सत्यमेव जयते

GENERAL SILVICULTURE

বন বিভাগ
পশ্চিমবঙ্গ সরকার

DIRECTORATE OF FORESTS
GOVERNMENT OF WEST BENGAL

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PREFACE

Silviculture is defined as the art and science of cultivating forest crops. The very definition suggests that silviculture forms a core subject of forest management, and that a forest manager must have clear knowledge on the subject. The knowledge of Silviculture enables the forest manager to adopt good practices for cultivation of forest crops and fetch optimum benefits from the forest resources. As part of the JICA project on ‘Capacity Development for Forest Management and Training of Personnel’ being implemented by the Forest Department, Govt of West Bengal, these course materials on General Silviculture have been prepared for induction training of the Foresters and Forest Guards. The object of this training manual is to help the frontline forest personnel have a better perception about Silviculture and enhance their capacity to deal with their task.

The subjects covered in these materials broadly conform to syllabus laid down in the guidelines issued by the Ministry of Environment of Forests, Govt of India, vide the Ministry’s No 3 - 17/1999-RT dated 05.03.13. In dealing with some of the parts of the course though, the syllabus has been under minor revision to facilitate better understanding of the subjects and to provide their appropriate coverage. The revised syllabus, with such modifications, is appended.

The contents of the course materials have been compiled and edited by A Basu Ray Chaudhuri, IFS (Retd). Many books and literature including those available in internet have been made use of in preparing these course materials and references of such books and documents have been cited in the respective lessons. Shri A Basu Ray Chaudhuri is indebted to many forest officers who have helped in the preparation of these materials.

Efforts that have gone into making of these course materials will be best rewarded if the frontline staff of the forest department find these materials useful in their day-to-day works.

Kolkata, 2015

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For IBRAD (Consultant)

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Syllabus (Revised) General Silviculture

General Silviculture (20 hours), Excursions 1day, Tour 3 days		
1. Introduction	1-1. Overview of the forests of the state 1-2. Tangible and intangible benefits of the forests 1-3. Forests and environment-Forest and hydrological/carbon cycle, carbon balance of trees*, global warming, climate change, Eco-system services, Development of REDD+ idea 1-4 Nutrient cycling*, Biodiversity*	4 hours
2. Forestry, its Scope and Classification; Growth of Trees	2-1. Protection, production and conservation forestry, Social Forestry, Agro-forestry. Trees. Various Stages of Growth -Seedling -Sapling -Pole -Tree -Crown Tree growth characteristics*	1 hour
3.Factors Governing growth of Forests	3-1. Climate 3-2. Topography and aspect 3-3. Soil 3-4. Biotic factors	4 hours
4.Plant Succession	4-1. Causes and types 4-2 Theory of succession 4-2. Climate climax 4-3. Pre-climax 4-4. Post-climax 4-5. Edaphic climax 4-6. Biotic climax*	2 hours
5.Important Forest Types of the State	5-1. Basis of classification* 5-2. Objects of classification* 5-3.Major Forest types of India* 5-4. Forest types of WB Distribution Floristic composition	4 hours
6. Crown Differentiation*, Tree Classification;	6-1. Crown differentiation 6-2. Tree Classification Dominant	1* hour

Tending	Dominated Suppressed Dead or moribund Diseased 6-3. Canopy cover & canopy closure* 6-4. Tending -Definition - Need -Weeding and cleaning	
7.Thinning	7-1. Concept, definition 7-2. Basic Principles 7-3. Kinds of thinning -Mechanical thinning - Ordinary thinning -Light (A grade) -Moderate (B grade) -Heavy (C grade) -Very heavy (D grade) - Very heavy (E grade) - Crown thinning - Selection thinning	2 hours
8. OJT: Tending and thinning*	8-1 On-the-job training on Tending and Thinning	2 hours*
Field Study	During the tour and Saturday excursions, growth factors, plant succession, forest types and stages of growth will be observed.	

* These are modifications to the MoEF-prescribed syllabus, indicating revision/addition of topics and change in lesson hours.

18	• Lesson Plan
	• Thinning in regular crops (Continued)
	  - Ordinary Thinning
	    - Definition
	    - Basic principles of ordinary thinning
	    - Grades of ordinary thinning
	    - Stocking in various grades of ordinary thinning
	    - Application of ordinary thinning
	  - Crown /thinning
	    - Definition
	    - Basic principles of Crown thinning
	    - Grades of Crown thinning
	    - Application of Crown thinning
	• Thinning in irregular crops - Selection Thinning
		107-111

19 & 20	• Lesson Plan • On-the-job training	112

Lesson 1

1 hour

Lesson Plan

To study

- Overview of the forests of the state
    - ➢ Recorded Forest Land
    - ➢ Forest Cover
    - ➢ Diversion of Forest Land for Non- forestry purpose
    - ➢ Protected Area Network
        - Tiger Population
        - Elephant census

Backward Linkage – Nil

Forward Linkage – Visit, during tour, to forests of various types and Protected Areas.

Training Materials Required-

- Copy of Lesson 1 to be circulated beforehand

Allocation of Time

• Recorded Forest Land	12 mts
• Forest Cover	13 mts
• Diversion of forest land for non-forestry purpose	12 mts
• Protected Area Network	13 mts
• Discussion/ Miscellaneous	10 mts

Overview of the forests of the state

1. Forest land and Forest Cover

Extending from the Himalayas in the north to the Bay of Bengal in the south the **geographic area of West Bengal is 88,752 km^2**.

1.1 Recorded Forest Land

Area of recorded forest land in the state is **11,879 km^2**. Based on legal classification, the total forest area can be divided into following three classes.

- **Reserved Forest – 7054 km^2**
  [Reserved forest means an area notified as reserved forest under section 20 of IFA, 1927]
- **Protected Forest – 3772 km^2**
  [Protected forest means an area notified as protected forest under section 29 of IFA, 1927]
- **Unclassed State forest – 1053 km^2**
  [An area recorded as forest but not included in Reserved Forest or Protected Forest category]

Thus **recorded forest land constitutes 13.38% of the geographic area**.

Following facts can be derived from above.

- Reserved Forest constitutes 59.38 % of total forest land.
- Protected Forest constitutes 31.75 % of total forest land.
- Unclassed State Forest constitutes 8.87% of total forest land.

District-wise distribution of forest land is given in the following table.

Table 1.1

(Area in Sq. Km.)

Sl. No.	District	Reserved Forests	Protected Forests	Unclassed State Forests & others	Total Area
1	Darjeeling	1,115	-	89	1,204
2	Jalpaiguri	1,483	217	90	1,790
3	Cooch Behar	-	42	15	57
4	Bankura	80	1,311	91	1,482
5	Purba Medinipur	8	1,166	535	1,709
6	Paschim Medinipur				
7	Burdwan	3	192	82	277
8	Purulia	112	729	35	876
9	Birbhum	8	54	97	159
10	Hooghly	3	-	-	3

11	Nadia	5	3	5	13
12	Murshidabad	1	7	-	8
13	Malda	8	5	7	20
14	Uttar Dinajpur	8	4	6	18
15	Dakshin Dinajpur				
16	24-Parganas (N)	43	-	-	43
17	24-Parganas (S)	4,177	42	1	4,220
18	Howrah	-	-	-	-
19	Kolkata	-	-	-	-
Total		7,054 (59.38%)	3.772 (31.75%)	1,053 (8.87%)	11,879 (100%)

(Source: Annual Report 2013-14 of WB Forest Directorate)

It may be seen from the above table that major portion of the forest land lies in the following parts of the state.

- Northern part – districts of Darjeeling and Jalpaiguri.
- South-western part – districts of Bankura, Purba Medinipur, Paschim Medinipur, and Purulia.
- Southern part – district of 24 Parganas (S)

Extent of forest land in the central part of the state is little or scanty.

1.2 Forest Cover

According to State of Forest Report 2013 of FSI -

Based on satellite data (obtained during the period Oct.2010 – Jan 2012) and the inventory of forests and TOFs (Trees outside forests) carried out by FSI, following figures for WB have emerged.

Forest Cover – 16805 km^2 (18.93% of geo area)
Very dense forest (tree canopy density ≥70%) – 2971 km^2
Moderately dense forest (tree canopy density ≥ 40% but < 70%) – 4146 km^2
Open forest (tree canopy density ≥ 10% but < 40%) – 9688 km^2

Forest cover including the tree cover outside forests is **21.35%** of the geographical area.

The forest cover includes all lands which have a tree canopy density of 10 percent and above and have a minimum area of one hectare.

2. Diversion of Forest Land for non-forestry purpose

Forest land has shrunk over the years. Traditionally forest has been seen as huge reserve of land of low productivity and inferior use, and it has been considered reasonable to make use of forest land for various economic and development activities of non-forestry nature. Thus as and when there has been scarcity of land for agriculture or other land based activities, forest has been made to part with chunks of land to meet the non-forestry demand. During the period 1951-52 to 1975-76, forest land of 3, 22,800 ha was diverted to other land use in West Bengal. Following the promulgation of Forest (Conservation) Act, 1980, forest area of 2352.6173 ha has been diverted in the State till March 2014. Forest land diverted over the years for non-forestry purpose may be seen in **Table 1.2.**

Table 1.2

(Area in Hectares)

Year	Net Diversion
1981-82	29.7720
1982-83	87.1900
1983-84	12.8850
1984-85	13.3091
1985-86	306.0000
1986-87	23.7479
1987-88	16.7020
1988-89	18.9250
1989-90	94.4500
1990-91	18.6830
1991-92	47.4180
1992-93	8.4400
1993-94	232.0000
1994-95	45.0000
1995-96	93.9600
1996-97	1.6459
1997-98	6.7978
1998-99	19.8700
1999-2000	3.0200
2000-01	0.9270
2001-02	285.9000
2002-03	10.0700
2003-04	0.0000
2004-05	191.6220
2005-06	352.7500
2006-07	115.3580
2007-08	37.3535
2008-09	0.0750
2009-10	70.4841
2010-11	170.5370
2011-12	28.8734
2012-13	0.0000
2013-14	8.8516
Total	**2352.6173**

(Source: Annual Report 2013-14 of W.B. Forest Directorate)

3. **Forest Types**

According to assessment made by Forest Survey of India (State of Forest Report 2011 of FSI; Atlas: Forest Types of India 2011, FSI), the state of West Bengal has 30 forest types which belong to 8 forest type groups, namely, (1) Tropical Semi-evergreen, (2) Tropical Moist Deciduous, (3) Littoral and Swamp, (4) Tropical Dry Deciduous, (5) Sub-Tropical Broadleaved Hill, (6) Montane Wet Temperate, (7) Himalayan Moist Temperate, and (8) Sub-alpine forests. Details of these forest types have been described in Lesson 12.

4. **Protected Area Network**

The state of West Bengal is rich in biodiversity, both flora and fauna. Central to conservation programme of this rich biodiversity is establishment and management of Protected Area (PA) network of national parks and sanctuaries, biosphere reserves, and identified wetlands and coastal areas. The PA network covers 4692 km^2 of forests, which amounts to 39.50% of the state's forest area and 5.28% of the total geographical area. The State has –

- 6 National Parks
- 15 Sanctuaries
- 2 Tiger reserves
- 1 Biosphere Reserve
- 2 Elephant Reserve

Following table (**Table 1.3**) shows particulars of the Protected Areas.

Table 1.3

Sl No.	Protected Area	Area in Sq. Km.	District
	National Parks:		
1	Singalila N.P.	78.60	Darjeeling
2	Neora Valley N.P.	159.8917	Darjeeling
3	Buxa N.P.	117.10	Jalpaiguri
4	Gorumara N.P.	79.45	Jalpaiguri
5	Sundarban N.P.	1330.10	South -24 parganas
6	Jaldapara N.P.	216.34	Jalpaiguri
Total		**1981.4817**	
	Sancutaries		
1	Jorepokhri Salamander W.L.S.	0.04	Darjeeling
2	Senchal W.L.S	38.88	Darjeeling
3	Chapramari W.L.S	9.60	Jalpaiguri

4	Mahananda W.L.S	158.04	Darjeeling
5	Raiganj W.L.S	1.30	North Dinajpur
6	Bethuadahari W.L.S	0.6686	Nadia
7	Ballavpur W.L.S	2.021	Birbhum
8	Ramnabagan W.L.S	0.145	Bardhaman
9	Bibhutibhusan W.L.S	0.64	North-24 Parganas
10	Chintamoni Kar Bird Sanctuary (old Narendrapur W.L.S)	0.07	S. 24 Parganas
11	Sajnakhali W.L.S	362.40	S. 24 Parganas
12	Halliday Island W.L.S	5.95	S. 24 Parganas
13	Lothian Island W.L.S	38.0	S. 24 Parganas
14	Buxa W.L.S	314.52	Jalpaiguri
15	West Sundarban W.L.S	556.45	S. 24 Parganas
Total		**1488.7246**	
	Tiger Reserves		
A.	Buxa Tiger Reserve	Buffer Area : 370.2886; Core Area : 390.5813; Total : 760.8699	Jalpaiguri
B.	Sundarban Tiger Reserve	Buffer Area : 885.27; Core Area : 1699.62; Total : 2584.89	S. 24 Parganas and N. 24 Parganas
Total		**3345.7599**	

Biosphere Reserve :			
1.	Sundarban Biosphere (including STR, Sajnakhali Lothian and Halliday WLSs areas)	9630	South 24 paarganas Noth 24 parganas
	Total	**9630**	
	Elephant Reserve :		
1	Eastern Duars Elephant Reserve	977.51 Core Area :484.00 Buffer Area:493.51	Jalpaiguri
2	Mayurjharna Elephant Reserve	414.00	West Midnapur, Bankura and Purulia
	Total	**1391.51**	

(Source: Annual Report 2013-14 of WB Forest Directorate)

Reference Materials:

1. Annual Report 2013-14 of WB Forest Directorate
2. India State of Forest Report 2013 of Forest Survey of India

Lesson 2

1 hour

Lesson Plan

Objective:

To know about tangible and intangible benefits from forests

- **Tangible benefits**
  - ➢ Definition
  - ➢ Industrial wood
    - Salient points
  - ➢ Fuel wood
    - Salient points
  - ➢ Non-wood Products
    - Salient points
- **Intangible benefits**
  - ➢ Definition
  - ➢ Salient points

Backward Linkage: Nil

Forward Linkage:

- Topics on Biodiversity, carbon balance, hydrological cycle, climate change etc. dealt with in subsequent lessons.

Training Materials Required:

- Copy of lesson 2 to be circulated beforehand

Allocation of time:

- **Tangible benefits**
  - ➢ Definition 6 mts
  - ➢ Industrial wood
    - Salient points 9 mts
  - ➢ Fuel wood
    - Salient points 8 mts
  - ➢ Outturn of timber and Firewood from WB forests 7 mts
  - ➢ Non-wood Products
    - Salient points 8 mts
- **Intangible benefits**
  - ➢ Definition 5 mts
  - ➢ Salient points 7 mts
- Discussion/ Miscellaneous 10 mts

Tangible and Intangible benefits from forests

1. Tangible benefits

Tangible benefits from forests are those which can be quantified, especially in terms of money. Thus intangible forests are those which cannot be measured in monetary terms. We derive both tangible and intangible benefits from forests.

1.1 **Tangible benefits include the following** –

- Industrial products, such as round and sawn timber, poles and posts, mining timber, plywood veneer, matchwood, wood panels, pulpwood / paper etc.
- Fuel wood, a product that is often over-looked by policymakers and planners but is of vital importance to millions of people in developing countries as the source of domestic energy – and is becoming more important as a source of renewable energy in developed economies.
- Non-wood products, such as roots, barks, leaves, flowers, fruits, seeds etc. – also often ignored in national accounts, but often of major importance to the livelihoods of rural people in developing countries and, again like fuel wood, of increasing importance in developed countries

1.2 Some salient points about industrial wood

- India is among the countries which are chief producers of industrial round timber. Again India is also one of the principal Commonwealth round wood importing countries (more than 100,000 m3/year) (Gary Q. Bull et al 2010 Commonwealth Forests).

  One can have an idea of the quantum of production of processed wood products in India from the following table.

Table 2.1

	Sawn wood (000 m^3)	Wood based panel (000 m^3)	Pulp for paper (000 tonnes)	Paper & paper board (000 tonnes)
2004	17500	2341	3425	4129
2006	14789	2554	4048	4183

(Source: Gary Q. Bull et al 2010 Commonwealth Forests)

- The industrial forest products industry is facing significant competition from other materials such as plastics, steel and aluminium in various applications
- Owing to low investment in research and development, there has been little innovation in wood based industries resulting in lack of new product development.
- In order to contain indiscriminate harvest and production of industrial wood, the industry, in the international market, now has to adopt standards, such as

certification, that aim to demonstrate that the wood product is coming from a sustainably managed forest.

