seedlings.
- Soil becomes compacted and porosity is reduced. This also results in poor aeration inthe soil. Under the hooves of heavy animals the soil aggregates break down leading to poor structure of the soil.
- Compaction of clayey soil due to grazing leads to increased runoff. Again, sandy soil under the hooves becomes loose. Thus both in clayey and sandy soil, soil erosion is increased due to grazing.
- Heavy uncontrolled grazing causes depletion of nutritive palatable grasses and in their place unpalatable, less-nutritive, thorny grasses do emerge. The grazing capacity of forests is considerably reduced.
- Adaptive character of nature also helps establishment of grazing-resistant inferior species in place of valuable crop which are mostly grazing prone.

10.2.3 Damage caused by browsing animals

Browsing animals cause more damage to plants than grazing animals. And among the browsing animals, the goat is the most destructive and damage inflicted by goat is most common. The goat eats up almost any plant including the thorny ones. In the process of browsing the leaves, the shoots are chewed and damaged to such an extent that they cannot re-grow. Adding to the potential for damage is the fact that the goat stands on its hind legs to reach leaves or shoots located at heights which it cannot reach in normal posture. Thus the browsing reach of a goat is more than its height. The sheep is, however, less destructive. Considerable damage is caused by the camel. Since it is a tall animal, the camel is capable of causing damage to a height of about 4 metre. The camel is, of course, found in some specific areas and therefore the damage caused by it is localized and limited to such areas.

10.2.3 Measures in management

Grazing in forests cannot be eliminated altogether by enforcement of law or by persuasion of the villagers. Complete stoppage of grazing as an object of forest management is not desirable either. Light controlled grazing, as stated earlier, is beneficial to regeneration. And when management practice, without compromising the object of development of forests, provides for grazing under certain regulations, it achieves one major input for forest enrichment. The input is support and active cooperation of the fringe population, which is the basis of joint forest management. The management measures to address the problem of grazing should therefore strike a balance between control measures necessary for scientific forestry and providing options for grazing to livestock of nearby villages. All measures, preventive or remedial, should flow from this principle.

10.3 Control Measures

10.3.1 Preventive measures

a) Preventive Measures for Grazing

Following are some examples of preventive measures that can prove to be helpful:

- **Discourage to keep large number of cattle:** People keep large herds for supply of milk, agricultural works and more importantly for dung which is used for manuring and burning. The villagers in the outskirts of forests need be explained that breed and quality of cattle are more important than the number. All the objects of keeping cattle are better served by less number of healthy cattle of good breed than a larger number of emaciated stock. It is also easier to manage and feed a fewer stock. They can be fed at home or put through regulated regime of grazing without much hassle. If the villagers are convinced and number of ill-fed cattle is reduced, the pressure on forests will automatically lessen.

- **Inclusion of grazing in forest function where compatible:** Forests are classified according to their most important functions. For example, there are reserved forests, protected forests, village forests, wildlife sanctuaries, tiger reserves etc. Unclassified forests also form a class. If grazing is not incompatible with the most important function of a forest, it may be allowed. And even if incompatible, grazing may be allowed in restricted time and zone if it helps to achieve the most important function of the forest.
- **Closure or regulation of grazing:** Some parts of the forest, called vulnerable areas, may be closed to grazing altogether. These vulnerable areas constitute concentrated regeneration areas, areas under active erosion, catchments of river valley projects, and other degraded areas.
- **The concentrated regenerations areas:** young plantations etc- are not large and therefore can be closed without much problem. As soon as the plants cross a stage when they are longer liable to be damaged, the areas in question may be opened to grazing subject to grazing capacityAreas which have become highly eroded or degraded owing to, among other things, heavy uncontrolled grazing, the same should be closed until remedial measures are taken and such areas become rehabilitated.

  In areas other than vulnerable areas, grazing may be regulated, that is, allowed in a restricted manner, depending on the grazing capacity of the area. There is a limit to the maximum number of cattle that a forest area can allow for grazing and still regenerate fodder necessary to sustain grazing by the said number of cattle. Grazing capacity of anarea is defined as the amount of grazing that the area can afford to sustain, and is expressed as the number of animals or equivalent cow-units per acre/hectare. Grazing capacity of forest areas is determined by various factors like forest type, canopy density, climatic and edaphic factors, slope, amount and quality of grass etc.

Limitation to grazing incidence to the grazing capacity may be effected by taking the following steps:

- Intensive discussion with the JFMC members or villagers, convincing them to appreciate the need to enforce the regulation;
- Issue of a circular or executive order following above discussion; the circular may, among other things, clearly indicate the number of cattle units permitted to graze over a specified area.
- Introduction of disincentive by levying grazing fee on an appropriate scale.

b) Preventive Measures for browsing

Rearing of goats and sheep forms a means, sometimes the only means, of income of some villagers in the outskirts of forests. These villagers leave their livestock free to browse in the forests. Forests thereby become the major source of fodder for these browsing animals and have to bear the damaging impact of browsing. When the herds are large, the degree of destruction is considerable, and often young plantations and other regeneration areas are damaged to such an extent that it becomes necessary to plant up the area afresh. It has been realized since long that admission of browsing animals into the forest is incompatible with the aims of forest management, and should be stopped as far as possible. The measures that merit consideration are:

- To stop, or contain as far as possible, entry of browsing animals into the forests;
- To meet the feeding requirement of these animals by allowing the villagers to collect from forests fodder of optimum quantity; a suitable arrangement should be in operation to allow collection of fodder by the villagers.
- To include in the regeneration plan of forests planting or growing of fodder plants;
- To raise fodder plants reserve as part of social forestry project;
- To educate the villagers on the necessity of adopting these measures.

10.3.2 Remedial measures

Despite taking preventive measures, such measures may not prove to be enough, and the damage due to grazing may continue. Foresters also often come across areas which have been damaged in the past due to grazing. Regulation of grazing, that is, allowing limited numbers of cattle to graze will not be appropriate measure in those areas. Remedial measures need to be taken in such case. Remedial measures are normally of two types –

a) Periodic or Rotational grazing: When the damage is not serious, further deterioration is arrested by taking recourse to these measures. Periodic grazing is defined as grazing by limited number of cattle for a definite number of years or months followed by closure (L.S Khanna 1998, Forest Protection).

- The object is to allow time (during the period of closure) for the grasses to regenerate and develop so as to afford grazing pressure again for some time;
- Repetitive periodic closure and opening of an area enables the area to regenerate palatable grasses and bear the impact of grazing during the periods it remains open for grazing.
- It is different from complete closure of regeneration or eroded areas for a period of 5 to 10 years or for longer periods. While the object of periodic closure, which is of shorter duration, is to allow time for grasses to regenerate, the object of complete closure, of a much longer duration, is to allow time necessary for establishment of tree species.

b) Rotational Grazing:It is defined as grazing of a limited number of cattle in the different parts of the grazing area in a predetermined sequence (L.S Khanna 1998, Forest Protection).

- In rotational grazing the forest area is divided into a number of blocks. The blocks, one at a time, are opened to grazing for a specified period in a sequence. Thus one block or the other of the forest remains open to grazing by limited number of cattle throughout the year, except may be for the rainy season (July-August)
- The cattle number is limited to the grazing capacity of the forest.

- For example, a forest of 1000 ha of grazing capacity 1.25 cow-units per ha is put to rotational grazing. It means that 1250 cow units can graze in the said forest. The said forest is divided into, say, 5 blocks. It is also planned that the forest will remain closed to grazing during the rains, that is, for the 2-month period of July and August. So under rotational grazing, during the 10-month period of the year each block will be opened for 2 months to grazing by cattle of number not exceeding 1250. The idea is that when grasses in a block are grazed up in 2 months, the cattle are moved to another block and the process repeats itself. Thus each block of 200 ha gets a respite time to regenerate itself. In order that a particular block does not open for a fixed grazing period of two months every year, the grazing period of a block is moved in successive rotations or cycles. It is illustrated in the table.