- The broad industrial trends indicate an increase in consumption in most industrial wood product categories, an increase in global trade in forest products, an increase in the use of engineered wood products, and an increase in material substitution. (Gary Q. Bull et al 2010 Commonwealth Forests)
- The manufacturing sector has seen a marked decline in some specific industries such as newsprint, but a growth in industries such as oriented strand Board (osB, panels made of narrow strands of wood fibre oriented lengthwise and crosswise in layers, with a resin binder) and medium Density Fibreboard (mDF) panels.

1.3 Some salient points about fuel wood

- "Fuel wood" refers to wood consumed for energy production purposes, whether for industrial, commercial or domestic use. It includes wood converted to charcoal.
- Wood as fuel is most important as a source of energy in the developing countries. India consumes the most wood fuel in the world (followed by China and Brazil). (Gary Q. Bull et al 2010 Commonwealth Forests)
- Wood energy consumption also increased in many developed countries in recent times. One important development, high-tech in nature, is the use of wood pellets, where sawdust, shavings and other residues are used
- A survey in 2004-05 showed that firewood and wood chips were used by 75% of rural households in India, followed by liquefied petroleum gas (LPG) which was used by 9% and dung (9%). In urban areas, on the other hand, 57% of the households used LPG, 22% firewood and chips, 10% kerosene and the balance other fuels. It is projected that by 2020, owing to the effect of increasing population, growing urbanization and greater wealth, the proportion of rural households using firewood will fall to about 65% – but the increase in population will still lead to an overall increase in fuel wood consumption of about 10%. (Gary Q. Bull et al 2010 Commonwealth Forests)
- Fuel wood use is still growing, since biomass energy is seen to be a relatively clean and renewable energy. The challenge is finding the sustainable combination of land use practices that still produces fuel wood while at the same time providing food crops and other environmental services. (Gary Q. Bull et al 2010 Commonwealth Forests).

1.4 **Outturn of timber and firewood** from forests in West Bengal from 1991-92 to 2013- 14 may be seen from the following **Table 2.2**.

Table 2.2

Year	Outturn of total timber(M^3)	Outturn of total Fire wood (M^3)	Total outturn (M^3)
1991-92	94,754	180,645	275,399
1992-93	117,164	184,052	301,216
1993-94	84,489	191,572	276,061
1994-95	84,903	125,807	210,710
1995-96	88,554	208,589	297,143
1996-97	86,363	196,595	282,958
1997-98	88,728	87,589	176,317
1998-99	86,769	152,800	239,569
1999-2000	145,031	299,563	444,594
2000-01	88,160	250,399	338,559
2001-02	147,031	275,514	422,545
2002-03	102,357	218,469	320,826
2003-04	130,551	306,729	437,280
2004-05	113,871	366,583	480,454
2005-06	85,993	324,092	410,085
2006-07	114,589	387,094	501,683
2007-08	231,578	262,023	493,601
2008-09	151,123	314,740	465,863
2009-10	183,401	207,625	391,026
2010-11	58,086	155,854	213,940
2011-12	95,612	103,250	198,862
2012-13	149,150	103,039	252,189
2013-14	1.32,733	1,49,640	2,82,373

(Source: Annual Report 2013-14 of WB Forest Directorate)

1.5 Salient points about Non-wood products

- Non-wood forest products (NWFP) have been defined as goods of biological origin other than wood, derived from forests, other wooded land and trees outside forests (Gary Q. Bull et al 2010 Commonwealth Forests).
- NWFP includes a wide range of products –
  - plant products used for food, fuel and fodder;
  - raw materials like leaves and rattan for use in hut and making furniture;
  - Raw material for medicines, dyes, detergent, oil, utensils etc.
  - Exudates such as gums;
  - Animal products such as honey, tasar silk, lac, etc.
- Non-wood forest products have been important in developing economies and have remained closely associated with livelihood issues of rural population. Now NWFP are increasing in importance in developed countries as well.

- It is difficult
    - To find reliable statistics to know quantum of production and utilization of NWFP.
    - To assess the sustainable harvest level of NWFP
    - To build up and enhance organized markets for NWFP.

2. Intangible benefits

(Gary Q. Bull et al 2010 Commonwealth Forests)

Intangible benefits are the environmental services that forests provide such as watershed control, conservation of biodiversity to sustain ecosystem services, the protection of farmland and livestock from the effects of the weather, the sequestration of carbon, and the social and cultural benefits that accrue from the production of these goods and services. Of the environmental services, those which are commonly described include biodiversity, water, carbon and aesthetics. Some of these services are described in subsequent lessons.

2.1 Salient points of Intangible benefits

- Since many of the environmental services are poorly defined, they often do not get the recognition they need and deserve.
- Once the environmental service is defined, it is a challenging job to find the sustainable level of such service for a forested ecosystem:
- The other issues are –
    - transaction costs of measuring and monitoring the environmental services of interest;
    - developing the markets and finding buyers for them,
    - Addressing issues of equity or fair distribution of the income generated, identifying appropriate levels of taxation, and developing an appropriate system of property rights.

Reference materials:

1. Commonwealth Forests 2010
   Commonwealth Original text for 2007 edition by Gary Q. Bull, Associate Professor, and Steven Northway, Research Scientist, Faculty of Forestry, University of British Columbia, Vancouver, Canada. Original Data updated and revision of text on Fuel wood and Employment by Jim Ball, Chair, Commonwealth Forestry Association.
   Available at: http://cfa.juice-e.co.uk/Commonwealth%20Forests%202010/cfa_layout_web_chapter3.pdf.
2. Burton V Barnes et al 1998 Forest Ecology, John Wiley & Sons, Inc.
3. Devendra Pandey 2002 Fuel wood Studies in India – Myth and Reality, Centre for International Forestry Research.

Lesson 3

1 hour

Lesson Plan

Objective:

To study

- **Forests and Environment**
  - **Hydrological Cycle**
  - **Carbon cycle**
  - **Carbon Balance of Trees**
  - **Climate**
    - Factors affecting Climate
  - **Climate change**
    - Major signs of global climate change- Global warming
    - Impact of Climate Change
    - Human activities that cause climate change
    - Forests vis-a-vis Climate Change
    - Climate Change policies
  - **Ecosystem services**
  - **REDD+**

Backward Linkage – Materials of Lesson 2

Forward Linkage – Materials of subsequent lessons

Training Materials Required:

- Copy of lesson 3 to be circulated beforehand

Allocation of time

Forests and Environment

- Hydrological Cycle — 3 mts
- Carbon cycle — 6 mts
- Carbon Balance of Trees — 6 mts
- Climate
  - Factors affecting Climate — 6 mts
- Climate change — 20 mts
  - Major signs of global climate change- Global warming
  - Impact of Climate Change
  - Human activities that cause climate change
  - Forests vis-a-vis Climate Change
  - Climate Change policies
- Ecosystem services — 7 mts
- REDD+ — 7 mts
- Discussion/ Miscellaneous — 5 mts

1. Forests and Environment

Forest ecosystem has both biotic and abiotic components (Fig.3.1). The biota or biotic community comprises plants, animals and microbes. The abiotic components are the climate (macro and microclimate), physiography (form of land and parent material) and soil (edaphic factors of water, air, nutrients, etc). The abiotic components together form the physical environment of the ecosystem. The physical environment and the biotic communities in an ecosystem are inseparable and they interact in complex but patterned ways. As a part of the structurally integrated ecosystem, the biotic community link the atmosphere and soil to form a functional system. We shall discuss here the role of forest vegetation in some of the natural processes that influence the composition and sustenance of physical environment.

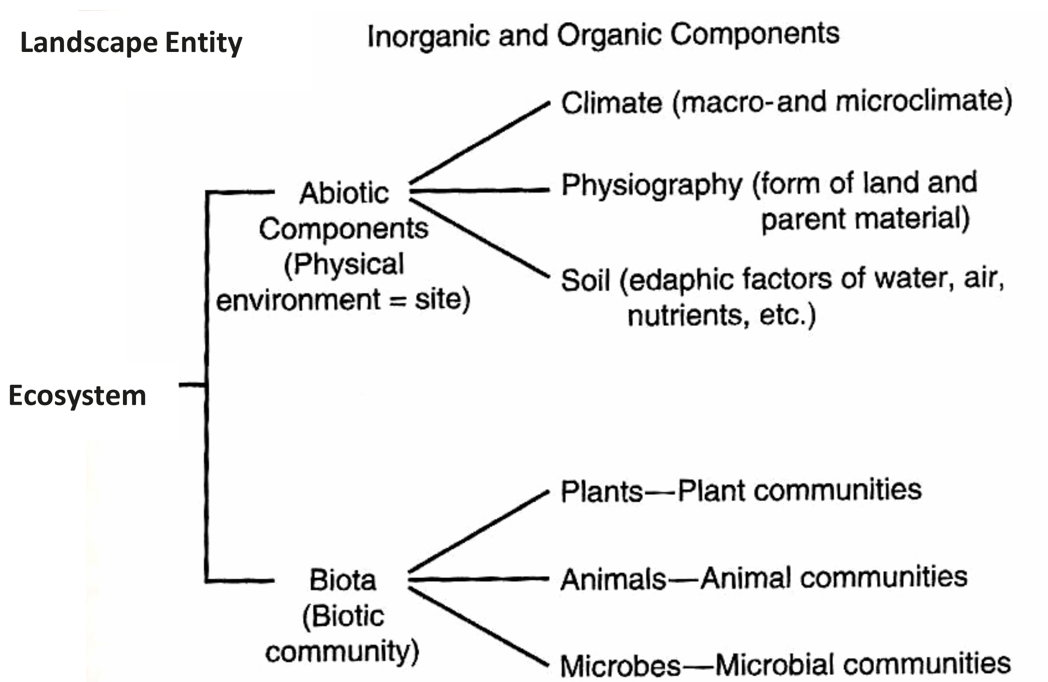


Fig.3.1 Biotic and abiotic components of ecosystems
(Source: Burton.V.Barnes et al.1998 Forest Ecology)

1.1 Hydrological or Water Cycle

Water cycle is the journey water takes as it circulates from the earth's surface to the atmosphere and back again. The storages of water on the earth include oceans, atmosphere, ground water, streams, lakes and plants**.** While the total amount of water on the earth remains fairly constant, in a never ending cycle, the water moves from one reservoir to another by the physical processes of evaporation, condensation, precipitation, transpiration, infiltration, run-off, and subsurface flow. Forest Ecosystems participate in the above processes of water movement from one storage to the other, both depending on those processes and influencing them as **described in Lesson 2 of Soil and Water Conservation**.

1.2 Carbon Cycle

Let us discuss first, in short, what is meant by greenhouse effect. The earth's atmosphere acts like a greenhouse, as it traps the light and heat from the sun. This natural process of warming the earth is called greenhouse effect. The gases that help regulate the temperature of the earth are called **'Greenhouse Gases'** (GHG). Having optimum amount of GHGs allows the earth to maintain the right temperature to support life. However, when human activities upset the natural process by adding more GHGs to the atmosphere, more heat is trapped and the earth becomes warmer.

1.2.1 There are many greenhouses gases in the atmosphere. But the most important GHG is Carbon dioxide (CO_2). It is formed when carbon combines with oxygen in the air. Increase of CO_2 is the biggest cause of climate change. It is thus necessary to understand how CO_2 is formed and how human activities affect the process. **Carbon** is one of the most common elements in the universe. It is present in the air, water, soil, forest and in humans. All life on earth needs carbon to grow and survive. But there is also carbon in non-living things such as rocks, gases, or fossil fuels**.**

1.2.2 Carbon dioxide is essential for natural process of photosynthesis. It provides carbon for plants to grow and oxygen for air. When plants or animals die or decay, carbon dioxide is produced naturally. However, CO_2 level in the atmosphere goes high due to human activities like burning of wood or burning of fossil fuels to run vehicles or engines or for household and other purposes. CO_2 produced by such human activities is the main factor to cause climate change.

1.2.3 Carbon thus moves or gets stored in the following manner.

- Carbon is either being pulled out of the air as part of carbon dioxide by plants and trees and used as energy and food for growth;
- Released back to atmosphere as part of CO_2 by plants, trees, animals and humans through respiration or breathing;
- Stored in the bodies of trees, animals, humans, as well as rocks and other non-living things.

Forests with vast vegetation store a large amount of carbon. Grasslands and farms store much less.

The natural process of carbon moving or flowing between the different places where it is used and stored (reservoirs) is called the **carbon cycle**.

(Source: **Climate Change & the Role of Forests,** A Community Manual by Susan Stone Mario, Chacón León. Conservation International 2010, www.conservation.org/climate_change_and_the_role_of_forests**)**

1.3 Carbon Balance of Trees

Forest ecosystems cover only 21% of earth's land surface. However, they constitute a disproportionately large share of terrestrial plant mass (75%) and its annual growth (37%) (Burton V Barnes et al 1998 Forest Ecology). Carbon (C) is a large constituent (47%) of plant body. Thus the extent to which forests are altered by human activities (harvesting or conversion to other use) has a substantial influence on carbon Cycle at local, regional and global scales (Burton V Barnes et al 1998 Forest Ecology).

1.3.1 Green plants use a small portion of radiant energy reaching Earth's surface (2%) to assimilate atmospheric CO_2 into organic compounds. The process is known as photosynthesis. Plants use these compounds to construct new tissue, maintain existing tissue, create storage reserves, or provide defence against insects and pathogens. **Thus trees grow or gain carbon when the amount of carbon fixed through photosynthesis exceeds the amount of carbon lost from respiring leaves, branches, stems and roots** (Burton V Barnes et al 1998 Forest Ecology). Plants which make the greatest net C gain in a given environment are often the best competitors.

1.3.2 Photosynthesis and **Respiration** are two opposing physiological processes and the balance of these two processes controls the net C gain of leaves. **Gross photosynthesis** is the total amount of C that plants assimilate from the atmosphere. A portion of total C fixed is returned to the atmosphere from leaves during **dark respiration**. The process is called dark respiration because leaf respiration can only be determined in the absence of C fixation and is measured on un-illuminated leaves (Burton V Barnes et al 1998 Forest Ecology).

Thus, Net photosynthesis = Gross photosynthesis – Leaf dark respiration

This net photosynthesis represents the amount of C available for growth and tissue maintenance. The net photosynthesis or net C gain is influenced by light intensity, temperature, , and the availability of water and soil nutrients (especially N).

2. Climate

Climate, a component of physical environment of ecosystem, is defined as the characteristic patterns, means, and extremes of weather. (Burton.V.Barnes et al.1998 Forest Ecology). Weather means local, short-term atmospheric conditions.

2.1 When someone says "it is raining a lot today," or "it has been very rainy this season," they are talking about the weather. Weather measures the temperature, rainfall, wind and cloud conditions that are happening that day or that season. **Climate** is "the average weather" or weather conditions that happen over a long period of time. When someone says, "it is always rainy here for six months of the year" or "it never snows here" they are talking about the climate. (Climate Change & the Role of

Forests, A Community Manual by Susan Stone Mario, Chacón León. Conservation International 2010)

2.2 Climate is a major factor determining formation of new species, genetic differentiation, species distributions, competition, disturbance regimes, and growth rates and carbon balance. Variation in climate with latitude, elevation and proximity to large water bodies and mountain ranges is linked to distribution of vegetation on global, regional and local scales. Characteristic temperature and precipitation patterns, as they interact with vegetation, parent materials, and physiographic position, are important in determining soil processes and soil development. (Burton.V.Barnes et al.1998 Forest Ecology). In a word, climatic features influence both biotic and abiotic components of the ecosystem.

2.3 Factors affecting Climate

A wide variety of natural and anthropogenic factors affect climate.

Factors operative on a geologic time scale include –

- Variations in earth's orbit and axis of rotation
- Changes in the sun's radiation output
- Continental drift and associated shifts in oceanic currents
- Shifts in the extent of volcanic activity
- Impacts of large meteors
- Changes in atmospheric composition

Factors operative in mid-to-short term time scales include –

- Volcanic eruptions
- Variations in oceanic currents
- Changes in atmospheric composition.

(Burton V Barnes et al 1998 Forest Ecology)

Change in the quantity of solar energy reaching earth's surface will make the earth warmer or cooler.

Volcanic eruptions release millions of tons of ash and sulphur dioxide (SO_2) into the air and thus blocking the passage of solar radiation into the lower layers of atmosphere and causing a cooling effect. Eruptions of individual volcanoes produce short term effects on earth's temperature.

Ocean water is always moving. These movements are called ocean currents. Wind moves water over the ocean's surface in regular patterns. Water also moves up from the colder, deeper parts of the ocean to the warmer surface. The temperature of surface waters has a direct influence on the temperature and moisture content of air masses. The movement of ocean water also moves heat around the globe. So ocean currents have a big impact on climate change. When the normal way in which ocean water moves is disturbed, extremes of rainfall or drought can happen.