Grazing Period	First rotation or cycle	Second rotation or cycle	Third rotation or cycle
January- February	Block I	Block II	Block III
March-April	Block II	Block III	Block IV
May-June	Block III	Block IV	Block V
September-October	Block IV	Block V	Block I
November-December	Block V	Block I	Block II

(Source: L.S Khanna 1998, Forest Protection).

- In order to ensure that grazing is done in the prescribed block, it becomes necessary to fence each grazing block.
- **Artificial regeneration of grasses:** When the damage due to grazing is serious and the land hardly provides any grass for grazing, the rotational grazing may not be adequate to regenerate the area and the option left is to go for artificial regeneration of grasses. Artificial regeneration is, however, feasible only in degraded forests or pastures. The open degraded forest is taken up for planting with superior grasses after suitable soil work.

Summary

References

a) Burton V Burnes et al 1998 Forest Ecology John Wiley & Sons, Inc

b) L.S Khanna 1998, Forest Protection, Khanna Bandhu, Dehradun,

Unit 11: Protection against injuries by wildlife

Unit Structure

11.0 Learning Objectives

After going through this unit, you shall be able to explain the injuries by various kinds of wild animals and the protection measures.

11.1 Introduction

Wild animals are an integral part of the forest ecosystem. In an ideal condition they should remain in a dynamic equilibrium among themselves and with the vegetation. That is, in an ideal scenario, the vegetation of a forest, while supplying food for the herbivores, gets time, space and nutrients to regenerate and sustain in terms of quantity and diversity. However, when the balance is upset, the trouble starts and damage to forest flora becomes manifest. Damage caused by wild animals depends on the animals, their size and feeding habit, and also on the plants, their age and the species concerned. Normally, mature trees can escape the risk of damage, and of course, the young plants are the worst victims.

11.2. Damage from wildlife

In this category injury from those animals are included which are other than insects and domestic animals. The term 'wildlife' includes all the animals other than domestic animals. Although a number of animals are included in "wildlife," yet the number of animals that are harmful to the forests are relatively small. While some of the wildlife are beneficial, others are injurious or harmful. Sometimes the same animal may prove to be harmful whereas the same animal may be beneficial to the forests, as they play important role in various ecosystem processes.

11.2.1 Injury by herbivores

Herbivores feed on grass, leaves, branches of shrubs and small trees, and other vegetative parts like flowers, fruits, bark etc. So as they thrive in the forests, the herbivores cause injury to the plants. The nature of damage caused by some of the herbivores is described below:

11.2.2Damage by Spotted Deer and Sambhar Deer

All species of deer and Sambhar are potential enemies of the forest in the sense that they will cause severe damage where overstocking occurs. The damage caused by deer in the forests is quite similar to that the damage caused by domestic animals. It does not mean that they have same food habits however it does imply that the main injury done is almost similar due to nature of browsing habits upon trees, upon ground cover and underbrush. Deer eat the same type of forage as sheep and goats, therefore, are very close to these animals than to cattle in their food preferences. In general, deer prefer to browse than to graze on grasses. They cause considerable damage to seedlings and saplings of forests. Young sal seedlings are heavily grazed by these animals. They also browse leaves and tender shoots of many species namely, *Pterocarpus marsupium* (Peasal), *Alibizzia lebek* (Kalo Siris), *Artocarpus chaplasha* (Lathar), *Chukrasia tabularis* (Chikrasi) etc.

11.2.3 Damage by wild boar

While being omnivorous the wild boar's favourite food is roots and tubers. As they look for roots and tubers, the boars dig the forest soil and kill the young seedlings of forest species. In North Bengal, damage of germinating Sal seeds and Sal seedlings by wild boar is very common. The wild boars are also very fond of bamboo rhizomes, and thus bamboo crop in forests is highly vulnerable to damage by the wild boars.

11.2.4 Damage by Indian Bison or Gaur

Gaur diet consists of grasses, herbs, shrubs and trees, with high preference for leaves. Some recent studies have reported that gaur feeds on a much wider variety of plants than any other ungulate species of India, with a preference for upper portions of plants, such as leaf blades, stems, seeds and flowers of grass species. Some early studies had however concluded that gaurs are primarily grass eaters. As they feed on grass and forest seedlings, the gaurs damage the regeneration of forests. They also cause mechanical damage to young trees. (http://www.threatenedtaxa.org/ZooPrintJournal/2009/February/o158926ii09128-130.pdf)

11.2.5 Damage from Rabbits

The injury caused by rabbits consists in biting off buds, small branches and stems and in gnawing the bark, often causing the girdling and death of the tree. The damage is done by these animals during the winter months when other food is scarce and occurs ordinarily within two feet of the ground but above the duff. In examining seedlings and trees which have evidently been gnawed by animals it is often difficult for the practicing forester to determine just what animal caused the injury. Each animal leaves distinctive tooth marks (Anonymous 1936-a) which tell the expert the identity of the animal. The tooth marks of rabbits lie horizontally across the stem of the tree. Tooth marks are broad and individually are about one eighth inch wide. Porcupines seldom eat from the base of a tree. Their teeth extend obliquely to main axis of branch. The width of cut by a tooth is 0.07 to 0.09 inch.

11.2.6 Damage from Mice and other small Rodents

A common type of injury from mice and other small rodents is the destruction of tree seed. This takes place throughout the forest, but is particularly to be feared in nursery seedbeds. Besides eating tree seeds, mice may cause serious injury to seedlings and young trees by gnawing the bark either above or below ground, often girdling them and causing death. Tops of seedlings may be bitten off. Perhaps the most common type of injury occurs right at the ground line under the forest litter where it is not noticed until after the next growing season when the brown foliage and dead branches indicate that the tree has been girdled. Injury of this character is caused by the mice during the winter time, particularly under deep snow when their food supply is scarce.

11.2.7 Damage from Birds

The beneficial influence of birds in destroying insects and small rodents far outweighs their injurious effects upon the forest (McAtee 1926). Nevertheless, in several respects they are a source of damage to the forest. Birds feed upon the seeds of forest trees and bite off the tops of seedlings. Woodpeckers peck holes in the trees. Birds occasionally injure the forest by roosting in the tree tops in such large numbers as to increase appreciably the nitrate nitrogen content of the soil. Such injury becomes of consequence only when the birds are gathered in flocks and have the habit of roosting each night in the same place for a considerable period of time. Where this happens the forest is injured in several ways. The trees may be killed by the effects of too high concentration of mineral nutrients, particularly of nitrate nitrogen in the soil, or the mechanical effect of the roosting birds may prove injurious to the foliage of the trees.

11.2.8Damage by wild elephants

Elephants are the largest herbivore in our forests and are most destructive by virtue of their size and quantity of food they need to survive. It is estimated that an adult elephant eats daily about 1.5 quintals of forage in the form of grasses, leaves, small plants, branches, roots, fruits and bark of trees. Tree bark is a favourite food source for elephants. It contains calcium and roughage, which aids digestion. Tusks areused to carve into the trunk and tear off strips of bark.

(http://seaworld.org/animal-info/animal-infobooks/elephants/diet-andeating- habits/). They damage Sal and Teak trees, particularly when young, by removing bark. Bark and leaves of *Ficus* species, *Artocarpus chaplasha* arefavourite food. The elephants also like to feed on bamboo, which is destroyed extensively in forests. Besides, consuming forage in large quantities, the elephants playfully cause damage by breaking or uprooting small trees.

The elephant population is on the rise. They cause damage not only to forests, but also agricultural crops, vegetable crops and human habitation. Elephant depredation is now very common phenomenon in West Bengal and has become one major problem in wildlife management. Indirect method of containing their ravage by capturing them by kheddah or pit method or by chemically immobilising some select individuals has not been found to be very effective. Following direct methods have been found to yield result in varying extent.