The relative abundance of CO_2 and other greenhouse gases (methane and nitrous oxide) is crucial for maintenance of the earth's temperature. Current concern for climatic change and global warming stems from increases in the quantities of these gases, especially CO_2 due to human activities. (Burton V Barnes et al 1998 Forest Ecology)

3. Climate change – global warming

The Earth has a history of climate change. We shall devote a part of the lesson to discussion on climate change and on role of forests and forest management in the context of climate change.

3.1 Climate change

Climate Change is the change of the normal weather patterns around the world over an extended period of time, typically decades or longer. The earth's average temperature has slowly increased over the last 100 years. The term 'global warming', used often when discussing climate change, means that the average temperature of the earth's atmosphere is getting higher. Climate change is not occurring uniformly or in equal measure everywhere. Some places might have cooling trend for a period of time. However, seen all over the planet for a long period of time, scientists have come to the conclusion that climate is changing and overall the earth is getting warmer. Changes are also happening much faster than they have in the past.

3.1.1 Major signs of Global Climate Change

The major signs of global climate change are:

- **Global warming**—the average global temperature has increased steadily during the last 100 years—about 0.74 degrees Celsius (1.3 degrees Farenheit). Temperature increases have occurred in all regions around the world

  (Climate Change & the Role of Forests**,** A Community Manual by Susan Stone Mario, Chacón León. Conservation International 2010)

- **Changes in Rainfall** - There have been changes in rainfall worldwide, due to changes in surface temperatures of oceans and land areas. Globally, the areas experiencing drought, or periods of extremely dry weather, have increased since the 1970s. While some regions are receiving less rainfall and suffering longer and more droughts, other regions of the world are experiencing much higher levels of rainfall. In many places the seasons or times of year when rain falls are changing. Rain is falling at different times and for shorter or longer periods than in the past.

- **Decreasing snow cover and Rise in sea level** – Glaciers at the earth's poles and on very high mountains are melting at a faster rate because of global warming. Fast melting of ice may cause sea levels to rise and pose a danger of flooding coastal areas. In the last 100 years, the average global sea level has risen about 6 inches or 15 centimeters. (Climate Change & the Role of Forests**,** A Community Manual by Susan Stone Mario, Chacón León. Conservation International 2010)
- **Extreme Weather Events More Frequent** - Over the past 50 years, while very hot days and nights have been more frequent, very cold days and nights have been happening less often. Periods of high temperature (heat waves) have become longer and hotter over most land areas. Big storms with heavy winds and rain are happening more often and causing more damage. (Climate Change & the Role of Forests**,** A Community Manual by Susan Stone Mario, Chacón León. Conservation International 2010)

3.1.2 Impact of Climate Change

As described earlier, climatic features have direct influence on all components of terrestrial ecosystems. Climate change has a direct bearing on all life forms of the earth. If the temperature, quantity and patterns of rainfall and other atmospheric events continue to change, there will be changes in the land, water bodies, forests and all other environmental components. Climate change will thus have a serious impact on nature and distribution of vegetation, survival and growth of individual species, and finally on the survival of all humans, flora and fauna. In order to ensure human existence on earth, we will need to contain anthropogenic activities that are causing climate change and learn to adapt to new ways of doing things.

3.1.3 Human Activities that cause Climate Change

The main reason of climate change is those human activities which upset the natural processes and cycles that control the earth's climate, like the greenhouse effect and the carbon cycle. Growing human population is obviously accompanied by increasing demand of food and energy. Meeting this increasing demand requires more of human activities that result in more and more CO_2 emissions, which are changing the balance of the earth's natural processes—causing global warming and climate change. Some human activities that enhance CO_2 emission and accelerate climate change are described below.

- Burning of fossil fuels (petroleum and natural gas) – vehicles, industries, thermal power units are heavy consumers of fossil fuels and large emitters of CO_2.
- Deforestation and fires – release large amounts of CO_2.

- Change of land use – change of forests into pasture or agricultural land reduces carbon reservoir and thus allows more of CO_2 to remain in the atmosphere.

3.1.4 Forests vis-a-vis Climate Change

Forests being one of the biggest reservoirs of carbon help to keep the carbon cycle and other natural processes working and help reduce climate change. When forest trees are felled or burned, CO_2 is released to air. Reduction in forest cover also means that there are fewer trees to absorb CO_2 from air and store carbon. But if we conserve forests and extend forest cover, we reduce the effect of climate change by storing carbon in the forests and making more trees available to remove CO_2 from the atmosphere as they grow.

3.1.5 Climate Change Policies

A United Nations body called the **United Nations Framework Convention on Climate Change (UNFCCC)** works to organize countries to design climate change policies. The object of the policies is to assist countries to stop or lessen climate change and to adjust to the effects of climate change that are already happening. These policies help countries and people reduce or improve some practices, like how much electricity is used or how factories are powered, in order to reduce the amount of greenhouse gases (GHG) released into the atmosphere. These kinds of action which try to stop or lessen climate change are called **mitigation**. The policies also help countries to find new ways to adjust to the changes already brought by climate change and to prepare for changes that are likely in the future. This is called **adaptation**. Within the UNFCCC, countries work to come to agreement on mitigation and adaptation actions. (Climate Change & the Role of Forests**,** A Community Manual by Susan Stone Mario, Chacón León. Conservation International 2010).

3.1.6 One important agreement made by the UNFCCC is the Kyoto Protocol (1997). In this agreement countries promised to reduce greenhouse gas emissions and to look for new ways to create energy that causes less CO_2 emissions.

4. Ecosystem Services

Please refer to Lesson Materials on Forest Botany to know what is an ecosystem. We discuss here the concept of forest ecosystem services as it would help to understand the concept of management of forests in the context of climate and climate change policies.

Ecosystem services are defined as the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life. (http://www.forest-to-faucet.org/pdf/ecosystem-services.pdf)

4.1 The ecosystem services are divided into four categories, namely:

- **Provisioning** - Provisioning ecosystem services are products derived from ecosystems. Examples from forests are such things as timber, water, fuel, non-timber forest products, medicinal plants, and genetic resources.
- **Regulating** - Regulating ecosystem services are those which maintain a livable world. Forests play key role in the hydrological cycle, regulating stream flow, prevention of soil erosion, diminishing impact from floods. Forests also have important function in carbon cycle, and mitigating climate change. These are some of the many regulating services forests provide to help keep the world running as usual.
- **Cultural** - Cultural ecosystem services are the non-material benefits people obtain from ecosystems. These include: aesthetic enjoyment, spiritual enrichment and fulfilment, recreational activities, and ecotourism opportunities.
- **Supporting** - Supporting ecosystem services are ones that are necessary in the production of the other provisioning, regulating and cultural ecosystem services. Though not as conspicuous as the other services, the supporting services form the foundation for the sustenance of the other ecosystem services. Examples of supporting ecosystem services from a forest include soil formation, photosynthesis, nutrient cycling, erosion control, habitat for flora and fauna, and watershed protection.

5. Development of REDD+ idea

(Climate Change & the Role of Forests**,** A Community Manual by Susan Stone Mario, Chacón León. Conservation International 2010).

REDD+ is described as policy approaches and positive incentives on issues relating to reducing emissions from deforestation and forest degradation in developing countries, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries.

At the initial stage of policy discussion on the impact of forests on climate change, attention was mostly focussed on stopping harmful practices related to forest use and management—such as rapid cutting of trees. Now the discussions have expanded to take into account the ecosystem services that forests provide. Governments are also discussing how to support sustainable forest management, and the role of carbon storage in the forests of developing countries as part of a process to mitigate climate change. The term REDD+ has now evolved to include these forest ecosystem services in the discussions. An outline as to how this concept of REDD+ has developed is given below.

5.1 RED

At the UNFCCC's annual meeting, held in Montreal, Canada, in 2005, Papua New Guinea and Costa Rica, countries with large tropical forests, proposed the idea of creating a way to provide benefits to countries that were able to reduce the amount of GHGs released into the atmosphere by reducing the cutting of forests—or "reducing emissions from Deforestation (RED)." At that time, countries agreed to ask a group of experts to think about how to create a process that could make the idea of RED work.

5.2 REDD

In the 2007 meeting in Bali, Indonesia, UNFCCC countries decided that addressing forest degradation was also important—adding a second D to arrive at REDD. They proposed that activities be tested to show how REDD could work and how REDD could be part of a new agreement to reduce GHGs after the Kyoto Protocol ends in 2012.

5.3 Concept of REDD+

After the UNFCCC meeting in Poznan, Poland in December, 2008, the + was added to REDD to recognize the climate benefits that come from the conservation and sustainable management of forests and forest carbon stocks. REDD+ became the official term in March 2009.

Reference Materials

1. Burton V Barnes et al 1998 Forest Ecology, John Wiley & Sons, Inc.
2. Susan Stone & Mario, Chacón León, Climate Change & the Role of Forests**,** A Community Manual, Conservation International 2010
3. Websites cited in the Lesson.

Lesson 4

1 hour

Lesson Plan

To study

- **Nutrient Cycling**
- **Forest Biodiversity**
  - ➢ Introduction
  - ➢ Status
  - ➢ Major threats to Biodiversity
  - ➢ Measuring Diversity – Species Diversity
  - ➢ Species Richness, Evenness
  - ➢ Biodiversity indices

Backward Linkage: Nil

Forward Linkage: Subsequent Lessons

Training Materials required: Copy of Lesson 4 to be circulated beforehand.

Allocation of time:

- **Nutrient Cycling** 10 mts
- **Forest Biodiversity** 40 mts
  - ➢ Introduction
  - ➢ Status
  - ➢ Major threats to Biodiversity
  - ➢ Measuring Diversity – Species Diversity
  - ➢ Species Richness, Evenness
  - ➢ Biodiversity indices
- **Discussion/Miscellaneous** 10 mts

1. Nutrient cycling

Carbon **(C),** Hydrogen **(H)** and Oxygen **(O)** form the basic building blocks of all biological tissues. However, plants require a set of 14 other elements, called **nutrients**, to maintain existing tissues and build new ones. These elements are Nitrogen (N), Phosphorus (P), Potassium (K), Sulphur (S), Magnesium (Mg), Calcium (Ca), Iron (Fe), Manganese (Mn), Boron (Bo), Molybdenum(Mo), Copper (Cu), Zinc (Zn), Chlorine (Cl) and Cobalt (Co). A diagram showing the processes by which nutrients flow into, within and out of forest ecosystems is shown in **Fig.4.1.** The movement of nutrients within the ecosystem is called **nutrient cycling.**

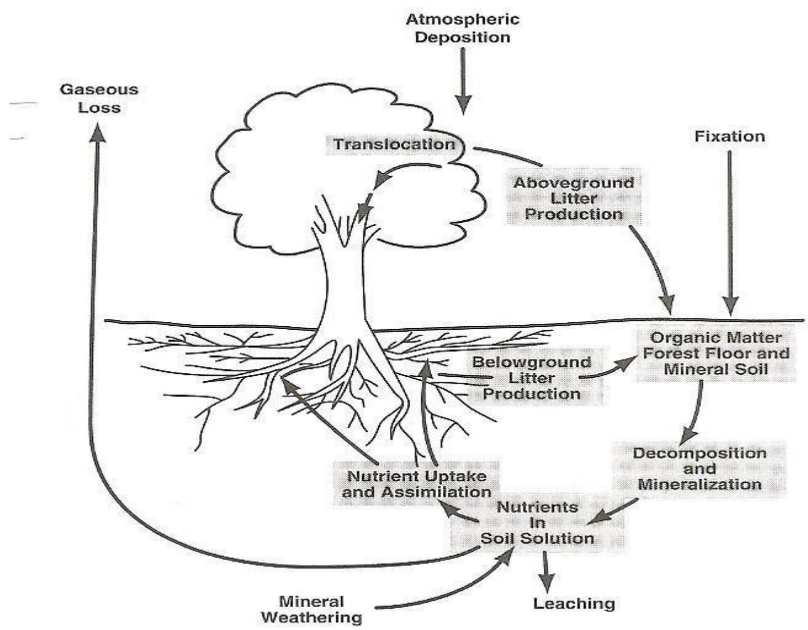


Fig.4.1 Nutrient cycling in a forest ecosystem
(Source: Burton.V. Barnes et. al 1998 Forest Ecology)

Nutrients enter forest ecosystems through atmospheric deposition (hydrological process), N_2 fixation (biological process) and mineral weathering (geological process). The cycling of nutrients within forest ecosystems takes place through the following processes.

- Uptake and assimilation by plants of nutrients from soil and incorporation with carbon (fixed by photosynthesis);
- Nutrient allocation to biomass construction and maintenance;
- Translocation of nutrients from senescent tissues;
- Production of plant litter returns nutrients to forest floor and mineral soil;

- Decomposition of litter by soil microorganisms which incorporate organically-bound nutrients (and C) into their biomass and release excess nutrients into soil solution in forms that can again be assimilated by plant roots
- Leaching and gaseous losses (denitrification) are processes by which nutrients are lost from forest ecosystems.

Thus the **nutrient cycling** constitutes biogeochemical processes and the rate at which nutrients flow within forest ecosystems is controlled by the physiological activities of plants and soil microorganisms, and their requirement for growth-limiting nutrients.

2. Biodiversity

Biodiversity is the **variety of life on Earth**. It includes **diversity at the genetic level**, such as that between individuals in a population or between plant varieties, the **diversity of species**, and the **diversity of ecosystems and habitats**. Biodiversity encompasses more than just variation in appearance and composition. Biodiversity **may be defined as the kinds and numbers of organisms and their pattern of distribution**. It includes diversity in abundance (such as the number of genes, individuals, populations or habitats in a particular location), distribution (across locations and through time) and in behaviour, including interactions among the components of biodiversity, such as between pollinator species and plants, or between predators and prey. **Biodiversity has evolved over the last 3.8 billion years or so of the planet's approximately 5 billion-year history**.

2.1 As the **basis for all ecosystem services**, and the **foundation for truly sustainable development**, biodiversity plays fundamental roles in maintaining and enhancing the well-being of the world's more than 6.7 billion people. Biodiversity comprises **much of the renewable natural capital** on which livelihoods and development are grounded. **Biodiversity forms the basis of agriculture, and enables production of food, both wild and cultivated contributing to health and nutrition.**

2.2 People rely on biodiversity indirectly, without being aware. There are bacteria and microbes that transform waste into usable products, insects that pollinate crops and flowers, diverse landscape that provide inspiration and enjoyment. However, How much biodiversity is needed for sustainable supply of ecosystem services remains largely unknown.

2.3 According to recent IUCN reports (2012 IUCN Red List),

- 20219 species have been identified as threatened out of 65518 species so far evaluated.

- Of the major vertebrate groups that have been comprehensively assessed, over 20% of mammals and 13% of birds are threatened
- Of mammals, birds and plants, assessment over a period from 1996 to 2012 showed a rise in the number of Critically Endangered and Endangered species. The number of Vulnerable species also showed rise for Birds and plants, though a decline for mammals
- India is reported to have 935 no of threatened spp. (mammals 94, Birds 80 and Plants 321)

2.4 Major threats to Biodiversity

- Habitat Loss /Conversion (caused largely by commercial agriculture)
- Fragmentation (caused by infrastructure development, human settlement)
- Invasive alien species (through deliberate and unintentional introduction)
- Over exploitation (to meet consumer demand)
- Damage caused by fire, disease and pests.
- Climate Change (causing changes in phenology, physiology, morphology etc.)
- Pollution (caused by pesticides, industrial effluents, run-off from urban areas, oil spills)

2.5 Measuring Diversity

Diversity includes two different concepts of variety: richness and evenness. Richness refers to the number of units (alleles, species, families, communities, ecosystems) per unit area, and evenness refers to their abundance, dominance, or spatial distribution. Applying these two concepts, biodiversity can be measured at many levels of organization: continental-level or macro-ecosystems, regional or mesoecosystem, local or microecosystems, species, and the genetic diversity within population of a species.

2.5.1 Species Diversity

Normally the focus of measurement is species diversity, because species are observed easily and the most common taxonomic unit in ecological studies of forest ecosystems. While species diversity encompasses all organisms, study is usually is restricted on practical grounds to certain groups of species. Thus the set of organisms to be studied is to be identified and predetermined before making study of diversity. Most studies of biodiversity are done at the local level in areas of < 1 to several 100 hectares (Micro ecosystem scale). Species diversity at a homogeneous site at microecosystem level is called alpha diversity.

2.5.1.1 Species Richness

The simplest way to measure species diversity is to count the number of species in a designated area. This number or species richness (S) is the most fundamental and the least ambiguous of diversity measurement (Source: Burton V. Barnes etal 1998 Forest Ecology). S depends on the area sampled and is often expressed as number of species per unit area.

Species Richness (S) = Number of species in the sample area

During study, the number of species being encountered increases with increasing size of sampled area, thus in order to find a dependable value for S, while doing enumeration it is important to use a sample plot size large enough, or enough plots, to capture most of the species. It is also important to recognize the ecosystem's boundaries whose diversity is so represented by the sample plot enumerated.

2.5.1.2 Evenness

Besides richness, the other factor of species diversity is **Evenness,** which means the degree to which all species share dominance in an area. For example, two forest stands, say 1 and 2, both have 10 species. Thus the species richness value S is same for the two stands. However assume that, populations of the species in the said stands are found as below

	Stand 1		Stand 2	
Spp.	Population (n)	Relative abundance (=n/N)	Population (n)	Relative abundance (=n/N)
1	40	0.40	10	0.10
2	44	0.44	09	0.09
3	2	0.02	11	0.11
4	2	0.02	08	0.08
5	2	0.02	12	0.12
6	2	0.02	10	0.10
7	2	0.02	10	0.10
8	2	0.02	09	0.09
9	2	0.02	11	0.11
10	2	0.02	10	0.10
Total (N)	100		100	

It is apparent from the above table that though the total population (N) and the number of species are same for both the stands, stand 1 is clearly dominated by two species (Species 1 & 2), whereas stand 2 exhibits almost equal abundance of all species and therefore has **greater Evenness.**

2.5.1.3 Biodiversity indices

Described below are two biodiversity indices that combine the dual concept of richness and evenness.

- Simpson's index – Simpson (1949 developed an index which is computed as

$$D = \sum_{i=1}^{S} \left(\frac{n_i(n_i-1)}{N(N-1)} \right)$$

Where n_i is the number of individual (=population) in species i, N is the total number of individuals (= total population) in the sample, and S is the number of species in the sample. This index **D** indicates the probability that two randomly selected individuals in the community belong to the same species. Maximum and minimum values of **D** will be as mentioned below.

D_{max}= 1, and D_{min} = 1 / S.

Diversity is inversely related to D, and so is expressed as its complement, 1-D or 1/D.

- Shannon-Wiener index – It is the most commonly used diversity index, and is computed as

$$H' = -\sum_{i=1}^{S} p_i \ln (p_i)$$

Where s = number of species in the sample,

p_i = proportion of individuals that belong to species i = n_i /N,

'ln' means natural log, that is log to the base 'e'.

Value of H' ranges from a low of around 1.5 to high of 4.5. (Burton.V Barnes 1998 Forest Ecology)

Reference materials:

1. Burton. V Barnes et.al 1998 Forest Ecology John Wiley & Sons, Inc

2. L S Khanna 1999 Principles and Practice of Silviculture, Milton Book Company.

3. UN Environment Programme's Global Environment Outlook-5 Report, 2012

4. IUCN Red List

5. Websites cited in the lesson.

Lesson 5

1 hour

Lesson Plan

To study

- **Forests, scope and classification**
  - Protection, Production and Social Forestry
- **Growth of trees**
  - Various stages of growth
    - Seedling
    - Sapling
    - Pole
    - Tree
    - Crown

Backward Linkage: Lesson materials on Forest Botany
Forward Linkage: Subsequent Lessons
Training Materials required: Copy of Lesson 5 to be circulated beforehand
Allocation of time:

- **Forests, scope and classification**
  - Protection, Production and Social Forestry — 15 mts
- **Growth of trees**
  - Various stages of growth — 35 mts
    - Seedling
    - Sapling
    - Pole
    - Tree
    - Crown
- **Discussion/ Miscellaneous** — 10 mts

1. Forestry, its scope and classification

(Source: http://www.agriinfo.in/?page=topic&superid=2&topicid=1605)

Forestry is defined as the theory and practice of all that constitutes the creation, conservation and scientific management of forests and the utilization of their resources. It includes all thinking and all actions pertaining to creation and management of forests, including harvesting, marketing and utilization of all forest products and services.

1.1 National Forest Policy of 1952, recommended that on the basis of Functions, all forest lands may be classified into:

A. Protection Forests
B. National Forests
C. Village Forests
C. Tree Lands

1.2 National Commission of Agriculture (1976) proposed that forests can be classified into:

A. Protection Forests:

The practices of managing the forests for their protection function are called Protection forestry. In protection forestry, the object is to protect the site due to instability of terrain, nature of soil, geological formations, etc. Such areas where manipulation of the forest cover is not desirable may be classed as protection forests. The forests located on higher hill slopes, national parks and sanctuaries, preservation plots, biosphere or nature reserves and wilderness areas may be included under protection forests. The practice of forestry with a view to conserving flora, fauna, soil and water, increasing water yields, reducing floods and droughts, amelioration of climatic conditions, comes under Protection Forestry.

B. Production Forests:

The practice of forestry with object of producing maximum quantity of timber, fuel wood and other forest produce is called Production Forestry. In Production forestry, there is a greater concern for the production and economic returns. The production forestry can be further classified into:

(i) Commercial Forestry: Commercial forestry aims to get maximum production of timber, fuel wood and other forest products as a business enterprise.

(ii) Industrial Forestry: Industrial forestry aims at producing raw material required for industry.

C. Social Forests:

Social Forestry is the practice of forestry on lands outside the conventional forest area, which aims at meeting the requirement of rural and urban population. The object of social forestry is to meet the basic needs of community, aiming at bettering the conditions of living through:
(i) Meeting the fuel wood, fodder and small timber requirements
(ii) Protection of agricultural fields against wind
(iii) Meeting recreational needs and
(iv) Maximizing production and increasing farm returns

Various forms of Social forestry are:

a) Community Forestry: The practice of forestry on lands outside the conventional forest area for the benefit of local population has been called Community forestry. Community forestry seeks the involvement of community in the creation and management of such forests.

b) Farm Forestry: Farm Forestry is defined as the practice of forestry in all its aspect on farms of village lands in the form of rows of trees on bunds and boundaries, individual trees in private agricultural land, creation of wind breaks etc. It is generally integrated with other farm operations.

c) Extension Forestry: Extension forestry which includes the activity of raising trees on farm lands, villages wastelands and community forest areas and on lands along the sides of roads, canal banks and railway lines.

d) Agro-Forestry: Recently, there has been emphasis on dynamic land use planning and efforts are made to maximise production on farmlands under agroforestry. Agro-forestry has been defined as a sustainable land management system which increases the yield of the land, combines the production of crops and forest plants and/or animals simultaneously or sequentially on the same unit of land and applies management practices that are compatible with the cultural practices of the local population.

e) Recreational Forestry: More recently, there has been considerable demand for Recreational forestry, which is defined as the practice of forestry with the object of developing and maintaining forests of high scenic value. Recreational forests are being developed near towns and cities. The areas are being planted with flowering trees, shrubs and creepers to provide forest atmosphere near towns and cities.

2. Growth of Trees – various stages

(Source: http://en.wikipedia.org/wiki/, http://www.nrs.fs.fed.us/environmental_literacy /curricula/, L S Khanna 1999 Principles and Practice of Silviculture, http://www.ehow.com/how-does_5365342_steps-tree-growth.htm, http://nfs.unl.edu/RuralForestry)

In its life cycle a tree goes through various stages. As it grows, the tree's physical form changes. Also changes its role in the forest ecosystem. The various stages of growth are as follows:

- **Seedling** - A **seedling** is a young plant developing out of a plant embryo from a seed. The young plant is called seedling till it reaches a height of about one metre, that is, the sapling stage. Seedling development starts with germination of the seed. A typical young seedling, at its initial stage, consists of three main parts: the embryonic root, the embryonic shoot, and the cotyledons (seed leaves). Once the seedling starts to photosynthesize, it is no longer dependent on the seed's energy reserves. The apical meristems start growing and give rise to the root and shoot. The first true leaves expand and can often be distinguished from the round cotyledons through their species-dependent distinct shapes. While the plant is growing and developing additional leaves, the cotyledons eventually grow old and fall off.

  The seedling grows and begins to develop woody characteristics. The stems harden, change color, and develop a thin protective bark. The stem may bend or develop branches that reach toward light. Seedlings compete for nutrients, water, sunlight, and space. At this stage the tree is susceptible to many threats that include fire, flood, drought, disease, insect attacks, and animals.
- **Sapling** – Sapling is defined as a young tree from the time when it reaches about one metre (3 feet) in height till the lower branches begin to fall. At sapling stage the tree is about 1-4 inches in diameter at 4.5 feet (breast height). As the tree starts to get taller the trunk thickens and branches develop. A sapling has all the characteristics of a fully grown tree, and lacks only in size and reproductive abilities. A sapling is characterized by the absence of dead bark and vigorous height growth. Growing rapidly, the sapling has the same competition and threats as seedlings.
- **Poles** – Pole is defined as a young tree from the time when the lower branches begin to fall off to the time when the rate of height growth begins to slow down and crown

expansion becomes marked. Generally, poles are greater than four inches but less than eight inches in diameter. Depending on the species, trees in the pole stage could be as tall as 30 feet.

- **Tree** – Tree is the stage of growth beyond the pole stage. With favourable conditions, a sapling or pole will grow into a mature tree (>8 inches DBH). During this stage, each tree will grow as much as its species and site conditions will permit. In addition, flowers develop, reproduction ensues, fruits form, and seed dispersal can occur. Trees provide the maximum environmental benefits to people during this stage.

2.1 Phenology

As a plant grows, it undergoes biological changes. It sheds leaves, produces new leaves; produces flowers and seeds after a certain age, and sheds them on ripening. These biological changes in the plant's life cycle are periodic events, and it is important to study these changes to know the silviculture of a particular species. The **scientific study** of periodic biological phenomena, such as flowering, breeding, and migration, in relation to climatic conditions, in the life cycles of plants and animals is called **phenology**.

2.1.1 The biological phenomena mentioned above however do not take place exactly at the same time every year. Variation in the time of occurrence takes place and such variation is due to changes in the climatic factors. Again the variation in the time of occurrence in response to change in climatic factors depends on the species concerned. For example, heavier rainfall and higher humidity sometimes quicken fruit ripening in *Albizzia procera* and Sal, but they appear to delay new leafing and flowering (L S Khanna 1999 Principles and Practice of Silviculture).

3. Tree Growth Characteristics

(Source: Tree Growth Characteristics by *Jennifer Franklin, Associate Professor, David Mercker, Extension Specialist, Forestry, Wildlife and Fisheries, University of Tennessee, Institute of Agriculture;* L S Khanna 1999 Principles and Practice of Silviculture; http://www.forestencyclopedia.net*)*

Please consult lessons in Forest Botany while going through this topic.

Primary Growth - Tree growth occurs in two ways. Growth from the root and shoot tips that results in increases in height and length is called **primary growth**. Growth that increases the thickness of stems and branches is called **secondary growth**. Primary growth occurs in small areas called apical meristems. All leaves, height growth and increases in the length of branches and roots are the result of growth at the apical meristems. One or more leaves are produced at a region called node, and the section of stem between nodes is called the internode.

- For most species, environmental factors like light, nutrients etc. determine the number of leaves produced in a season.
- However, the size of a leaf and length of the internode are influenced more by water availability during the time they are maturing. A spring drought or damage to the roots may cause less water availability, and results in smaller leaves.
- Arrangement of leaves is a typical characteristic of the species, which helps in tree identification. Pattern of leaf arrangement also, in a major way, determines the form of a tree.
- The apical meristem, along with the tiny developing leaves around it, is referred to as the **terminal bud**. The terminal bud is found at the end of each branch. In most young trees, normally one of the terminal buds grows straight up, and this is called the leader.
- Small buds often appear on the stem, just above where the leaf is attached. These are called lateral buds, and can grow to become a branch. Many of these buds will not expand, but lie dormant in the stem, ready to grow if new branches are needed.
- The largest branches off the main stem are called the first order lateral branches. Branches growing from the first order laterals are referred to as second order laterals, and so on. The smallest woody branches, often fourth order branches in a mature tree, may be referred to as twigs.

Secondary Growth - Tree stems, branches and roots increase in thickness or diameter, through secondary growth.

- The soft inner layer of bark next to the wood is the **vascular cambium**, and every year it creates **xylem** (new wood) on the inside, and **phloem** (new inner bark) on the outside. The xylem carries water and nutrients from the roots upward, while the phloem carries sugars from the leaves downward.
- In temperate climates, the cambium does not grow during the winter and a dark line can be seen in the wood indicating slowing of cambial growth at year’s end. These are the annual growth rings that are visible in many species. In tropical climates, growth may occur round the year, and annual rings may not be visible. In some species, the rings are pronounced, because wood produced in the favourable conditions of spring (earlywood) is less dense than wood produced in the summer and fall (latewood).
- Cork cambium also produces a certain amount of diameter growth. As it grows the cork cambium produces cork, the outer layer of bark. While new cork is produced each year, the outermost layer is shed so that the bark thickness of a mature tree remains nearly the same from year to year. Thus growth in cork cambium contributes greatly to diameter growth in sapling stage as a sapling develops a thick bark, but diameter growth of a mature tree is mainly due to the production of wood by the vascular cambium.

3.1 Energy for Growth

- Approximately half of all photosynthate (sugar) produced by photosynthesis is used for respiration, e.g., maintenance of the trees' living parts. This includes energy needed to take up water and nutrients, to produce chemicals that deter herbivores, to adapt to changing temperature and water availability, and to make ongoing small repairs to cells. If the tree is stressed by insects, disease, poor weather or is growing in an environment where that species is not normally found, a greater proportion of the photosynthate will be used for maintenance.
- Photosynthate is also used for growth of the roots, stems and branches. Photosynthate is required for primary growth of shoots each year to produce new leaves, to store food in the roots and stem to maintain the living tissues during the period of stress, and to support the spring growth of new leaves in deciduous species. If growing conditions are favorable, enough photosynthate is produced for all maintenance, growth and storage requirements, and any additional photosynthate is usually used for additional growth. This excess photosynthate often goes to secondary growth, and can be measured as an increase in stem and trunk diameter. Therefore, the annual rings in wood often are wider during good growing years, and narrower during years with poor growth conditions.

4. Crown Shape

The crown is defined as the upper branchy part of a tree above the bole (L S Khanna 1999 Principles and Practice of Silviculture). It contains live branches and foliage. Crown shape is of interest to foresters because it indicates the amount of growing space (or stocking) that is needed to maximize timber production. Crown shape is also an important factor of consideration for trees around buildings and in urban settings, because it influences contrast, view, shading and screening.

4.1 The live crown ratio expresses the relationship of the portion of the tree with live branches (crown depth) to the total tree height. For example, a tree with a total height of 100 feet, having live branches in the upper 40 feet, would have a live crown ratio of 40 percent (calculated by 40/100). When trees are young and/or open-grown, they will have high live crown ratios because live branches often exist nearer the ground level. However, as trees age or experience competition from adjacent trees for sunlight, lower limbs succumb and the live crown ratios shrink.

4.2 The shape and size of the crowns of trees vary with species and the conditions in which they grow. In conifers generally, the lower branches are longer and upper branches are shorter, and thus the crown has conical shape. However, trees like *Mangifera indica* (Am), *Azadirachta indica* (Neem), *Madhuca indica* (Mahua), *Tamarindus indica* (Tentul) have spherical or round crown. In forests, the crown shape is influenced by a tree's position within the canopy. Although the basic shape is characteristic of a species, branch growth and death is modified by the environment. Trees grown in close proximity to others can have vastly different crowns than those grown in an open setting.

4.3 Perhaps most influential in determining crown shape is differences in the degree of apical dominance. Apical dominance is the upward growth of the leader, at the expense of lateral shoots. Trees with strong apical dominance grow in height much faster than in width. Typically, these species will have a single, dominating central trunk and leader. Many conifer species exhibit strong apical dominance. Lateral branches often grow outward, rather than upward. Such trees are said to have an excurrent crown that favours oblong or pyramidal shapes.

Reference materials:

1. Tree Growth Characteristics by Jennifer Franklin, Associate Professor, David Mercker, Extension Specialist, Forestry, Wildlife and Fisheries, University of Tennessee, Institute of Agriculture
2. L S Khanna 1999 Principles and Practice of Silviculture, Milton Book Company.
3. Websites cited in the lesson.

Lesson 6

1 hour

Lesson Plan

To study

- **Factors of Locality governing growth of forests**
  - **Climatic factors**
    - **Solar radiation**
      - **Light**

Backward Linkage: Previous lessons and lessons on Forest Botany

Forward Linkage: Subsequent lessons on climatic factors

Training materials required: Copy of lesson 6 to be circulated beforehand.