- **Scaring them away**: Elephants are scared away from young plantations and human habitations, desired to be protected, by beating drums, firing crackers and lighting torches.
- **Elephant proof trench:** This method is employed to protect young plantations or villages adjacent to forests. Trench, 2 metre wide at the top and 1.2 m at the bottom, and 2 metre deep is dug all around the plantation, or along the boundary between forest and village to keep away the elephants. However, this is a costly method and the trenches require maintenance.
- **Power fencing:** Entry of elephants to forests or human habitation can be checked quite effectively by installing power fencing. Mild shock as they come in contact with the energized fencing keeps the elephants off from the plantations or village boundary. However, on account of cost and need for maintenance, power fencing cannot be employed to protect large areas for a long time.

11.3 Protection measures

Protection measures against damage by elephants have been described above. A general preventive measure against the damage by herbivores is to fence out the regeneration area. Wire fencing or vegetative fencing around young plantations for the first two years saves a lot of damage from the herbivores. However, fencing is not an effective measure against large herbivores like elephants and animals like monkeys. If a plantation of sapling/pole size crop is heavily damaged by browsing, and if the main crop is a coppicer, then the stems can be cut.

Unit 12: Forest fires and their control measures

Unit Structure

12.0 Learning Objectives

After going through this unit you shall be able to:

- Know about forest fires
- Classify the damage caused by forest fires
- Know about control measures

12.1 Introduction

In the previous units, you became familiar with the various kinds of damage to forests i.e., damage by humans, damage by domestic animals, damage by wildlife, damage by various kindly of diseases and damage to forests from insects- pests. Additionally, you also became acquainted controlling measures.

In this unit, we will discuss about the damage caused by forest fires. After going through this unit, you will come to know about forest fires and various kinds and ways the forest fire causes damage to the forests. Forest fires are the most common hazards that occur in the forests. They have a history as old as the forests themselves. They pose a threat and often cause damage not only to the forests but also to wild flora and fauna. In addition to this, forest fires cause disturbance to the whole ecosystem by bringing about imbalance to the bio-diversity and ecology and, thus, whole environment of the region. It is particularly in the summer season when we often see forest fires. Summer season is very favourable for forest fires as there is no rain and a lot of dry burning material remains lying on the forest floor which catch fire very quickly even by a slightest spark. In the Himalayan forests, the dominance of coniferous forests and their dried needles often set huge area of forests into fire, thus, causing tremendous loss in monetary as well as aesthetic terms.

12.2 Basics of forest fire

A forest fire involves combustion of organic material (fuel) that releases a large quantity of energy. The combustion energy is transferred from the burning fuel to unburned fuels ahead of the fire front. This phenomenon ensures the fire spread. The fire start depends on the flammability of the vegetation. The fire spread depends on a number of variables, including fuel characteristics (size, moisture content and arrangement), weather and topography. The fire processes develop in three phases:

(a) evaporation of water in the fuel,

(b) emission of flammable gas by pyrolysis, and

(c) ignition

The ignition is ensured by an external energy source. In the following process one part of the released combustion energy is reabsorbed by the fuel in order to sustain the combustion. In the case of a forest fire the released energy is absorbed by the vegetation ahead of the flaming front, which causes the fire propagation.

12.2.1 Combustion, release of energy and fire intensity

Combustion is defined as “It is a fast and exothermic oxidative reaction that releases heat, requiring an oxidizing agent to burn the fuel”. In the case of a forest fire this oxidizing agent is the air in the atmosphere with the vegetation being the fuel. Thus, the combustion requires the presence of three elements: **fuel, oxidizing agent and initial energy**.

The fuel consists of leaf litter, grass (highly flammable in the dry season), low woody material (shrubs and trees with a height of less than two meters) and high woody material (with a height of more than two meters). Further, the spatial arrangement of the fine fuels (such as leaves, needles, and branches) influences the fire intensity as loosely packed fine fuels have better contact with oxygen and ease the combustion process whereas the densely packed heavy fuels don’t cooperate with fire easily.

Compositions of plant material influences fire intensity. Presence of high water content in the vegetation with is not very flammable and combustible. Dry material is composed of organic matter, minerals and less water content. A plant with high mineral content has a reduced heat yield and is less combustible. It is the organic material that only burns and releases the necessary energy for the fire propagation.

Oxidizing agent includes oxygen which remains available in abundance in the forest atmosphere. It is the presence of this element in which strongly depends ignition and combustion. An oxygen content of at least 15.75 % in the air is required for ignition of flammable gases (the product of pyrolysis) and sustenance of flame. It is estimated that the average oxygen content of the air (by volume) is 20.95 %. Further, movement of air (wind) plays an essential role in fire spread because it supplies oxygen to the active fire.

The capacity of a fuel to catch fire depends on its characteristics, the energy source and the exposure time − A weak energy supply allows the ignition of grass, whereas the energy supply has to be much higher for the ignition of wood. − In order to ignite dry vegetation by a glowing ember the presence of wind is required. − An electric arc cause by a broken power line or by lightning.

Initial source of energy plays key role in strength of fire. A weak energy supply allows the ignition of grass, whereas it is not sufficient for burning woody material for which the energy supply has to be much higher. In order to ignite dry vegetation by a glowing ember, the presence of wind is required. An electric spark cause by a broken power line or by lightning provides sufficient energy for ignition of dry vegetation.

Fire intensity depends upon total fuel load, type of available fuel and wind speed. **Total fuel load** may be defined as the quantity of all aboveground combustible materials (usually measured in grams of organic matter (dry weight) per square meter, or tons per hectare). During a forest fire only a fraction of the total fuel is consumed and it is only the available fuel that actually burns. **Available fuel** is defined as the portion of the total fuel that actually burns or would actually burn under specified burning and fuel conditions. The amount of energy released as a result of burning is called **Energy release** which is measured as total heat release per unit area (kilojoules per square meter (kJ/m2). After the fire is set in, its rate depends on speed of wind and called as **rate of spread** which is measured in meters per second or in km per hour.Another important term is **Fire line intensity** which is the released energy per unit time per length of the fire front (leading fire edge) and calculated in kilowatts per meter of the fire front (kW/m). **This fire line intensity** equals the product of available combustion energy and the fire rate of spread.

12.2.2 Heat transfer and fire spread

The heat transfer mainly takes place by three ways i.e., conduction, convection and thermal radiations.

The conduction is a process of heat transfer resulting from the molecular movement. It can happen in a material that is solid, liquid or gas. The heat spreads from the warm to the cold body. In practice, it has least role during the spread of a vegetation fire as it transfers only 5% of the total heat transfer. However, exception is a ground fire or a peat fire where **conduction** is the predominant heat transfer method.

In Radiation heat or energy transfer takes place through electromagnetic radiations or waves with or without particles. All bodies having absolute temperature above 0 K (= –273°C) emit an electromagnetic radiation. The quantity of the transferred energy from one body to another body augments with the increase of the temperature difference between these two bodies. Heat transfer during a forest fire is mainly by electromagnetic infrared radiation.

Convection is a heat transfer by macroscopic movements of a fluid (gas in the case of a fire) whose mass transports the containing heat. In vegetation fires, combustion produces hot gases which mix with also heated ambient air. These hot gases are lighter and go up quickly. They bring a great quantity of heat to fuels located above (crown), desiccate them and raise their temperature up to the ignition point. The wind, by pushing hot gases ahead of the flaming front, even in the lower layers of the vegetation, accelerates the fire spread. The variations of the topography also influence the displacement of hot gases. For an upslope fire, the convection ahead of the fire front is more marked with increasing slope steepness. It is the opposite in a downslope fire. The convection is the dominating process of heat transfer in the forest fires spread. In addition, the moving gases often transport burning materials ("firebrands"), which can fall down up to several hundred meters in front of the fire and ignite new fires ("fire spotting").

12.2.3 Flammability, combustibility

Flammability qualifies the proneness of the fuel to ignite under heat. It characterizes the quantity of energy necessary to the desiccation of the plant and the pyrolysis. One of the methods employed to estimate this flammability consists in measuring the following parameters of vegetation samples that are subjected to thermal radiation:

- **The time of ignition**, corresponding to the exposure time necessary to the appearance of a flame. This factor can be measured using a stop watch.