Allocation of time:

• Factors of Locality – Introduction	7 mts
• Climatic factors	
➢ introduction and classification	10 mts
➢ Solar radiation	10 mts
- Light	23 mts
• **Discussion / Miscellaneous**	10 mts

1. Factors of Locality

As one moves from one locality to another, one can easily discern the change in the nature and composition of forests borne on such localities. Forests in Darjeeling hills are different from those in the lateritic tracts of south-west Bengal. Again forests in the plains of north Bengal will be altogether different from the estuarine forests in the Sundarbans down in the south. That is, with change in locality, the nature of forests changes. Such changes manifest in flora and fauna, and their characteristic features like species, relative abundance of species, composition of vegetation in different stories, ground vegetation etc. This happens because forests and its biota (flora and fauna) in a particular locality are governed by the climate, soil, topography and biotic factors prevailing in that locality. In other words, it is not a matter of chance that a forest of a specific nature and composition gets established in a locality or site, rather forest of a locality is the result of complex influence of the climatic, edaphic, topographic, and biotic factors of the locality.

1.1 The **factors of the locality** are thus defined as the effective **climatic, edaphic, topographic and biotic** conditions of a site, which influence the vegetation of the locality. These factors are also referred to as **site or habitat factors**. Factors of locality are broadly classified into four categories, namely,

- Climatic factors
- Topographic factors
- Edaphic factors, and
- Biotic factors

The site factors interact among themselves to yield the inputs like light, heat, water, nutrients etc. that are directly available and used by the plants.

2. Climatic factors

Definition and concept of climate and factors that affect climate have been described in Lesson 3. Climatic factors which influence the forest ecosystem are those relating to the atmosphere in which the above-ground and below-ground portions of plants grow. These include solar radiation, air temperature, air humidity, wind, lightning, and the CO_2 content of the air. Climate also determines the below ground temperature, moisture, CO_2 and weathering of nutrients from rock substrate.

2.1 Among the climatic factors, the most important are solar radiation, which provides light and heat, moisture and wind. The climatic factors are thus classified as

- Solar radiation
  - Light
  - Heat & Temperature
- Moisture
- Wind

2.2 Solar radiation

Interaction between solar radiation and the atmosphere surrounding the earth produces earth's climate. The sun provides, directly or indirectly, energy in two forms, namely light and heat. Light energy is essential for photosynthesis, a process by which plants produce their food. The plants, in turn, provide food to herbivores and the latter to carnivores. Thus the food chain in the nature's ecosystem owes its origin, among others, to light energy of solar radiation.

2.2.1 A very small portion of sun's intense radiation reaches earth. However, solar energy reaching earth's surface is not same everywhere. On an annual basis, the equatorial regions receive the most and the Polar Regions receive the least. That is why, the equatorial regions are the hottest and the Polar Regions are the coolest area on earth. Since hot air has a tendency to move up and the cold air to sink down, the variation in temperature between the polar and equatorial regions becomes the driving factor of air movement on earth.

2.2.2 The spectrum of solar radiation reaching the earth can be divided into three ranges of wavelength, namely

- Ultraviolet – Wavelength less than 0.4 micro meter (µm, 10^{-6}m)
- Visible spectrum – Wavelength 0.4 µm-0.7 µm
- Infrared – Wavelength greater than 0.7 µm

Radiation in the visible spectrum is referred to as **light,** since radiation in this wavelength range (0.4 µm-0.7 µm) is visible to human eye. The intensity of solar energy increases rapidly through the ultraviolet range and reaches peak value in the visible spectrum. However, about 50% of total solar energy is received in the infrared range.

2.2.3 As solar radiation reaches the earth's atmosphere, a part of it is reflected from clouds and dust particles in the atmosphere. Further a part of solar radiation is reflected from the earth surface. The proportion of the incoming radiation that is reflected back into the space is known as **albedo.** It consists approximately 30% of the incoming radiation on average, and is lost from the earth-atmosphere system. The remaining 70% of the solar radiation is absorbed by the atmosphere, earth surface and vegetation. Ultimately, for the earth to maintain a constant average temperature, all of radiation absorbed radiate back out into space. (Burton. V. Barnes et.al 1998 Forest Ecology).

2.2.4 The solar radiation reaching the earth also depends on latitude, altitude, season of the year and time of the day. As latitude increases, intensity of solar radiation, decreases. Please refer to Para 2.2.1.

2.2.5 Light

Light is an important locality factor as it has the following effects on trees and othervegetations

- **Chlorophyll formation**- Light is an essential factor responsible for chlorophyll formation.
- **Functioning of stomata**- Light influences the opening and closing of stomata, thus effecting respiration and photosynthesis.
- **Photosynthesis-** Photosynthesis, the process by which plants produce food, cannot take place in absence of light. Plants actually use only a small part of the total light falling on the leaves. The leaf allows only a portion of incident light to be absorbed; and most of the light energy absorbed is used up in raising leaf's temperature and is lost as heat or consumed in transpiration. Since Chlorophyll is green, green foliage reflects a higher percentage of green lights than the blue- violet or the longer yellow- red wavelengths. Thus the blue- violet and the yellow – red coloured light get absorbed instead of being reflected, and have relatively greater influence onphotosynthesis.
- **Growth-**The most obvious importance of light to forest vegetation lies in the dependence of tree-growth on Photosynthesis and latter's dependence, in turn, on light. The influence of light on tree growth depends on the wavelength, duration and intensity.
  - The wavelength or colour of the light influences the height and shape of the plants.
  - Duration of light or the length of exposure to day light influences the growth of plants. The response of plants to the timing of light and darkness, called **Photoperiodism,** is a biological clock enabling plants to adjust their metabolism to certain seasonal fluctuations. Photoperiod largely controls the entrance into dormancy of many woody plants. Photoperiod is particularly important in higher altitudes where seasonal differences are very muchpronounced.
  - Before we describe **effect of intensity of light**, let us define a couple of terms. **Light Irradiance** is the amount of radiation received per unit area in the visible spectral brand. The **Light Compensation point** is the light intensity at which carbon gain from photosynthesis equals carbon loss from respiration (Please see "carbon balance of trees" in Lesson 3). **When the irradiance is increased above**

the compensation point, photosynthesis is increased proportionately. It has been observed by scientists that in the range of 1 to 15 % of full sunlight, photosynthesis is directly proportional to irradiance, if other factors are favourable. The increase in photosynthesis will continue until other factors combine to bring growth to halt**.** At very high irradiance, factors like high respiration, water deficit causing stomatal closing, and over-accumulation of photosynthate may result in decreased photosynthesis (Burton. V. Barnes et.al 1998 Forest Ecology).

- **Form and quality of trees** – Growing axes of trees elongate mainly between sunset and sunrise in low irradiation. That is why trees growing in shade are usually taller than those of the same age growing in open provided other growth factors are not restricted. Light also influences the form of trees. In congested forest crop, lower branches of trees die and fall off due to deficiency of light caused by upper story resulting in long clear boles. Continued competition for space restricts development of crown and tends to produce stem of more cylindrical shape. Exposure to light favours formation of relatively large crown and consequently, rapid growth. That is why, towards the end of rotation, forests are opened up to allow the selected trees to put on rapid diameter growth.

- **Species stratification, size and structure of Leaves** – The intensity of light in a typical forest varies widely along vertical heights from top canopy to forest floor. The top canopy receives the full light. However, the intensity of incident light reduces as light gets filtered down through the canopies and foliage. Ultimately, light that reaches forest floor is of very low intensity. This variation of light intensity down the heights results in stratification of species in different canopies, according to requirement of light.

  Light also affects the size and structure of leaves. In typical forest trees, shade leaves are thinner, and less deeply lobed. Shade leaves have a larger surface per unit weight and fewer stomata than comparable sun leaves off the same tree. (Burton. V. Barnes et.al 1998 Forest Ecology)

2.2.5.1 Light requirement of species

Light required by a species for growth and establishment varies from species to species. Based on tolerance to light intensity, species are classified into following categories –

- **Light Demander** – requires abundant light for its best development
- **Shade bearer** – is capable of persisting and developing under shade

- **Shade demander** – requires, at least in its early stage, some shade for normal development.

In practice, however, all species cannot be categorized rigidly under the above classification, because plants may respond to light intensity differently under different growing conditions, and at different stages of growth. For example, *Shorea robusta* (Sal), known to be light demander, requires shade at the early (seedling) stage. However, based on broad observation, some examples of classifications are given below.

Light Demander - *Shorea robusta* (Sal), *Tectona grandis* (Teak), *Dalbergia sissoo* (Sissoo), *Acacia catechu* (Khair), *Bombax ceiba* (Simul), *Terminalia alata* (Pacasaj, Asan), Eucalyptus etc.

Shade bearer – *Quercus dilatata* (Katus), *Cupressus torulosa*, *Toona celiata* (Toon), *Pterocarpus marsupium* (Peasal), *Pongamia pinnata* (Karanj), *Schima wallichii* (Chilauni) etc.

Shade demander – *Taxus baccata, Xylia dolabriformis* (Lohakath), *Schleichera oleosa* (Kusum), *Mallotus philippinensis* (Sindure), *Litsea glutinosa* (Leda) etc.

Reference materials:

1. Burton. V Barnes et.al 1998 Forest Ecology, John Wiley & Sons, Inc.
2. L S Khanna 1999 Principles and Practice of Silviculture, Khanna Bandhu, Dehradun

Lesson 7

1 hour

Lesson Plan

Objective:
To study

- **Factors of Locality governing growth of forests (Continued)**
  - **Climatic factors (continued)**
    - **Temperature**
    - **Moisture**
    - **Wind**

Backward Linkage: Previous lessons, lessons on Soil and Water Conservation

Forward Linkage: Subsequent lessons on Locality factors

Training materials required: Copy of lesson 7 to be circulated beforehand.

Allocation of time:

- Temperature
  - Factors affecting temperature — 8 mts
  - Effects of temperature — 12 mts
- Moisture
  - introduction — 3 mts
  - Essential role — 5 mts
  - Source — 5 mts
  - Effect of rainfall on vegetation — 5 mts
- Wind
  - Beneficial effects — 3 mts
  - Harmful effects — 9 mts
- Discussion / Miscellaneous — 10 mts

1. **Temperature**

Solar radiation is the source of heat that governs the temperature of the earth surface. The mean annual temperature at any given spot of earth surface is basically controlled by the incoming solar insolation and by secondary heat transfer owing to terrestrial radiation and air movement. Temperature at various places on earth varies and is affected by the following factors

- **Latitude –** It is the angular distance north or south from the equator of a point on the earth's surface, measured on the meridian of the point. As one moves to north or south from the equator, the temperature decreases with increasing latitude. In the Indogangetic plain, the normal fall in the main temperature is estimated to be roughly 0.55° C for increase of each degree in latitude. (L S Khanna 1999 Principles and Practice of Silviculture)
- **Altitude –** Temperature is also a function of altitude. As altitude rises, there is fall in temperature.
- **Distance from the sea-** Sea has a moderating affect on temperature. The ranges of diurnal and seasonal variation of temperature become wider, as the distance of a place from the sea increases.
- **Winds-** The winds, particularly when blowing from the sea, affect the temperature. In India the south west monsoon brings rain and lowers the atmospheric temperature.
- **Mountains -** The location and orientation of mountain ranges interact with winds and rainfall and thus influence the temperature. The windward slopes of a mountain have lower temperature than the leeward side.
- **Forest Vegetation – A** forest with light crown cover and trees without foliage (Deciduous trees during the leafless season) allows the solar radiation to penetrate, but tend to reduce air movement relative to outside the forest. Under such condition the mean air temperature within the forest may be higher than the outside. On the other hand when trees are in full foliage, the extremes within the forest are generally less than outside, and the diminution of radiation within the forest may result in lower mean annual air temperatures. (Burton V Barnes et.al 1998 Forest Ecology)

2. **Effect of temperature**

Atmospheric temperature influences the activities of shoots of plants, while soil temperature influences those of their roots.

2.1 Air temperature

Solar radiation provides heat to the plant body. However plants regulate their temperature by dissipating part of the energy they absorb by three mechanisms namely, re-radiation, transpiration and convection. Through such adaptations, the plant maintains a heat balance with its environment.

- **Effect on growth –** As temperature increases, plant activities increase upto an optimum temperature and then decrease until, at very high temperatures, the plant dies. (Burton V Barnes et.al 1998 Forest Ecology). Temperature influences strongly the following growth processes –

- **Activity of enzymes** that catalyze biochemical reactions, especially, Photosynthesis and respiration
- Solubility of CO_2 and Oxygen in plant cells
- Transpiration
- Ability of roots to absorb water and minerals from the soil, and
- Membrane permeability

Since various growth processes demand different optimum temperatures, it is difficult to characterise the total growth or biomass production of a species by a certain optimum temperature.

- **Effect on microbial activity -** Increase in air temperature facilitates microbiological activity on soil surface, and consequently enhances decomposition of organic matter and release of nutrients to be available to trees.
- **Effect of germination of seeds –** Temperature is essential for germination of seeds.

2.2 Soil Temperature

Soil temperature has the following effects on vegetation

- Absorption of soil moisture by plants increases markedly with rise in temperature upto a certain limit. When soil temperature grows above 35^{o} C absorption of moisture starts declining. Again, when soil temperature falls below 27^{0} C, water absorption is greatly reduced till at 0^{o}C it becomes insignificant. (L S Khanna 1999 Principles and Practice of Silviculture)
- In temperate climate, soil temperature influences cambial activity.

2.3 Effect of excessively low temperature

In tropical region, temperature below 5^{o} C may cause chilling injury to plants. Such low temperature causes the injury by upsetting the carbon and water balance of plants. At very low temperature, loss of water by transpiration exceeds gain by absorption, and loss of carbon by respiration exceeds carbon gain by photosynthesis. Further fall in temperature results in frost and snow, which cause injury to trees and forest vegetation. Rapid freezing may cause death of plant tissues, particularly of actively growing plants and succulent tissues. Rapid thawing is also very harmful, causing certain changes that disrupt cell membranes.

2.3.1 Effect of Frost and snow

Injuries due to frost and snow have been described in **lesson 10 on Forest Protection**. The concerned lesson materials may please be referred to.

3. Moisture

Water and its availability across the surface of the earth, in the soil, and atmosphere have an enormous influence on the biota. Water is essential for various physiological activities of plants and for soil formation. Major storages of water on earth are ocean and atmosphere. Water is also stored in ground water, water bodies and plants. Atmosphere stores large amounts of moisture, most of which is in the form of vapour, and is referred to as **humidity.** Warm air is capable of holding more water than cold air. **Water holding capacity** is the amount of water that can be held by air, that is, the stage of humidity at saturation. **Relative humidity** is the percentage of water vapour to the total water holding capacity.

3.1 Essential Role of Moisture

- Water is a major constituent of plant cell. It constitutes about 80% of protoplasm which forms the basis of plant life.
- Water is present in cell vacuoles as cell sap and influences plant growth.
- Water is an essential material for photosynthesis.
- Water carries soil minerals to the plants and is essential for translocation of food.
- It is necessary for essential physiological functions of respiration and transpiration
- It is an important factor for germination and viability of seeds.
- Water is necessary for both physical and chemical weathering of rocks and minerals in the process of forming soil. Rocks and minerals undergo physical weathering and breakdown through heat, water, ice and pressure. Chemical weathering involves processes like acidification and dissolution in which water plays an important role.
- As water plays a vital role in the physiological processes of plant life and formation of soil, it has a significant influence on vegetation. Spatial humidity pattern coupled with soil water may play a major role in determining regional vegetation patterns. Trees tend to have leaf shapes, stomatal distributions, and stomatal characteristics that are suitable for the environments in which they grow. Water thus determines the tree species of a region, their density and growth, as well as those of other vegetation.

3.2 Source of Moisture

Sources of moisture that may be available to plants for their growth are as follows.

- **Precipitation –** water enters terrestrial ecosystem as precipitation. When a humid air cools too much it can no longer hold water. If sufficiently small, water drops remain suspended in air to form **clouds**. When the cloud is at or near the ground, it is called fog. When particles become large and too heavy to remain in the air, what results is **precipitation**. **Snow** is formed when the water particles are frozen. Again, at temperature above freezing point, precipitation occurs in the form of **rain**. Rain that freezes while falling through subfreezing layers of air becomes **sleet** or **hail**. If liquid precipitation freezes when it hits a surface, it forms **ice** or **glaze**.

- **Dew and hoar frost -** Water vapour may also condense directly onto a cool surface near the ground to form what is known as **dew, if the temperature is above freezing point.** If the temperature is below freezing, water vapour condenses to produce **frost, hoar-frost**, or **rime**.
- **Invisible condensation of moisture –** On clear nights, even in absence of dewfall, as water vapour slowly descends during afternoon and night, condensation of moisture on ground takes place. While such condensation is not visible as is dew, studies have revealed absorption by soil of such moisture.