− **The frequency of ignition**, i.e., the number of samples where a flame appears, in relation to the total number of samples.

The average values of above two parameters allow classification of plants according to their flammability.

Combustibility is the fire intensity related to the characteristics of the vegetation. It describes the fire intensity that a vegetation formation can build up, **without taking**

into account the topography and the wind. It characterizes the proneness of the vegetation to burn by releasing sufficient energy and to induce, by heat transfer, the ignition of the next plants. The combustibility of vegetation is correlated to

- the amount of biomass combusted,

- the heat content of the particular species burned,

- the spatial structure, and

- the water content (i.e., the season).

12.2.4. Importance of flammability and combustibitlity

The importance of flammability and combustibility in the context of estimating forest fire hazard as follows:

- The flammability of a plant varies according to its parts. The bark of the Pine does not have the same flammability as its needles. The fire in a pine forest starts in the litter, made up mainly of dry needles. The risk analysis of an ignition in such a stand requires the knowledge of the flammability of these needles
- The study of flammability starts with the analysis of the risk of a fire occurrence, either temporal (follow-up in time), for example, resulting to a preventive mobilization of fire fighting forces at days with high risk, or spatial.
- The combustibility study allows defining fuel types in function of fire behaviour models.

12.3 Causes of Forest Fires

The causes responsible for the origin of forest fires are numerous and vary from region to region, country to country and also from one season to another season in the same region or country. Most of the forest fires are of human origin, i.e., caused by accident, negligence or intention.All other fires, approximately 90 per cent of the total, are man-caused and consequently preventable. It has been found that the chief causes of forest fires are: **incendiarism, smokers and debris burning**. **Evidently man is the chief cause of forest fires**. Fire causes may be grouped into two divisions as either natural or man-caused.

12.3.1 Natural causes

Lightning (directly or indirectly) is among the most important natural causes of forest fires. It accounts for 5 to 10 % of the forest fires. The natural causes that prompt fire are lightning, rolling stones or rubbing of dry bamboos. The major among these causes is the lightning. Between 70 and 100 lightning flashes are estimated to occur every second worldwide, but not all strike the ground (Burton V Burnes et al 1998). In our country the number of fires that may be caused by all the three natural causes are not more than 5 % of the total number of fires caused in a year (L S Khanna, 1998).

12.3.2 Human made causes

A. Involuntary cause

- **Fires due to negligence**: Negligence results from carelessness vis-a-vis the fire hazard and is correlated with the visitor frequency in the forest or its immediate surroundings. The type of carelessness depends on the activities in the forest and its immediate surroundings.

  In each country the distribution of causes is very different: in villages or rural areas fire starts are very often at the limits of a forest due to negligence of villagers.

  Smokerscarelessness or negligence: Smokerswhich may be tourists or villagers, may through lit cigarette or match carelessly in forest floor which later on catches fire.

  Camp Fires: Fires resulting in any manner, smoking accepted, from carelessness of campers and travelers through the forest, such as stockmen, prospectors, picnickers, surveyors, berry pickers, hunters and fishermen, and camp fires of woods workers.

- **Accidental Fires:** Fires caused by accidents are usually much less frequent than fires due to negligence. This may happen through:

  - Traffic in the forest or its periphery: the forest / road interface are zones with a strong probability of a fire start. The projection of fire sparks during the passage of a railway train, or by the muffler of a vehicle (car, motor bike, etc.) can cause a fire. Fires from sparks or cinders of all classes of locomotives and construction engines, clearing of rights-of-way and all other fires incidental to operations on, or to the occupancy of, the right-of-way of an established common carrier railroad or to common carrier railroads under construction, may cause forest fire to set in.

- Power lines: strong winds can cause electric arcs between swaying lines and set vegetation at fire.
- Garbage dumps: either authorized or clandestine, in any case, garbage dumps constitute a potential fire source by ignited papers or internal combustion caused by fermentation.
- **Debris Burning:** Fires which are caused for clearing lands for any purpose (other than for rights-of-way for common carrier railroads and brush burning in lumbering operations) or for rubbish, garbage, range, stubble, or meadow burning, and which, without intent on the part of the burner, spread to lands not his own.
- **Lumbering:** Fires, excepting those set by smokers and from camp fires of woods workers, incidental to all lumbering operations; caused by sawmill engines, logging railroad locomotives (except on such logging railroads as are common carriers) and wood camps; through carelessness of employees engaged as wood choppers, slash burners, shake makers, etc., and by persons cutting free use timber.

B. Deliberate or intentional causes

- Burning the undergrowth to collect minor forest produce;
- Inducing new shoots of grass by burning the dry grass;
- Scaring away wild animals from the villages in the forest fringe;
- Destroying or charring the stumps of illicitly-felled trees.
- **Pyromania:** Certain individuals set a fire out of pleasure, as a game, to draw attention, to see fi re engines in action, etc. This pyromania is more or less morbid, according to the degree of responsibility feeling of the individual. This cause plays, however, only a limited role, even if there is often a tendency, in the case of an uncertain fire origin to blame a pyromaniac.
- **Revenge:** Fire can be a tool of revenge caused by a controversy with the administration (hunters) or a neighbour, social exclusion (dismissed worker), expropriation, etc.

12.4 Forest Fires and their Classification

Forest fires are generally distinguished into three classes in accordance with the vegetation strata or soil they are spreading through. These are:

- Ground fire
- Surface fire
- Crown fires.

12.4.1 Ground fires

Ground fires are those fires which take place in the organic material of soil i.e., humus and peat layers, which remain lying beneath the litter or undecomposed portion of the forest floor. Thus, this kind of fire burns the ground cover only, i.e. the carpet of herbs and low shrubs which cover the soil. It is sometimes also known as **peat fire**. These organic layers remains either closely compacted or of fine texture and also remains away from wind and thus, from oxygen supply. Therefore, a ground fire has a very slow burning nature and may or may not produce much smoke, however, there is practically no flame. However, it produces intense heat and causes uniform destruction and can penetrate in very deep organic deposits. It has a capacity of burning ranging over several acres in a day to only a fraction of an acre. Ground fires may be further subdivided based on the type of damage, mode of spread and development characteristic of fire into two types i.e., **Duff fires and Peat fires. Duff fires** are those ground fires which occur on upland areas where thick deposits of litter, duff and humus have accumulated whereas **Peat fires** include the ground fires which take place on swamps and bogs where layers of duff and peat are found several feet beneath the surface. Ordinarily **all trees on the burned-over area are killed by a peat fire through overheating the roots**. The roots are, thus, easily killed by the ground fire. When the surface is wet but the duff beneath is dry, a ground fire may burn **the lower layer of organic material**, leaving the surface intact supported by a network of plant roots. It is very difficult to determine the exact location of groundfire.It has been observed that **Peat fire** scan remain live in swamps for several months whereas **duff fires** may remain active all the winters under a blanket of snow. In swamps and lowlands, with excess of water, the organic matter does not readily decay. In Northern latitudes at high altitude regions due to the cold damp climate thick beds of duff can be developed. This is particularly true in conifer dominated areas. In such areas ground fires are of relatively rare occurrence in comparison to surface fires because the material on which they feed dries out less frequently than the top litter. Furthermore, the sites on which ground fires may occur form a relatively small percentage of the total forest area.

12.4.2 Surface fires

Surface fires burn the low and contiguous layers on the ground (litter, grass, undergrowth). They are the most common kind amongst all kinds of forest fires. It burns not only the ground cover but also the undergrowth. This is the most common type; it consumes litter, killing aboveground parts of herbs and shrubs, and typically scorching the trees.

Surface fire is very sensitive to wind speed. It tends to kill young trees of all species (often, however, just the aboveground portion) and most of the trees of less resistant species of all sizes (Burton V Burnes et al 1998). It burns on or near the ground surface in the litter, ground cover, underbrush and recruitments/ seedlings or sapling. If only the top of a thick accumulation of duff is dry enough to burn, the fire is classed as a surface fire, whereas, if the entire accumulation of duff were burned, the fire might be classed as a ground fire. Typical surface fires injure only the lower part of the trunks of trees beyond the seedling and sapling stage and, if trees are killed, it is because the fire kills portion of tree stem by heating at surface level.The material which support surface fire are very inflammable on account of its light and loose nature. This fire and its damage are further aggravated by the speed of wind and abundant supply of oxygen, therefore, surface fires are characterized speed, abundance of flame and heat, but dies out very soon.

12.4.3 Crown fires

Crown fires as the name indicates are those fires which spread through tree crowns. It burns the foliage of trees and the trees are generally killed by overheating of the branches. Crown fires are usually found in such forests where the tree foliage is of highly inflammable nature. Therefore, it **is restricted to conifers having inflammable foliage**. Hence coniferous forests are mostly affected however; there are examples where certain broadleaved shrubs and dwarf trees species with evergreen foliage of an inflammable character have also been affected. In most broadleaved species, leaves remain green till it remains on trees and are less inflammable. Further, the foliage does not occur in such close arrangement as in conifers. However, in some broadleaved species the dead leaves remain in trees for some time and therefore, it becomes burning material for crown fire. The crown fires are again categorized into two types: :

i) Independent crown fires or running crown fires: The running crown fire progresses independently through the crowns of the trees independently from a surface fire. It spreads with great speed although it is slower than a quick running grass and brush fire. It is closely followed by a surface fire.

ii) **The dependent crown fire** which spread in the tree tops only because of the heat released by the surface fire. It is accompanied by a surface fire. The burning material on the ground furnishes the volume of heat which ignites the crowns and maintains the crown fire.

Practically all fires start as surface fires and the favourable conditions **may** turn it into a ground fire or a crown fire. Some of the factors that promote upward movement of fire and thus help in ignition of the crowns are:

- Dry moss hanging from the trunk or branches
- Inflammable pitch on the bark
- The burning tops of a mass of reproduction
- Flames from a hot grass fire

Crown fires sometimes may originate from striking of sky lightning on dry tree. Crown fires advance only in the direction of the wind. Crown fire may also leap ahead a quarter of a mile or more if supported by the wind whereas sometimes leaving unburned patches of timber in its way. Crown fires are characterized by initiating new fire points ahead of the original point which makes it dangerous.

The rates of fire spread are extremely variable. A fire in a peat swamp advances only by a few meters in several weeks. The rate of spread of a surface fire or a crown fire depends on the characteristics and the state of the vegetation, the slope and the wind speed. Rate of forest fires may be expressed in a number of ways i.e., number of miles per hour at which the fire advances, acres burned over per hour, length of the perimeter developed in a given period of time, usually expressed as rate of perimeter increase in chains per hour between time of discovery and the time when work of suppression is started.

The rate of fire spread is higher in low and continuous fuel types where the biomass is small (grass), sometimes exceeding 10 km/h.In stands with a dense understorey, this speed decreases because the vegetation forms a screen obstructing the wind and the heat transfer. Under these conditions, the spread rate is 5 to 6 km/h however, more biomass is burnt.

12.5Effects or injury or damage caused by forest fires

The passage of a fire results in the more or less serious deterioration of vital parts of the plant such as foliage, stem and roots, resulting in a loss of tree vitality which can cause death. The deterioration degree is a function of the combined damage of various tree parts (foliage, stem, roots), resulting from fire type (surface or crown fire) and fire intensity, as well as the species' fire sensitivity. A rapid passing fire causes much less damage than a slow fire with longer "residence time". The injuries caused by forest fires are as follows:

Effects or injury to root: When heat from a fire reaches the roots of trees, severe injury or death results, because tree roots are less thoroughly protected by thick bark than the portions above ground, and hence are more sensitive to heat. Similarly, trees with shallow root systems suffer more than the deep-rooted ones.

12.5.1 Effects on stem and injury to merchantable material or bole

t may cause simple fire scars on bole base to complete damage to stem or tree. A temperature of approximately 540C (129.20F) is sufficient to kill the cambium. If the cambium is killed from all around, the tree gets girdled and it causes the disconnection of trunk above the girdle and below the girdle resulting into death of tree. Further, cambium has sensitivity in different stages of its life being most sensitive in early stage. Presence of bark particularly thick bark provides more resistance from fire. In some trees another layer of cork is developed which provides additional resistance from fire as it is non-conductor of heat. Further, old trees are better protected than the young trees as bark thickens increase and tends to develop more cork coverings. Species with resin are more sensitive as resin is highly inflammable. Pitch exudates which are result of insect attacks on trees also attracts fire and thus, easily get damaged. In general, conifers suffer more severely from fire than broadleaf species.Since the first log of the tree contains timber of better quality than the upper logs, the injury from hollowed-out butts destroys the best part of the tree. Killing of portions of the cambium whether in the crown of the tree or near the ground must interfere with the life processes of the tree and unfavorably affect its health and growth. In this weakened condition the tree is more susceptible to the attacks of insects. Sometimes the insects seem to prefer to enter the tree through the bark covering recent fire scars. Though the fire-injured trees attract the bark beetles, however, they may not offer good breeding places on account of changed conditions affecting the tree's moisture content. An increase of the bark-beetle population on the burned-over area is likely to occur as a result of the fire. The outcome is increased damage for a few seasons by insects on burned-over area. Many fungi find entrance to living trees through wounds. For this purpose fire scars are frequently utilized. Given time enough, the fire-scarred tree is destroyed either through the attacks of insects or fungi or by being burned down by repeated fires. If trees containing merchantable material are killed outright they should be cut and utilized before the timber decays or is attacked by insects infesting dead trees.

12.5.2 Effects or injury to forage

Dry grass and other plants of nutritional or forage value catches fires very readily. Fire tends to kill the root zone of the plants, thus reducing the density of stocking. It also promotes replacement of good species with those of inferior quality. Damage to forage can be checked by regulated grazing as it helps removal of dry and inflammable forage which has a direct impact on reduction of forest fire. In some forests having inflammable forage, the fire spread can be checked by using the excess stock of this forage while it is green, thus, the danger of fire is considerably reduced.

12.5.3 Effects and injury to young growth including regeneration

Trees below the merchantable size, and reproduction, with thinner bark and crowns near the ground, are more easily killed and consumed by fire than trees of merchantable size. Even a light fire will kill small seedlings. Where light fires take place repeatedly at intervals of a few years, the reproduction may be severely affected. Fire causes injury to small trees the same way as to large ones, however, causes relatively greater injuries to small ones than large ones. Even where small trees are only partially girdled by a fire their potential value is greatly reduced as it takes longer time before the small trees become merchantable and during these years insects and fungi have abundant time and opportunity to enter inside the trees through the fire scars or elsewhere resulting in weakened condition of the trees and thus, results in poor quality of wood by the time merchantable dimensions are attained.

12.5.4 Injury to wild life

Fire poses threat and hazards either directly or indirectly to various wildlife in the forests and causes destruction of biodiversity i.e., loss of many birds, animals and fish species. Forrest fire also destroys the eggs and young ones of wild animals. Sometimes the bigger animals also become victims of fire. Many animals are actually burnt to death during the forest fires. Habitats of many are either disturbed or damaged severely resulting in loss of the species. Thus, although the wild life may escape at the time of fire but its future development is seriously impaired.

12.5.5 Effects to micro-organisms

The fires damage the surface organic cover badly in which micro fauna survive, thus, damaging micro fauna. Recovery of these micro-organisms takes place very slowly. Thus, vital ecosystem processes are severely affected.