3.3 Influence of rainfall on vegetation

Characteristics of rainfall in India and in the state of West Bengal have been dealt with in **Lesson 2 of Soil and Water Conservation**, which may please be referred to. Even as monsoons affect most part of the country, the amount of rainfall varies over a wide range from heavy to scanty in different parts. There is great regional and temporal variation in the distribution of rainfall. Over 80% of the annual rainfall is received in the four rainy months of June to September.

3.3.1 Areas of heavy rainfall (exceeding 2500 mm), like Western Ghat (windward side), north Bengal, upper Assam etc bear luxuriant vegetation known as tropical wet evergreen forest. In areas where rainfall is less (<2500 to > 900 mm), one comes across wet semi-evergreen, moist deciduous and dry deciduous forests. Again, in areas of lesser rainfall (< 900 mm), we find dry deciduous forest of poor quality and desert scrub vegetation.

3.3.2. It is not the amount of annual rainfall alone but **seasonal distribution of rainfall** also has a considerable effect on the vegetation of an area. Rainy months in a year vary from place to place. Seasonal distribution of rainfall, that is, the rainy months in a region have a great effect on the vegetation that grows in such region.

3.3.3 Rainfall intensity, that is, the rate at which the rain falls, is also an important factor to determine nature of vegetation, particularly in dry zone, which is under moisture stress. Rainfall of low intensity over a long period is more beneficial to plants of dry zone than the same amount of rainfall of high intensity. Low-intensity rain of long periods make more water available to plants, whereas a major part of high-intensity rain that persists for a shorter period is likely to be lost as runoff.

4. Wind

Wind has both beneficial and harmful effects on trees.

4.1 Beneficial effects

- Wind circulates fresh air within the canopy and thus provides a continuous supply of carbon dioxide for photosynthesis.

- Wind helps in dispersal of pollen and seeds. Wind-assisted dispersal of seeds occurs with many forest trees, e.g *Holoptelia, Bombax, Toona* etc.

4.2 Harmful effects

The earth's surface the wind sweeps over causes turbulence of wind. The rougher the surface, the more turbulent is the wind. Forests provide rough surface and thus wind over them is much more turbulent than over farmland or meadow. The turbulence produces sudden blasts of air or gusts. Each gust is associated with rapid increase of speed and downward movement of air into the canopy. The gusts exert much larger force than normal wind on the trees and cause damage. (Burton V Barnes et.al 1998 Forest Ecology)

4.2.1 Direct Harmful Effects

- **Windthrow** (uprooting of trees) is most apt to occur where the concentration of air currents causes high wind velocities at a particular spot (Burton V Barnes et.al 1998 Forest Ecology).
- Trees on forest edges, roads, and other open areas are more vulnerable to damage due to upper deflection of wind.
- In general, shallow rooted species, trees on shallow soils or with impeded damage suffer more from windthrow. The mass of soil adhering to the root system of a tree determine whether the tree is wind-firm. In other words, depth and spread of central core of roots and density of soil determine the wind-firmness of a tree. Tall trees with heavy crown are normally more susceptible to wind damage.
- When wind blows continuously in one direction, the trees get bent.
- When tree branches on the windward side get broken, the tree form becomes asymmetrical and growth is hampered.
- Strong gusts often rupture the timber.

4.2.2 Indirect harmful effects

- Wind may fan and intensify forest fire and extend the spread.
- Wind influences atmospheric humidity. Dry air reduces humidity and increases transpiration, which may adversely affect the plant growth.
- Wind increases loss of water by evaporation from the soil and over ground.
- In dry areas wind causes soil erosion.

Reference materials:

1. Burton. V Barnes et.al 1998 Forest Ecology, John Wiley & Sons, Inc.
2. L S Khanna 1999 Principles and Practice of Silviculture, Khanna Bandhu, Dehradun

Lesson 8

1 hour

Lesson Plan

Objective:

To study

- **Factors of Locality governing growth of forests (Continued)**
  - **Topographic factors**
    - Landform or configuration
    - Altitude
    - Slope
    - aspect
  - **Edaphic factors**
    - Soil
    - Soil formation
    - Soil Classification
    - Soil profile and horizons
    - Soil depth

Backward Linkage: Previous lessons and Lessons on Soil Science

Forward Linkage: Subsequent lessons

Training materials required: Copy of lesson 8 to be circulated beforehand

Allocation of Time:

Topographic factors	
- Introduction	3 mts
- Landform or configuration	4 mts
- Altitude	7 mts
- Slope	5 mts
- Aspect	5 mts
Edaphic factors	
- Soil	3 mts
- Soil formation	7 mts
- Soil Classification	5 mts
- Soil profile and horizons	6 mts
- Soil depth	5 mts
Discussion/Miscellaneous	10 mts

1. Topographic factors

Topography or physiography is the surface features, their form and substance, of a given regional or local area. Topographic factors may be defined as those relating to land form or configuration, e.g altitude, slope, aspect etc. Among the major ecosystem components, topography or physiography is the most stable component and least affected by human or natural disturbances. The topographic factors markedly influence the ecosystem functioning as they control local climate, soil formation process, soil moisture and soil nutrients which in turn influence the vegetation. We now discuss thevarious topographic factors.

1.1 Landform or configuration

A landform is defined as any physiographic feature on the earth's surface, such as a plain, valley, and hill etc., caused by erosion, sedimentation, or movement. (Burton V Barnes 1998). Land configuration or land surficial shapes and their parent materials modify the fluxes of solar radiation, soil water and nutrients and thus regulate establishment, distribution, growth and productivity of plants. For example, let us consider a newly exposed landform which offers different local climates on its sunny or shaded slopes. Based on their compatibility with temperature, humidity and soil, different plant communities colonize these different slopes. The plants in turn select the fauna that adapt with the microclimate of the different slopes. Further soils develop over time through interactions of land forms, local climate and biota. Interactions of all components through time result into similar ecosystem on similar landforms.

1.2 Altitude or Elevation

Altitude or elevation of a specific landform is important as it is a rough indicator of climatic factors affecting plants. It should be, however, borne in mind that climatic factors at a given altitude depend on latitude and many other factors that may have greater influence than elevation.

- **Solar radiation** – Solar radiation passes through lesser turbid atmosphere to reach places of higher altitude. Therefore, solar radiation increases with altitude.
- **Temperature** – With increasing altitude, air becomes rarer and progressively loses its capacity of absorbing and retaining heat. As a result, temperature drops with increase in altitude. Generally upto 1500 m, there is a fall of 1^0C in the mean temperature for a rise of 270m in the hills, but beyond 1500 m, the fall in temperature is more rapid. (L S Khanna 1999). Based on their response to temperature, various plant communities thrive at different altitudes. This results in altitudinal zonation in vegetation in hills.
- **Rainfall** – It has been estimated that half the water vapour in the air lies below 2000 m altitude and three quarters below 4000 m. A high mountain range acts as a barrier and

moves the humid air to ascend and get cooled. Cooling brings about condensation and results in precipitation. On a high mountain range the rainfall is more on the windward side. That is why, southern slopes of outer ranges of Himalayas receives heavy rainfall, whereas there is much less rainfall on the interior ranges of Himalayas. On the windward side of a mountain range, condensation starts at a certain level and continues up to an altitude beyond which air contains little water vapour to condense. Along the altitude there is a zone of maximum precipitation which is normally below the top of the ridge. On the Himalayas the zone of maximum precipitation is at an altitude of about 1220 m above sea level. Rainfall increases with altitude upto this height and then begins to decline. (L S Khanna 1999)

1.3 Slope

The slope gradient or the angle of repose of geologic material is expressed in degrees or in terms of percentage. The greater the slope, the greater is the surface per hectare or other unit area which is measured horizontally. That is why, good forest sites of moderate slope contain more trees and produce more yields per hectare than do comparable level sites (Burton.V barnes et.al 1998).

1.3.1 Compared to a site of gentle slope –

- A steep slope allows more rapid movement of water and snow, that is, greater runoff.
- A steep slope exhibits better drainage.
- A steep slope is fraught with greater danger of soil erosion, avalanche and mass soil movement.
- In general, have less soil depth and less humus content in the soil.

1.4 Aspect

Aspect is the orientation of the slope with regard to the sun's position. It determines the amount of insolation received by a hill slope. At any given latitude the hottest and the driest sites are those that most nearly face the sun's angle during the middle of the summer day, that is, receive more intense sunlight than any other. In India, all southerly aspects receive more sunlight than northern slopes and are therefore warmer. This is true in general in northern hemisphere, where north slopes receive less sunlight and are cooler and moister. The situation is of course reversed in the southern hemisphere. The difference in temperature on southerly and northerly aspects gives rise to different vegetation on such aspects in high altitudes. East and west slopes also exhibit variation in temperature, but the degree of variation is less extreme. East facing slopes are exposed to direct sunlight during the morning when the air temperature has not sufficiently warmed up, and are normally somewhat cooler and moister than west-facing slopes.

2. Edaphic factors

Edaphic factors are those related to the soil in which the plants grow. Among the primary resources that plants need for their growth and development, soil provides three major ones, namely, water, mineral nutrients and a porous medium for physical support. Thus edaphic factors, that is, soil characteristics which form the root environment are very crucial for plants and forest vegetation. It is suggested to go through the **lessons on Soil Science** while studying the topics on Edaphic factors.

2.1 Soil

Soil may be defined as a porous medium consisting of minerals, organic matter, water and gases. It is very diverse in nature. It is influenced by the local climate, the parent material or landform on which it develops and the plants that grow on it.

2.1.1 Soil has two major subdivisions

- **Surface soil or top soil –** It is the top layer which is almost completely weathered. It is rich in soluble material, organic matter and fine earth. It forms the zone of intense root and microbial activity.
- **Sub-soil** – It is the layer located below the surface layer. Partly weathered the sub-soil contains much less of soluble nutrients, organic matter and fine earth.

2.1.2 Soil Formation

Rocks and minerals are broken down on earth's surface to form soils by the process known as **weathering**. Rocks and geological sediments are the main parent materials of soils (the materials from which soils have formed). There is a very wide variety of rocks in the world, some acidic, some alkaline, some coarse-textured like sands, and some fine-textured and clayey. It is from the rocks and sediments that soils inherit their particular texture. Based on the agencies of weathering, the process of weathering is classified into three types, namely, Physical or Mechanical weathering, Chemical weathering, and Biological weathering. Often all these three processes work simultaneously.

2.1.2.1 Mechanical or physical weathering involves the breakdown of rocks and soils through heat, water, ice and pressure. It is an isochemical process because chemical properties of the rocks remain unchanged. Chemical weathering is the decomposition of rocks through a series of chemical processes such as acidification, dissolution and oxidation. Chemical weathering changes the materials that make up rocks and soil. **Biological weathering** is the weakening and subsequent disintegration of rock by plants, animals and microbes. **Please go through the Lesson 1 on Soil Science.**

2.1.2.2 Factors influencing soil formation

- **Climate** – Climate influences the weathering process in many ways. Among the climatic factors, the two most important elements that affect the soil formation are temperature and precipitation. These factors affect the physical and chemical weathering process and the most important effect that becomes manifest is the formation of clay minerals. Climatic also causes movement of clay and mineral salts etc. in the soil as rain water carries products of weathering from one place to other. Again through its impact on vegetation, climate governs the accumulation of forest litter on forest floor and their decomposition to form humus. Humus has a great impact on physical and chemical properties of soil.
- **Biological agencies** - Agencies of biological weathering are the flora and fauna available on a site. Plants cause both physical and chemical weathering. Growing plant roots disintegrate rocks. Again on the one hand by adding humus and nutrients to the soil and on the other by absorbing water and nutrients from the soil, plants affect the physical and chemical properties of soil. Different plant species tend to develop soils suitable for them. Similarly, animals play a significant role in soil formation. Termites and ants carry materials through layers; burrowing animals move rock fragments and facilitate weathering process.
- **Parent Rock** – Soil at a site inherits some of the important properties of the parent rock on which it has developed. Though the process of weathering brings about many changes in the soil, still the physical and chemical properties of the soil are largely determined by the parent material.
- **Topography** – Topography affects the local climate and the parent material. It modifies the local climate by affecting temperature, insolation, precipitation, wind, moisture etc. and thereby affects vegetation also. Topography modifies the parent rock by physical movement down the slope of weathered material in solid or dissolved state. Thus by affecting the climate and the parent material, both of which have impact on weathering, topography modifies the soil forming process.
- **Time** – Soil formation is a long and slow process. Based on the stage of development, soils are classified into immature and mature soil. **Immature soil** is the soil which has not reached the stage of development that might be expected under existing weathering and biological processes. **Mature soil**, on the other hand, is a soil which has reached the full development that might be expected under the existing weathering and biological processes and is in equilibrium with the environment. (L S Khanna 1999)

2.1.3 Classification of soils

Based on **place of development**, soils are classified into–

- **Sedentary soil** – soil formed from parent material insitu
- **Secondary soil** – soil derived from pre-existing soils by translocation and redeposition. Based on **agency of transportation**, secondary soil is further classified into–
  - **Alluvial soil** – a secondary soil derived essentially from flood plain material. Immature, without horizon, alluvial soil may have, however, strata owing to different materials deposited by water at different times.
  - **Aeolian soil** – a secondary soil transported and deposited by wind, e.g sand dunes, wind deposits of volcanic ash etc.
  - **Colluvial soil** – a secondary immature soil deposited by local erosion or slow downhill movement of soil.

2.1.4 Soil Profile and Horizons (Please see Lesson 1 on Soil Science)

As parent material weathers and gets colonized by flora and fauna during the soil formation process, it differentiates into more or less distinct **horizontal zones** giving rise to **soil profile.** In a forest ecosystem in moister parts of earth's regions, water gain by precipitation exceeds loss of water by evaporation and transpiration. Under such scenario, following two factors dominate the process of soil formation and development of soil profile.

1) The excess water infiltrates the ground and percolates through the soil removing soluble minerals.
2) Tree roots remove water and nutrients from soil; trees transpire most of the water and return most of the nutrients to soil surface as leaves, twigs, fruits, cones, fine roots etc.

Each soil attains a characteristic soil profile reflective of the environment where it develops.

2.1.4.1 Special Features of Soil Profile

Soil profiles sometimes exhibit following two special features–

- **Accumulation of Salts** – Sometimes some salts get deposited at or near the surface. Being harmful these salts make the site unproductive. The salts are mainly carbonates, chlorides, and sulphates of Sodium. Some calcium and Magnesium salts are also found sometimes. Accumulation of salts can occur due to many reasons, for example, excessive loss of water due to evaporation in dry areas, high water table, poor sub-soil drainage etc.
- **Pan formation** – Pan is a compacted or cemented soil horizon. Its formation is effected by materials like iron hydroxides, organic materials, silica, calcium carbonate etc.

2.1.5 Soil Depth

Soil depth is an important edaphic factor, because –

- It governs development of roots, and
- Influences the plant growth as soil depth determines quantity of available water and nutrients.

Soil depth at a site depends on local climate and topography. Generally, soils in hot and moist climates are deeper, as temperature and precipitation prevailing in such areas facilitate soil formation. Topography again controls transportation of soil, and affects soil depth. For example, soil depth in hilltops is much less than that in the valleys.

Reference materials:

1. Burton. V Barnes et.al 1998 Forest Ecology, John Wiley & Sons, Inc.
2. L S Khanna 1999 Principles and Practice of Silviculture, Khanna Bandhu, Dehradun
3. Lesson materials on Soil Science

Lesson 9

1 hour

Lesson Plan

Objective:

To study

- **Factors of Locality governing growth of forests (Continued)**
  - **Edaphic factors (continued)**

    Physical properties of soil

    Soil water

    Chemical properties of soil

    Soil Organic Matter

    Soil air

    Nitrogen Cycle

    Carbon-Nitrogen ratio

    Special features
  - **Biotic factors**

Backward Linkage: Previous lesson on edaphic factors, Lessons on Soil Science, Lessons on Forest Protection

Forward Linkage: Subsequent lessons

Training materials required: Copy of lesson 9 to be circulated beforehand

Allocation of time:

• Physical properties of soil	7 mts
• Soil water	12 mts
• Chemical properties of soil	5 mts
• Soil Organic Matter	4 mts
• Soil air	5 mts
• Nitrogen Cycle	11 mts
• Carbon-Nitrogen ratio	3 mts
• Special features	3 mts
• Biotic factors	5 mts
• Discussion/Miscellaneous	5 mts

Edaphic factors (Continued)

1. Physical properties of soil (Please see Lesson 2 on Soil Science**)**

As plant roots grow within the soil, they provide the mechanical support to the stem, and supply the plant with water and nutrients. Roots also need oxygen for respiration, which is controlled by the rate at which oxygen diffuses through water and other gases in the soil. Physical properties of the soil have substantial influence on supply of water, nutrients and oxygen for metabolism and on availability of physical space for anchorage of the stem. Physical properties of soil relate to its texture, structure, porosity etc.