12.5.6 Effects to soil structure and composition

Forest fires alter the physical and chemical properties of soil, however, it affects physical properties more critically than its chemical properties. It has been established that physical properties of soil are very important for tree growth which can easily be influenced by fires through its negative effect the humus content. Well-decomposed humus is in fact an indicator of good physical condition of the soil which influences the water relations in the upper layers of soil. A severe fire opens the forest canopy by killing most of the trees and burns off the litter, thus, exposes the soil to the drying influences of sun and wind. Loss of moisture from the humus makes it susceptible to burning and after fire it results into disappearance of humus from the soil. Such soil on bare burned areas consequently deteriorates more in physical condition. Heavy soils become dry, hard, impervious to water and often crack opens. Sandy soils become hotter, more porous and leachy, which in turn affect the colloidal properties of the soil. There are many chances of mineral salts left in the wood-ashes being blown away or washed off the surface or leached away through the soil. However, lightest fire which only consumes the litter and does not directly injure the standing trees, causes little or no injury to the soil, provided that the loss of the accumulated litter maintained by standing trees without delay. Single and light fire may be beneficial but such benefits are not augmented by repeated fires since the entire humus content is exhausted by such fires. The single fire occurring on barren areas may have some benefits but are purely temporary. Light fires which are repeated year after year over the same ground consume the annual leaf-fall and thereby rendering the ground devoid of litter matter. Under such circumstances, when the humus in the soil is once exhausted, the soil deteriorates. Hence repeated light fires seriously injure the soil. The forest litter contains nutritive materials, principally nitrogen, calcium, phosphorus and potash. The last two remain in the wood- ashes but the nitrogen is volatilized and lost to the soil when the forest litter is consumed by fire. As a consequence, if the forest is destroyed by the one fire so that no new litter forms or if the fires recur so frequently as to burn up the annual fall of litter, the nitrogen content of the soil becomes impoverished. In some cases, forests grow with boulders or solid ledges of rock only a few inches below the surface. Here the soil consists largely of organic material and may be completely consumed by a severe fire. The bare rock may be left exposed, the soil having been entirely destroyed. Such soils which lack in humus and devoid of litter are quite prone to soil erosion. This process carries away the most fertile portion of the soil. In extreme cases the entire surface layers of soil may be eroded leaving exposed the subsoil or even the underlying rock. Fires often create conditions favorable for the start and continuance of erosion.

12.5.7 Effects on vegetation dynamics and on productive power of the forest

The productive capacity of forests is greatly influenced by forest fires. The loss may be either in terms of reduced quantity or reduced quality of production or both quality as well as quality. This primarily depends on the condition of the soil after forest fire and the extent of damage to individual trees due to fire. Frequent fires damage even evergreen forests and in severe cases such forests get degraded into inferior deciduous forests with fire resistant species or converted into grasslands. The fire injury to the productive power of the forest may be classified as follows:

12.5.8 Effects on landscape, recreational and scenic values

The forests are known for providing exceptional recreational and scenic opportunities. However, the burnt areas are relatively less attractive or unattractive. Thus, it hampers tourism and other economic activities in such areas and thereby causing monetary loss also thus, affecting negatively the community income from the tourist trade.

12.5.9 Economic losses and loss of human life

Forest fires damages buildings, livestock and property of all kinds which fall in its way. It causes damage to the adjacent villages and domestic livestock as well. The principal losses are to property of forest department within the forest, schools or other offices inside the forest. Sometimes forest fire causes damage to adjacent whole village. Forest fires also results loss of human lives particularly of forest guards, villagers, and others who get caught in forest fires.

12.5.10 Effects to forest by replacement of good by poor species

The fire brings about changes in composition of species as it injures valuable species which are more sensitive to fire and brings about new fire hardy species or other associate inferior species to establish in the area. Thus, the composition of a forest is changed from good species to hardy inferior low value species. The area in subsequent year gets dominated by inferior species as a result of their reproduction and proliferation. It has been observed that bush and woody shrubs usually are fire resistant and as a result of frequent fires they take over the possession of the area from valuable tree species.

12.5.11 Effects to forest by reduction in the density of stocking

At times, natural reproduction is adversely affected by the fire resulting the affected land becoming a barren land. Although all the fires does not destroy whole forests, but most of them at least break the canopy and reduce the density of species to the extent which adversely affects the production processes.

12.5.12 Effects to forest by poor growth of individual trees

Those trees which are partially girdled at the base lose their capacity to translocate food materials to different parts and for building woody elements. This results into additional load on the cambium layer of the portion other than girdled ones. The increase in food supply causes increase in growth due to increased food supplies which pass through it, or in response to the greater mechanical strains following the injury. It has been observed that the fire-injured trees show increases rate of growth on the stump section and reduction on sections above the wounds. As a result of poorer physical condition of the soil and decrease in available plant food, production on burned areas may be less than on the unburned regions. This is particularly true when the areas are burned over annually for a series of years.

12.5.13Effects to forest by reduction in protective capacity of the forests

A healthy and properly tended forest offers itself considerable protection. However, when injured, the forest loses its protective capacity to a greater or lesser extent. The forest provides protection against landslides, avalanches, shifting sands, erosion and floods. Surface runoff of water is delayed and decreased, thus stabilizing the stream flow. However, when forest fires occur, it reduces the cover over the surface and loosens the soil which in turn accelerates the erosion processes. This results into filling of river channels and reservoirs with detritus, deposits of rock and soils. However, deposition of fine textured soil in lands increases its productive capacity, thus such lands get benefitted, however, the harmful effects of erosion far outweigh any such advantage. A bare soil has many disadvantages like it prevents the forest from performing as regulator of stream flow, lack litter and humus on bare soil surface results in loss of its sponge-like action and rapid surface runoff takes place which in turn results in floods. It impairs with navigation, power plants and agricultural production processes.

12.5.15Erosion

The exposure of the soil following the fire as well as the structural modifications induced by the fire increase very strongly erosion risks. These depend on slope (the steeper the slope is, the more significant the risks of gully erosion), Geological and pedological nature of the ground (Clay soils are very sensitive to erosion), Distribution and intensity of precipitation (Violent rains on an cleared ground can generate considerable damage on the spot and downstream).

12.6The Beneficial Effects of Fire

Forest fires are usually harmful for forests, wildlife and other lifeforms; however, in some instances it may give certain beneficial results also. When we rank the amount of damage caused by insects, fire and diseases, it is estimated that the highest amount of damage is caused by insects followed by fire and diseases, respectively. However, in certain circumstances where an epidemic plant disease prevails and becomes serious, the loss or damage may exceed than that of damage caused by fire or insects. However, it has been established that indirectly fires promote the growth and development of insects and fungi by creating wounds or other weakened conditions which enable plant and insect pests to gain foothold and accelerate the injuries initiated by fire. Fire is a sudden and large scale destroyer of forests and at the same time it is a more effective control for some enemies of the forest also. Some of the beneficial effects of fires are as follows:

12.6.1 Assistance in establishing natural regeneration

Fire may help in assisting establishment of natural reproduction of the desired species (Show and Kotok 1924; Unwin 1927). As the thick forest litter over the forest surface gets burnt in forest fire thereby creation of favourable space and light conditions for the growth and development of some desired species is attained or forest fire may also result in the removal of advance growth of some undesired species resulting in suitable conditions for the growth and development of desired species. Further, forest fires also forces the seed eating rodents to leave the areas which also favours the growth and development of seedlings.

12.6.2. Forest fires help in controlling plant diseases

It has been reported that the various plant diseases are controlled by the forest fires which are particularly harmful to seedlings (Siggers 1934). As the raw humus gets burnt in forest fire, thus, improvement in the physical condition of the soil i.e., aeration and increase in warmth, takes place resulting into better growth of the forest species.

12.6.3. Changes in chemical composition of soil

Forest fires may result into increase bacterial activity in the soil, thereby, promotes the production of nitrogen compounds i.e., nitrates. Sometimes beneficial changes in the chemical composition of the soil have been reported as a result of fire. For example, Heyward and Barnette (1934) reported that relatively large increase in replaceable calcium and small increases in organic matter and nitrogen associated with repeated fires, while acidity of the soil was consistently less in longleaf pine in Florida. This is particularly attributed to the addition of ash following the fire. Probably other constituents of ash such as potassium, magnesium and phosphorus also get increased more or less. Increase in organic matter and nitrogen due to the decay of the grass vegetation which usually results after forest fires has also been reported by Heyward and Barnette in long terms (generally in a period of 8 to 10 years). Further, it has also been observed that leguminous plants usually invade the area after fire. Having the capacity of nitrogen fixation, it results into increase of nitrates in soil.

12.7 Factors Influencing the Spread and Severity of Forest Fires

There are four primary factors that govern the spread and severity of forest fires. These are:

- Amount and character of the fuel
- Moisture content of the fuel
- Wind
- Topography

12.7.1. Quantity and type / character of the Fuel

The amount and extent of fire mainly depends upon type of burning material available in the forest floor. The total potential fuel in the forests consists of the humus, litter, ground cover, underbrush, fallen limbs and trees, tops left after logging and the standing trees large and small. Although forests as a whole is potential fuel, however, only a portion of material in the ground is actually available as fuel for a forest fire. Some materials are very inflammable whereas others are less. Further, the forest fire depends upon the amount of burning material available. If highly flammable material is available in very low quantity, then there are less chances of severe forest fires whereas if burning material is available in high quantity, than forest fire may spread miles once initiated. The litter composed of fallen leaves and twigs dries quickly and is easily kindled by a spark. Coniferous needles, if dry and not compacted, burn faster and create a hotter fire than the litter from broadleaved trees. Grasses and other herbaceous vegetation become as dry as tinder at certain times of the year. During extended droughts the humus and even deep peaty deposits in swamps may become thoroughly dry. Large limbs and dead trees do not dry out as quickly as the litter but ultimately may attain an exceedingly dry condition. The material which makes possible the start and quick spread of a fire is the fuel of a light loose character, such as the top litter, herbaceous vegetation, dry moss, resinous needles and the outer surface of the more solid material. Exposure to the air with plentiful supply of oxygen enables combustion to progress rapidly.

12.7.2. Moisture Content of the Fuel

Another important factor that has relation with severity of forest fire is the amount of moisture content in the burning material. Moisture content has inverse relation with forest fire. The more the moisture content the less chances of severe fires. In other words, it can be said that there will be available no burnable fuel while moisture content is in abundant quantity. Thus flammability of fuel is highly dependent on moisture content. The potential fuel matter in the forest floor remains in inactive state till sufficient moisture content is maintained by abundant and uniformly distributed precipitation. Unfortunately in most forest types such high moisture conditions can not be maintained throughout the year. Although the amount or volume of potential fuel remains relatively the same for long periods but the moisture content in these burning material remains fluctuating from season to season, day to day and even hour by hour. Thus, the same burning material available in the forest floor may change its character of flammability with changing moisture content with season. Fire hazards are more prevalent in dry seasons when there is low precipitation and it gets more pronounced with enhanced period of drought. Thus, it is the weather of the area that controls the moisture content of forest fuels. Further, air temperatures and wind are weather factors which exert influence upon relative humidity and hence affect fuel inflammability. Certain parts of the forest ecosystem, such as the living trees and shrubs, if dry out due to some reason, becomes burning material and burn readily. However, green foliage except those which are of resinous nature, burns with much difficulty even in extended dry periods. A rise in air temperature causes evaporation of moisture from the fuel into the air and similarly a fall in temperature has the opposite effect. Under normal conditions the fuel in the forest is likely to absorb at night approximately the same amount of moisture as is evaporated during the daytime. Relative humidity of the atmosphere is so vital in this connection that it may serve as an indicator of the dryness of the more inflammable forest fuels. From the point of view of forest fire, the relative humidity remains changing with cloudy versus sunny days, hot versus cold days and day versus night. The burning materials which is not in contact of dry air, is relatively less affected by hourly fluctuations whereas those which remain in direct contact of air are highly affected. This is the reason for readily burning of tree trunks after an extended drought period even though relative humidity at the time of the fire may be comparatively high. The severity of the fire is more directly dependent upon the amount of available fuel than the rate of spread. A fire may run rapidly under certain conditions even if the fuel supply is scanty, but such fires are neither severe nor damaging. It is when a large amount of dry fuel gets accumulated in the forest floor then only there are chances of huge forest fire. A forest fire itself acts as a drying agent, reducing the moisture content of the fuel which occurs within range of the heat developed. If once a large volume of heat can be created the fire gathers momentum and progressively dries the fuel for its own advance. This is why slash-covered areas with a large accumulation of dry fuel may be a menace to adjoining green timber. When the moisture content is high a great deal of heat is used up in evaporating the water, which must be accomplished before the material will ignite.

The uniformity and compact arrangement of the inflammable material have great influence on the spread and severity of the fire. Fastest spread occurs when the material is of light inflammable character, and arranged uniformly so that the fire suffers no check but not so compactly as to prevent the ready access of air. Severity of the fire increases with the density of material if other factors are favourable. Density makes for slow advance of the fire but keeps the fire in one place for a relatively long time. This results in more complete consumption of the material and in greater injury.

12.7.3 Wind

The wind determines the general direction in which surface and crown fires advance. Given the same fuel conditions, the rate of spread of these fires is governed by and increases with the velocity of the wind. However, relative humidity of the atmosphere which largely controls the moisture content of the fuel ordinarily is more important in determining the spread and severity of a fire than the wind velocity. With 100 per cent relative humidity there can be no fires, but on a day without wind, if low humidity occurs, fires may spread. Show and Kotok (1925) indicated through a study of California that both wind velocity and relative humidity are of primary importance in determining spread of fires. They have found that rate of spread varies as the second power of the wind velocity. A dangerous combination is a strong wind blowing from a dry region. This brings in dry air and changes the absolute humidity of the air. The effect is to lower the relative humidity and hence the moisture content of the fuel. The wind assists in more thoroughly drying out the fuel ahead of the fire, both by increasing evaporation through the new air supply brought in and by driving the heated air, out of its normal upward direction, horizontally into contact with new fuel as yet not ignited. A steady wind is required to carry the heat from tree to tree in a running crown fire. Otherwise when the wind slackens the fire dies down in the tops and burns as a surface fire. The fire itself creates a draft upward because of the tendency of hot air to rise. Such an air current may result in picking up burning material and carrying it forward to start new fires. On slopes the upward movement of the hot air tends to increase the speed and severity of the fire.

12.7.4. Topography

The slope, aspect and surface conditions each affect spread and severity of the fire. In a rugged country, owing to the frequent and wide variations in topography, the progress of a fire is irregular. Regions without distinguishing topographic features favor a more uniform development of all sections of the fire. A fire burning uphill advances rapidly. The heated air rising vertically and radiating horizontally passes near (particularly on very steep slopes) the ground ahead of the fire and by its heating and drying action hastens ignition and increases the intensity of the fire. Trees are injured worst on their uphill sides, both because humus and litter tend to accumulate there, and because the flames protected by the tree trunks from the draft burn longer in proximity to the tree. Fire progresses downhill very slowly and relatively weekly burning as it has to overcome the upper draft of heated air. Where the available fuel is of such a character as to roll down hill easily, burning sticks or cones may set new fires some distance below the original fires. Fires so set are likely to sweep up the slope quickly until they meet the other fire. Cones furnish the most dangerous material for carrying fire down a slope. The spread of fire is obstructed by the mist areas and areas barren of vegetation. A stream or a narrow strip of moist ground at the bottom of a ravine may serve to stop a fire. The fire has burned slowly down the slope and on approaching the stream has not sufficient momentum to leap this obstacle. Slopes with northern or eastern aspects do not suffer so severely as those with southern or western exposures. This is because of the fact that the southern slopes usually have dried fuel due to the heat of the sun as these slopes are comparatively more exposed to sun. A smooth surface on which the inflammable material occurs uniformly distributed tends to make the fire burn more evenly and intensely. Bare rocks tend to delay and break up the front of the fire.