1.1 Soil Texture.
(Please go through the Lesson 2 on Soil Science.)

Soil texture refers to relative proportion of sand, silt and clay-sized particles contained in a particular soil. This physical property plays an integral role in regulating – (1) availability of water and mineral ions for plant uptake, and (2) the rate at which gases (O_2 and CO_2) are exchanged between soil and overlying atmosphere (Forest Ecology by Burton V Barnes et.al).

1.2 Soil Structure
(Please go through the Lesson 2 on Soil Science.)

Soil structure is the arrangement and binding together of soil particles into larger clusters, called **aggregates or peds.** Aggregation is important for increasing stability against erosion, for maintaining porosity and soil water movement, and for improving fertility and carbon sequestration in the soil. (Source: Soil and Water Management Module I, Montana State University)

1.3 Porosity
(Please go through the Lesson 2 on Soil Science.)
Porosity is the fraction of the total soil volume that is taken up by pore space. Thus it is a single value quantification of the space available to fluid within a specific body of soil. Typical values for soil porosity are between 0.3 and 0.7 (Porosity and Pore Size Distribution by J.R Nimmo, US. Geological Survey at wwwcamnl.wr.usgs.gov.). An important soil characteristic, porosity determines the moisture and air relations of the soil. It affects internal drainage and diffusion of soil air.

2. Soil Water
(Please go through the Lesson 2 on Soil Science.)
The main source of water in a forest ecosystem is precipitation in the form of snow and rain. Although broad-scale pattern of precipitation controls the total amount of water entering

forest ecosystems, it is the interaction of water molecules with soil particles that largely influence the amount of water that can be used by an individual plant for growth (Forest Ecology by Burton V Barnes et.al). Water flows along a continuum extending from the atmosphere, through the plant and into soil. **Please see hydrological cycle in the Lesson on Soil and Water Conservation**.

2.1 Soil texture and properties dependent on texture, like porosity, control the movement of water and air in the soil, which in turn affect use of water by plants and their growth. As soil becomes dry or wet, the proportion of pore space occupied by water and by air varies. Water is available in the soil in two places – (1) in deeper layers and underlying rocks, and (2) in upper layers of the soil.

- **Ground water -** water available in deeper layers and underlying rocks. Sometimes ground water, under the influence of capillary force, rises to a certain height, and is known as **capillary fringe**.
- **Water in upper layers –** available as **gravitational water, capillary water or hygroscopic water**.

2.2 Ground water – Rain water having infiltrated into the soil percolates down through pores and cracks until it is stopped by an impervious strata or rock. The **body of water** that gets accumulated above the impervious layers and completely fills the pore space up to a level is referred to as **ground water**. The zone occupied by ground water is referred to as zone of saturation; and the upper surface of zone of saturation of soil by ground water is referred to as **water table** (L S Khanna 1999). The **depth of water table** depends on varieties of factors like climate, geology and topography. The depth of water table fluctuates under the influence of different processes that affect gain or loss of soil water, like precipitation, evaporation, transpiration, spring flow etc.

2.2.1 Capillary fringe – Under the force of capillary action water rises above the water table. The extent of rise depends on the physical properties of the soil. For example, capillary fringe is nil for gravels, upto 1 metre in sandy soils, and upto 2.5 metre in clayey soils (L S Khanna 1999). If the water table is very deep, ground water may not be available to the plants. If the depth of water table is within 5 to 10 metres, and the capillary fringe brings water to a depth of few metres from the surface, plants can absorb the water with the help of their root system which lies in the upper layers of the soil. **While deep water table does not facilitate plant growth, very high water table also causes injury**. Very high water table which is normally accompanied by inadequate soil drainage creates a condition known as **waterlogging** when the soil pores get filled with water to the exclusion of air. The condition of waterlogging cuts off the supply of oxygen to plant roots, and continuous or prolonged waterlogging may cause mortality of plants.

2.3 Gravitational water – It is defined as the water in the soil body in excess of the capillary capacity (L S Khanna 1999). It usually fills the macro pores (> 0.05 mm diameter) and moves down in conditions of free drainage under the force of gravity. While remaining in pores in the plant root zone in its downward movement, gravitational water becomes available to plants. However, as it drains out from the upper layers in a couple of days, gravitational water can hardly facilitate plant growth. If gravitational water remains longer in soil pores, it will lead to the condition of water logging.

2.4 Capillary water - It is defined as the water that is retained around the soil particles and the capillary pores (< 0.05 mm diameter) in the soil. Capable of moving under surface tension capillary water is the main source of supply of moisture to plants, or plant available water (PAW). [**Please see Lesson 2 on Soil Science**]

2.5 Hygroscopic water – It is defined as that portion of soil water which is retained as a thin film by the soil particles after capillary water has been removed**.** It is not available to plants (L S Khanna 1999).

3. Chemical Properties of Soil

Chemical properties of soil – cation exchange capacity, soil pH – have been described in details in Lesson 2 and 3 on Soil Science. Please go through those lessons.

4. Soil Organic Matter (SOM)

SOM has been dealt with in Lesson 3 on Soil Science. The said lesson on Soil Science may please be gone through.

5. Soil Air

Soil pores are filled with water and air in inverse proportion. It means greater the water content in pores, the lower is the amount of air, and vice versa. Unless the soil is waterlogged, non-capillary or macro pores are normally filled with air; capillary or micro pores are filled with varying amount of air depending on water content. **Soil air is defined as the combination of gases in the gaseous phase in the soil** (L S Khanna 1999)**.** Compared to atmospheric air, soil air has a larger proportion of CO_2 and water vapour.

5.1 Soil Aeration

When the water content in soil pores increases, air is expelled into the atmosphere and air content in pores is reduced. Again, when water content reduces due to downward movement of gravitational water or drying up of the soil, air is sucked in. Thus there is a continuous exchange of soil air with atmospheric air. **Soil aeration is the process by which air and other**

gases in the soil are renewed (L S Khanna 1999). Soil aeration depends on soil structure and amount of water in the soil. Good soil aeration favours root growth and survival of plants.

6. Nitrogen Cycle

(http://apcentral.collegeboard.com/apc/public/repository/nitrogen-cycling-in-ecosystems.pdf, L S Khanna 1999)

Nitrogen constitutes about 25% of dry weight of plants and is a very important mineral nutrient. Nitrogen is continually moving back and forth between soil, plants and animals. **This continual transfer of Nitrogen from the abiotic (non-living) part of the ecosystem to the biota (living part) and back again is called Nitrogen cycle.** We discuss here some processes that are involved in Nitrogen cycle in an ecosystem.

6.1 Nitrogen Fixation: Nitrogen Fixation is the conversion of atmospheric nitrogen (N_2) into reactive compounds such as ammonia (NH_3) and nitrate (NO_3^-). The breaking of the bonds between the nitrogen atoms requires a great deal of energy and occurs naturally in two primary ways:

(i) Abiotic Fixation: Nitrate is the result of high energy fixation in the atmosphere from lightning and cosmic radiation. In this process, N_2 is combined with oxygen to form nitrogen oxides such as NO and NO_2, which are carried to the earth's surface in rainfall as nitric acid (HNO_3). This high energy fixation accounts for approximately 10% of the nitrate entering the nitrogen cycle.

(ii) Biological fixation: Biological fixation is accomplished by a series of soil micro-organisms such as aerobic and anaerobic bacteria. Often, symbiotic bacteria such as Rhizobium are found in the roots of legumes and provide a direct source of ammonia to the plants. In root nodules of these legumes, the bacteria split molecular nitrogen into two free nitrogen atoms, which combine with hydrogen to form ammonia (NH_3). The breakdown of these legumes by bacteria during ammonification actually returns excess nitrogen not utilized by the plant to the surrounding soil. Some free-living aerobic bacteria, such as Azotobacter, and anaerobic bacteria, like Clostridium, freely fix nitrogen in the soil and in aquatic environments. Some members of the photosynthetic Cyanobacteria phylum fix nitrogen in aquatic environments as well.

6.2 Nitrification: Nitrification is the process by which ammonia is oxidized to nitrite ions (NO_2^-) and then to nitrate ions (NO_3^-), which is the form most usable by plants. The two groups of microorganisms involved in the process are Nitrosomonas and Nitrobacter. Nitrosomonas oxidize ammonia to nitrite and Nitrobacter oxidize nitrite to nitrate.

6.3 Loss of Soil Nitrogen: Nitrogen is lost from the ecosystem on account of various factors like (i) leaching by rain water, (ii) denitrification, described below, (iii) crop removal and (iv) forest fire.

6.3 Assimilation: Nitrates are the form of nitrogen most commonly assimilated by plants through root hairs. Since heterotrophic organisms cannot readily absorb nitrogen as plants do, they rely on acquiring nitrogen-based compounds through the food they eat. Since plants are the base of the food chain, the nitrogen-based compounds they have assimilated into their tissue will continue to pass from one organism to another (through consumption) as matter and energy transfers through the ecosystem's food web.

6.4 Ammonification: In ammonification, a host of decomposing microorganisms, such as bacteria and fungi, break down nitrogenous wastes and organic matter found in animal waste and dead plants and animals and convert it to inorganic ammonia (NH_3) for absorption by plants as ammonium ions. Therefore, decomposition rates affect the level of nutrients available to primary producers.

6.5 Denitrification: Denitrification is the process by which nitrates are reduced to gaseous nitrogen (N_2) and lost to the atmosphere. This process occurs by certain bacteria in anaerobic environments. Waterlogged fields and soils that have high clay content are especially vulnerable to nitrogen losses due to denitrification.

6.6 Operation of the cycle

It has been described above how nitrogen undergoes transformation through various processes.

6.6.1 Source of soil Nitrogen

Nitrogen is contributed to soil by the following processes –

- Nitrogen fixation (atmospheric Nitrogen) – abiotic and biological, and
- Ammonification – fixation from organic matter.

6.6.2 Conversion to usable form

Fixed Nitrogen is converted into forms usable by plants (primary producers) through the process of **Nitrification.**

6.6.3 Consumption by biota

Except for what is lost from the soil, Nitrogen in usable form is consumed by plants and animals through **Assimilation**.

6.6.4 Return to abiotic environment

From plants and animals (living part of ecosystem) Nitrogen goes back to soil and atmosphere through Ammonification. Nitrogen which is returned to soil or air again goes through the cyclic process and becomes available to plants. Thus a regular cycle of Nitrogen continues in nature.

7. Carbon-Nitrogen Ratio

Carbon-Nitrogen ratio (C/N ratio) is defined as the ratio of the weight of organic carbon to the weight of total Nitrogen in a soil, or organic material. The ratio is a measure of nitrate status of soil. The lower the ratio, the greater is the amount of Nitrogen converted into ammonia and finally into nitrates to be available to plants (L S Khanna 1999).

8. Special features of Edaphic factors

- While climatic factors determine the broad nature of vegetation, edaphic factors determine the inner details. That is, in a broad spectrum of vegetation determined by the prevailing climate, occurrences of particular group of species at various places are governed by the edaphic factors.
- While climatic and topographic factors are beyond the control of foresters, edaphic factors can be manipulated, to varying extent, to suit particular group of vegetation and to enhance forest productivity.

9. Biotic factors

Besides the climatic, topographic and the edaphic factors, the forest vegetation is also subject to influences by living organisms including plants, animals and humans. The statuses of forest vegetation, particularly the disturbance features, depend greatly on how such forest is impacted by the biotic elements. Biotic factors are defined as the influence of living organisms (L S Khanna 1999). Biotic factors interact directly with the vegetation and also influence the latter by virtue of their impact on soil. Influence of biotic factors can be described under the following categories.

- Influence of plants
- Influence of animals – domestic and wild
- Influence of insects
- Influence of humans.

From the foresters' point of view, the above categories of influences should be seen in the context of disturbance to forest ecosystem or in terms of injuries they cause. The above disturbances and the respective preventive and protective measures have been dealt with in great details in the **Lessons on Forest Protection**, which may please be gone through.

Reference materials

1. Burton. V Barnes et.al 1998 Forest Ecology, John Wiley & Sons, Inc.
2. L S Khanna 1999 Principles and Practice of Silviculture, Khanna Bandhu, Dehradun
3. Lesson materials on Soil Science
4. Lesson materials on Forest Protection

Lesson 10

1 hour

Lesson Plan

Objective:

To study

- **Plant Succession**
    - Basic Concept
    - Definition
    - Types of Succession
    - Key characteristics of plant succession
    - Causes of succession
        - Initial causes
        - Continuing causes

Backward Linkage: Lesson 13 of Forest Botany

Forward Linkage: Lesson 11

Training materials required: Copy of Lesson 10 to be circulated beforehand

Allocation of time:

Plant Succession	
➢ Basic Concept	12 mts
➢ Definition	3 mts
➢ Types of Succession	10 mts
➢ Key characteristics of plant succession	14 mts
➢ Causes of succession	
Initial causes	6 mts
Continuing causes	5 mts
Discussion/Miscellaneous	10 mts

1. Plant Succession - basic concept

The topic of plant succession has been dealt with in **Lesson 13 of Forest Botany.** The said lesson of Forest Botany may please be gone through while studying this lesson. It has been described in the previous lessons that vegetation in a locality is determined by the locality factors prevailing in that locality. The plant community in a given locality and the locality factors are mutually interactive and they influence each other. As a result, the site factors undergo change and allow colonization of new plant community which eventually replaces the original community. The new plant community also changes in composition with the change of habitat. This process continues over time. For example, we may consider the case of riverine succession. Immediately after the disturbance of flood, the sandy soil along the river bank is barren. Slowly the barren sandy soil is colonized by grass. As the grass cover arrests silt, and grass leaves, on decay, add organic matter to soil, the soil properties undergo change; soil fertility increases. The improved soil condition invites and allows a few hardy tree species to colonize. The species that colonize at the initial stage, called the **pioneer species**, are hardy and tolerant of still-inhospitable conditions.

1.1 Individuals of pioneer species appear gradually and form a plant community. The plant community, through its growth and colonization, continues to impact the site factors. The soil receives more silt and organic matter. Soil moisture regime improves. The tree canopy moderates air temperature inside forest as also soil temperature. These changed conditions become suitable for colonization of less hardy species. Arrival of new species, competition for survival among the species, and continuing change of locality factors and consequent improvement brings about gradual changes in the plant community. Each stage creates the conditions for the next stage. Temporary plant communities are replaced by more stable communities until a sort of equilibrium is reached between the plants and the environment. This process is called **plant succession**.

2. Definition

Plant succession is defined as a progressive alteration in the structure and species composition of vegetation. According to another definition, plant succession is the directional change with time of the species composition and vegetation physiognomy of a single site. (Burton.V Barnes et. al 1998)

3. Types of Succession

Succession is classified in two ways:

(1). On the basis of presence or absence of vegetation
(2). On the basis of moisture condition of the site

On the basis of presence or absence of vegetation, plant succession is classified into

- **Primary Succession –** It is defined as the succession that occurs on previously unvegetated terrain and proceeds in absence of catastrophic disturbance. Primary succession is an **autogenic process,** that is, a process caused by endogenous factors (plant driven). In other words, successive changes in plant community are brought about by the plants themselves on the site.

- **Secondary Succession –** It is the succession that follows a disturbance to an existing forest, disrupting ecosystem processes, and destroying existing biota. Secondary succession is known as an **allogenic process,** which means a process caused by exogenous factors. In other words, the process is driven by periodic disturbances, independently of the plants themselves.

It may be mentioned that the above classification is a classical concept, and often the distinction between primary and secondary succession is not real, and the causal factors do not fit strictly into autogenic or allogenic category.

On the basis of moisture condition of the site, plant succession is classified into **Xerarch** and **Hydrarch** succession. The unvegetated sites on which primary succession begins range from pure mineral material (rock, soil, or detritus) to water. However, mixtures of soil and water are the most favourable for plant colonization and growth.

- **Xerarch Succession –** Primary plant succession beginning with dry rock material (either as rock or as mineral soil) is called xerarch succession. The successional stages of this succession are called **Xeroseres**.
- **Hydrarch Succession –** Primary plant succession that begins with water is termed a hydrarch succession. The various stages of this succession are called **Hydrosere**.

There is another category called **Mesarch Succession,** meaning a succession which begins with moist but aerated soil.

4. Key characteristics of Plant Succession

Plant succession is essentially the change in vegetation in a fixed site with changing time. The key characteristics that determine the direction and pace of succession are broadly described below.