12.8 Fire Control Measures

Fire control measures include all those measures which are adopted before the fire sets off and measures adopted after the fire sets off. Thus, it includes reduction of fire hazards, education and awareness among people, legislation and law enforcement etc. and suppression of forest fire after it sets off. Therefore, fire control measures include prevention of fire, pre-suppression measures and suppression measures.

12.8.1 Prevention measures

Prevention includes all those measures or actions which are aimed at removal of every chance of fire occurrence. Preventive measures are those which reduce the chances of occurrence of fire. There are many factors that create an environment where fire becomes a likely phenomenon. The aim of the preventive measures is to address those causal factors. Although it is impossible to remove all chances of fire initiation, but can be reduced to minimum by the means of Education and sensitization, Legislation and Law enforcement, Management of forests and reduction of hazard. Broadly, preventive measures can be grouped into two major classes, namely, (1) indirect measures and (2) direct measures.

1) Indirect Preventive Measures: Indirect measures are those which, although not directly confronting the causal factors of fire environment, reduce the fire risk by containing the factors. Examples of indirect measures are education and sensitization of people, Cooperation of forest fringe villagers, Legislation and law enforcement, System of incentive and disincentive. Briefly they are summarized as follows:

a) Cooperation of forest fringe villagers: Since most of the forest fires are man-made, either by way of carelessness or by deliberate actions, the foremost measure is to sensitize the fringe villagers to the danger of forest fire and obtain their cooperation in prevention of accidental or deliberate fires caused by humans. Cooperation of the villagers can be best obtained by deliberating the issue of forest fire in JFMC meetings. JFMC can take an effective role in making the fringe population aware of the destructive potential of forest fires, and of their responsibility in prevention of man-made fires.

b) Education and sensitization of people: The education and sensitization may be carried out by adopting following methodology:

- The selection of target groups should include all age groups in urban as well as rural areas. It is always more effective to target only one population group at a time. This allows adopting the public awareness campaigns according to the characteristics of the group of individuals.

- Public campaign can be carried out using press and radio, posters, gadgets, social media, films and lectures, demonstration, personal contacts and competitions.
- Fire prevention lessons may be included in school curricula. Education of school children is extremely important as in decade time these children would grow into adult and may influence directly or indirectly the factors causing forest fires.
- Educational efforts in fire prevention include effective media, motion pictures, posters and signs, lectures in person or radio, items in newspapers, published literature for people of all ages. The means of educational efforts must be according to the local conditions.
- Personal contact with people living in or passing through the forested areas is a most effective method of education.
- Frequent publicity is needed, especially during seasons of high fire hazard, since warnings against carelessness with fire seem to make temporary rather than permanent impressions.

Besides the forest fringe population, people in general need be educated. They should be convinced that uncontrolled or repeated forest fires deplete the potential of ecosystem services of forests. In other words, fires cause a decline in the ability of forests to produce timber, non-wood forest produce, and other benefits. People should be educated that it is their responsibility to protect forests from all damaging factors including fires. Such education can be imparted through press, radio, television, workshops and educational institutions. One of the effective means will be to involve the students of schools and colleges and spread through them the importance of conserving forests and the role they play for human existence.

c) Legislation and Law enforcement (Regulatory provisions): Legislation and Law enforcement regarding framing of suitable laws regarding fire activities in and around forest and inside forest are necessary for prevention of fire. Fire Prevention will be ensured through:

- Having an effective force of people for the purpose of discovering and catching forest law breakers.

- Closure of forest areas or restrictive regulation of various types for entering and using forest areas. Restrictive regulations make the forest users fire conscious and have a deterrent influence upon carelessness with fire while in the forest.
- Absolute closure of a forest area for entry of visitors may be used in periods of high vulnerability.
- If complete closure is deemed unnecessary or impracticable than registration of people entering the forest will serve as a preventive measure. The degree of fire hazard should determine when such an extreme measure as closure of a forest area would be adopted in preference to the registration of visitors or to no restrictions other than the usual regulations being placed on people entering the forest.
- Restrictions on smoking should be issued and strictly enforced during the fire season. The customary restrictions on smoking prohibit smoking in the forest except at designated places.
- Permits to build camp fires should be required where visitors are allowed to camp in the forest. Sometimes the right to build camp fires is included under a general permit allowing the privilege of entering and camping in the forest.

d) System of incentive and disincentive: There may be in place a system of incentive and disincentive for forest personnel in the matter of detection and prevention of forest fires. Forest personnel who do a good job in this regard may be suitably rewarded. The system of reward may also include as beneficiary the villagers. At the same time, there should be provision of suitable punishment for forest functionaries for dereliction of duty.

e) Management of forests & Reduction of hazard: Management of forests and hazard reduction includes:

- Prevention of railroad hazards is achieved through elimination of fuels which cast sparks.
- Use of spark-arresting devices on locomotives.
- Track should be kept free of inflammable material.

- Camp grounds should be kept so free of inflammable fuel that fires cannot start.
- It is more difficult to prevent fire originated from smokers than those set by campers because all classes of people may be responsible for smokers' fires whereas camp fires originate only with the relatively restricted class of people who camp in the forest.
- Smoking may be prohibited in the forest during the fire season. Such a regulation if enforceable would eliminate smokers' fires except those originating beside the highways which pass through the forest. Fires set by smokers have proved to be one of the most difficult classes to prevent. Indeed, only through educational efforts and law enforcement constantly continued over many years can satisfactory results in prevention of smokers' fires be hoped for. They are likely always to remain one of the chief causes of fires.
- A still more severe restriction would close the forest areas entirely and keep all people but members of the forest organization out of the forest during critical periods.
- In general, fires originating from human carelessness can best be reduced by education and law enforcement.

2) Direct preventive measures: These are those measures which directly address the factors of fire environment. Following are some examples.

a) Forecast of forest fire: In developed countries, prediction of fire is done from studies of temperature, humidity, wind etc. and weather analysis by sophisticated equipments. Forecast of fire can alert the forest personnel and help them take precautionary measures.

b) Reduction of risk: Risk of forest fires can be reduced by limiting the exposure of forests to fire. This can be done by the following measures:

b) Controlled burning: The objective is to burn the inflammable materials such as grass, shrubs, fallen leaves and wood in identified blocks or strips under controlled conditions and thus reduce the risk of later fire damage. Ideally, such controlled burning should be done before the advent of dry season. The blocks or strips which undergo controlled burning are less likely to catch fire during the dry season and they restrict fires from spreading across them. Controlled burning is done patch by patch beginning from the patch which has most of the grass dry. Control is exercised so that fire does not spread beyond the boundary of the patch taken up for burning.

Controlled burning is done to protect plantations, natural regeneration areas, timber depots and other valuable forest resources. A belt of sufficient width round such areas is subjected to controlled burning so that fire, caused accidentally or otherwise, cannot cross this belt and damage the plantations, depots etc. inside.

It is advisable to take up controlled burning after the dusk because the flame in the dark is easily visible and it is much easier to control the extent of burning within the envisaged boundary. In bright sunlight flame of fire is often not visible and there is risk that fire may spread beyond the limits without getting detected.

c) Fire line: Fire line is defined as a cleared permanent fire break (a barrier from which all or most of the inflammable materials have been removed) intended to prevent fires from crossing from one area to another. In other words, It is a permanently clear-felled strip in a forest which is burnt every year before the commencement of hot weather to destroy all inflammable materials so that it may prevent the spread of an accidental fire (L S Khanna, 1998). Fire lines are carefully aligned so as to divide the forest into small blocks. Thus fire, even if originated at a block accidentally, remains localized within the block and does not spread to other blocks easily. Even when fire is intense enough to spread across fire line, it permits time to start fire-fighting operations and contain the damage.

Fire lines 3 to 5 meter wide are optimum. Fire lines should be maintained motorable so as to permit easy and quick movement of fire-fighting squads.

Summary

References

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