(1). Following disturbance, a substrate is available for colonization and growth by organisms. For primary succession, it could be a new land (unvegetated); for secondary succession it could be a disrupted forest or a site which is more or less vegetated.
(2). Species from the surrounding areas or from the site itself (in case of disrupted forest site) occupy the disturbed site in many patterns and temporal sequences.
(3). The invading plants may die or get established and develop on the site.
(4). Establishment and development of any plant is largely influenced by plant interactions and competition.

(5). Even as the plants continue to change the site conditions (light, temperature, soil properties and processes), the latter, in turn may or may not affect them over time in their continuing interactions with other plants and animals.

(6). Multiple disturbances that are ecosystem specific in kind, frequency, and severity may modify all the above processes with differential effects through time.

(7). Over time, some species persist, thrive and become dominant in their time, whereas others drop out or diminish in the short or long run.

(8). The nature and rate of change depends on the spatial and temporal scales under study, the site conditions of regional and local ecosystems, species' life history traits and regeneration strategies, disturbance regimes and other miscellaneous factors.

5. Causes of Succession

[(L S Khanna 1999 Principles and Practice of Silviculture); (A. B Lal, 1967 Indian Silviculture)]
Causes of succession may be classified under two categories, namely, **initial causes** and **continuing causes.**

5.1 Initial causes – Initial causes are those which provide the basis for succession to take place. In case of primary succession, they are responsible for creation of a new soil, while in case of secondary succession, they are responsible for making the soil bare.(L S Khanna 1999).

5.1.1 Initial causes of Primary Succession

1. **Erosion:** Wind and water erode the soil and deposit it elsewhere. Thus new soils are created in the form of alluvial deposits, coastal sands, estuarial deposits, sand dunes etc.
2. **Physiography:** The configuration of the land surface helps the agents of erosion, i.e. wind, water and gravity to create new soils.
3. **Elevation and subsidence:** Seismic disturbances cause elevation and subsidence of the soil resulting in formation of new soils. For example, geological disturbances in the Himalayas result in the formation of new soil for primary succession.

5.1.2 Initial causes of Secondary succession

1. **Climate:** Climate becomes the initial cause when the vegetation is destroyed by the action of drought, wind, snow or frost. For example, a part of a forest may suffer mortality due to drought , or trees over an area may be uprooted by wind. If left to itself, secondary succession will start on such area laid bare.
2. **Physiography:** Physiography becomes the initial cause when land configuration, coupled with other factors, is responsible for destruction of vegetation, e.g. land slide on a steep slope destroying a forest.
3. **Biotic factor:** Biotic factor is the initial cause where a forest is destroyed by the activity of man, his animals, or wild animals,eg., heavy grazing, cutting, burning, etc.

5.2 Continuing causes

Continuing causes are those which facilitate development of plant communities and their eventual replacement by other plant communities. Thus while initial causes create suitable conditions to begin succession, continuing causes help formation and subsequent alteration of plant communities. Continuing causes are –

1. **Migration:** Mass movement of plants from one place to another is called migration. It begins when germule (spore, seed, fruit or plant) leaves the parent area and reaches the final resting place. This depends upon the degree of mobility of their seeds or their germinating parts, nearness of the parent area, topography, etc.
2. **Ecesis or establishment:** It is the whole process whereby a plant establishes itself in a new area from germination or its equivalent (eg., rooting of some detached portion) to reproduction whether sexual or asexual. Species' establishment on a new area can only be accomplished when the seeds germinate, which depends on the condition of seeds and sites.
3. **Grouping and aggregation:** Aggregation is defined as grouping, following establishment of scattered colonizing invaders as a result of propagation. The colonizers invade new areas gradually. The immigrants after establishment grow while more migration takes place. Thus in course of time, the colonizers make a closed canopy.
4. **Competition:** It is the struggle for available food, light and moisture, among the species and individuals in a plant community. Competition is especially more intense among the individuals of the same species, as their demands are similar. In the process, weaklings are left behind in the struggle for existence, and they drop out.
5. **Reaction:** The effect of vegetation on site is called reaction. It is the most important driver of succession. Reaction can be grouped into two classes: (i) Effect on climatic factors, and (ii) Effect on soil

(i) Effect on climatic factors: Vegetation affects climatic factors by:

(a) Altering the light conditions – light incident on the floor of the new site is reduced as the colonizing species form canopy.

(b) Decreasing the air temperature and diurnal fluctuation

(c) Reducing the wind velocity and thus lessening evaporation from surface soil

(d) Reducing danger of radiation frost due to presence of leaf canopy.

(e) Increasing relative humidity

(ii) Effect on soil: The vegetation affects the soil by:

(a) Addition of organic matter in the form of leaf fall which on decomposition releases nutrients in respect of which bare soil was deficient.

(b) Improving the structure of the soil

(c) Increasing the colloidal complex, both of organic and inorganic origin, thereby improving moisture retentively of the soil.

(d) Improving the stability of the soil by the binding action of the roots.

(e) Development of maturity of soil under the combined action of climate and vegetation.

Reference materials

1. Burton. V Barnes et.al 1998 Forest Ecology, John Wiley & Sons, Inc.
2. L S Khanna 1999 Principles and Practice of Silviculture, Khanna Bandhu, Dehradun
3. A.B Lal 1967 Indian Silviculture, Jugal Kishore & Company, Dehra Dun.
4. Lesson materials on Forest Botany.

Lesson 11

1 hour

Lesson Plan

Objective:

To study

- **Plant Succession**
  - Theory of Succession
  - Clementsian Succession
  - Flaws in Clements' model
  - Climax
    - Climatic climax
    - Edaphic climax
    - Preclimax
    - Bioticclimax or Subclimax
  - Importance of study of plant succession

Backward Linkage: Lesson 10

Forward Linkage: Subsequent lessons

Training materials required: Copy of lesson 11 to be circulated beforehand

Allocation of time:

- Theory of Succession — 5 mts
- Clementsian Succession — 20 mts
- Flaws in Clements' model — 5 mts
- Climax — 15 mts
  - Climatic climax
  - Edaphic climax
  - Preclimax
  - Bioticclimax or Subclimax
- Importance of study of plant succession — 5 mts
- Discussion/Miscellaneous — 10 mts

1. Theory of Succession

A general theory of plant succession and foundations of plant ecology as a study of vegetation dynamics were initiated by Henry C. Cowles. In 1911, Cowles noted that the original plants in any habitat give way “in a somewhat definite fashion to those that come after.” He also recognized that changes in vegetation caused by climatic, topographic, and biotic changes occurred concurrently, at different rates, and at times in different directions. (Burton.V.Barnes et al 1998).

1.1 It was Frederic E. Clements who presented an elaborate philosophical structure of plant succession (1916, 1949) that attempted to systemize and formalize all eventualities of plant community change.
He developed a complex nomenclature and introduced some terms that persisted with time.

1.2 Clementsian Succession

[http://www.uwyo.edu/vegecology/pdfs/readings/clements_plantsuccession%5B1%5D.pdf]
In Clements’ view, plant community is an organic entity having attributes describable in terms of an individual. As an organism, the climax formation arises, grows, matures and dies. The life history of a climax formation is a complex but definite process, comparable in its chief features with life-history of an individual plant.

1.2.1 The most striking feature of succession is the movement of populations, the waves of invasion, which rise and fall through the habitat from initiation to climax. These are marked by a corresponding progression of vegetation forms from lichens and mosses to the final trees.

1.2.2 Clements described the essential processes in the development of climax formation as follows.

Every sere[1] must be initiated, and its life forms and species selected. It must progress from one stage to another, and finally must terminate in the highest stage possible under the climatic conditions present. Thus succession is readily analyzed into initiation, selection, continuation and termination. A complete analysis, however, resolves these into the basic processes of which all but the first are function of vegetation, namely (1) **nudation**, (2) **migration**, (3) **ecesis**, (4) **competition**, (5) **reaction**, (6) **stabilization**. These may be successive and interacting. They are successive in initial stages, and they interact in most complex fashion in all later ones.

[1][Sere is the series of plant communities resulting from process of succession or any recognizable stage in plant succession.]

1.2.3 According to Clements, the essence of succession lies in the interaction of three factors, namely, habitat, life-forms and species in the progressive development of a formation. In this development habitat and population act and react upon each other, alternating as cause and effect until a state of equilibrium is reached. Succession may be regarded as the development or life-history of the climax formation. All the stages that precede the climax are the stages of growth. They have the same essential relation to the final stable structure of an organism that seedling and growing plant have to the adult individual. As an adult plant repeats its development, when conditions permit, in like fashion, a climax formation may repeat every one of its essential stages of growth in a primary area, or it may reproduce itself in its later stages, as in secondary areas.

1.2.4 The progressive invasion typical of succession everywhere produces stabilization. Stabilization is increase in dominance culminating in a stable climax. It is the mutual and progressive interaction between the habitat and the community by which extreme conditions yield to a climatic optimum, and the life-forms with the least requirements are replaced by those which make the greatest demands, at least in the aggregate. The essential cause of stabilization is dominance. Dominance is the ability of a characteristic life-form to produce a reaction sufficient to control the community for a period. Initial life-forms like algae, lichens, mosses are characteristic but not dominant. The essential difference between the initial and final stages of succession lies in the fact that while both react upon the habitat, the reaction of the one invites the invaders, that of the other precludes them. The reaction of the intermediate stages tends to show both effects.

1.2.5 At the initial stage, reaction is slight, and aggregation of the occupants is favoured. Then the reaction becomes more marked and produces conditions more and more favourable to invasion. However, when the reaction is distinctly unfavourable to the occupants, the next stage develops with greater rapidity. Reaction is thus the cause of dominance, as well as of the loss of dominance. Thus a community develops, dominates for a period only to be replaced by another, and a stage able to maintain itself as a climax finally appears.

1.2.6 The end of the process of stabilization is climax. Each stage of succession plays some part in reducing the extreme condition in which the sere began. It reacts to produce increasingly better conditions favourable to the growth of a wider range of species.

1.2.7 According to Clements' model, the process of succession is orderly, predictable and therefore deterministic. In stabilization, the end point of a given succession is reached as the **climax** formation or association, the "adult organism" is attained. The climax dominants modify their environment such that they perpetuate themselves and are the community of maximum stability (i.e. resisting change) and self-perpetuation.

1.2.8 Flaws in Clements' model

- A critical flaw was Clements' analogy of community and organism that led to the concept of the climax as an "organic entity". (Burton.V Barnes et.al 1998)
- He also assumed that all primary successions in a climatic region eventually converged to the same climatic climax from multiple starting points. The term **mono-climax** is therefore applied to his conceptual model (Burton.V Barnes et.al 1998). Clements' mono-climax theory has been challenged by many scientists. If accepted, the mono-climax theory would mean that in a given general climate, if the disturbing factors are removed for a long time, the whole landscape of that given climate will be covered with a uniform plant and animal community, which is not possible.
- In Clements' mono-climax theory, macro-climate was the dominant community-forming factor, whereas other factors (physiography, soil, fire, biota) were of secondary importance. Based on the argument that other factors are of equal importance, many scientists have theorized a different climax community for different physiographic settings, soil types and disturbing factors. This is the **polyclimax** theory which holds that for any combination of environment and organisms, biotic succession will take place toward a climax, but that the specific nature of the climax will vary with the specific environmental factors and biotic conditions. (Burton.V Barnes et.al 1998)

2. Climax

The question of climax, that is, what the last stage of succession is, if any, has been a subject of discussion and debate. Because climax terminology has found place in the literature, it is necessary to know how the climax terms are used. Based on what has been described herein before, the definition and concept about climax terminology is furnished below.

2.1 Climatic climax

(L.S.Khanna 1999 principles and Practice of Silviculture)

It is the climax which owes its distinctive characters to climatic factors in conjunction with only such biotic influences as plants and animals naturally occurring in the area.

Sal is a climax in the following subtypes:

(a) North Indian Tropical Moist Deciduous Forests/ Moist Siwalik Sal forest (subtype 3C/C_{2a});

(b) North Indian Tropical Moist Deciduous Forests/ Moist peninsular sal (subtype 3C/C_{2c})

2.2 Edaphic Climax

It is defined as a community which differs from the climatic climax of the area owing to the influence of special soil factors. In other words, within the general climatic climax, there may be characteristic vegetation locally due to the influence of soil characters.

2.3 Preclimax

Preclimax is the plant community immediately preceding, in seral development, the climatic climax of the region and found under conditions drier than are usual in the climate of the region.

2.4 Post Climax

It is defined as a plant community more exacting than the climatic climax of a given region and found under exceptionally favorable site conditions within that region. It actually occurs on sites very much moister than the normal sites in that climatic region.

2.5 Biotic Climax or subclimax

It is a climax which differs from the climatic climax of the area owing to the action of biotic factors. Subclimax represents vegetation whose development toward climatic climax has been arrested at some stage by factors, natural or artificial, other than climatic.

3. Importance of study of Plant Succession

The study of plant succession is useful in the following context.

- Classification of forests into forest types – stage of development in succession is one of the factors to classify forests into types.
- Choice of species for plantation – study of the seral stage and the habitat will help in selection of species that will be favoured under the prevailing site factors.
- Obtaining the succession stage which provides economically valuable crop – Knowledge of succession helps to determine the stage when dominant crop consists of economically valuable species. If necessary and possible under the prevailing conditions, forest managers may try to obtain a biotic climax of valuable crop through suitable management practices.

Reference materials

1. Burton. V Barnes et.al 1998 Forest Ecology, John Wiley & Sons, Inc.
2. L S Khanna 1999 Principles and Practice of Silviculture, Khanna Bandhu, Dehradun
3. A.B Lal 1967 Indian Silviculture, Jugal Kishore & Company, Dehra Dun.
4. Lesson materials on Forest Botany.

Lesson 12

1 hour

Lesson Plan

Objective:

To study

- **Forest types**
  - Basis of classification
  - Definition of forest type
  - Object of classification
  - Forest types of India
  - Forest types of West Bengal

Backward linkage: Lesson 10 and 11 on plant succession and climax.

Forward linkage: Subsequent lessons on forest types

Training materials required: Copy of lesson 12 to be circulated beforehand.

Allocation of time:

Basis of classification	5 mts
Definition of forest type	5 mts
Object of classification	5 mts
Forest types of India	10 mts
Forest types of West Bengal	25 mts
Discussion/Miscellaneous	10 mts

1. Basis of Classification of forests

The nature and composition of a forest is determined by the environmental factors under the influence of which the forest grows. One or two of these factors can be the basis for classification of the forest. Some of the criteria for classification are described below.

- **Classification based on vegetation** – This mode of classification is based on the study of plant communities.
- **Classification based on climate** – There are many ways of classifications under this mode. Some are based purely on temperature, while some others are based on temperature coupled with other factors like latitude, altitude, rainfall etc.
- **Classification based on ecosystem –** This system of classification gives sufficient weightage to both vegetation and climate. The forest types of India, as originally suggested by Champion (1936) and further revised by Champion and Seth (1968) are based on this system of classification.

2. Definition of Forest Type

Forest type means a category of forest defined with reference to its geographical location, climatic and edaphic features, composition and condition. Champion and Seth define it as a unit of vegetation which possesses (broad) characteristics in physiognomy and structure sufficiently pronounced to permit its differentiation from other such units. (L S Khanna 1999 principles and Practice of Silviculture)

3. Object of Classification

As forests vary from place to place, one single set of management practices cannot have universal application. It is therefore necessary to classify forests into types so that suitable management practices can be evolved for each type, and practices suitable for one type may be applied to forests of similar types. Thus classification is an important tool to identify and prescribe appropriate silvicultural and management practices in the field.

4. Forest Types of India

In 1936 Champion suggested provisional forest types for India based on locality factors like climate, topography, soil and biological factors. Taking into consideration additional information, Champion and Seth revised the earlier classification in 1968, and recognized five major types:

1) Tropical forests;
2) Montane subtropical forests;
3) Montane temperate forests;
4) Sub-alpine forests;
5) Alpine scrub.

4.1 The major types described above have been further divided into **type groups** or, simply, **groups** on the basis of climatic data and vegetation. The division is shown below.

1) Tropical forests – divided into **7 groups**
2) Montane subtropical forests - divided into **3 groups**
3) Montane temperate forests - divided into **3 groups**
4) Sub-alpine forests - divided into **1 group**
5) Alpine scrub - divided into **2 groups**

The **type groups** are further differentiated into number of **sub-groups** depending on whether the forest is situated to the north or south of Tropic of Cancer, or in eastern or western Himalayas. Each **sub-group** is again divided into **types** in which **climax formations** have been designated by letter **C, edaphic climax formation** by letter **E**, **primary sere** by **1S**, and **secondary sere** by **2S.** Within each subgroup, the types are given in serial number, like C_1, C_2, E_1, E_2 and so on. These types are differentiated into subtypes by suffixing letters a, b, c and so on.
Following is an example of representation of forest type:

3C/C_{1a} means a forest belonging to

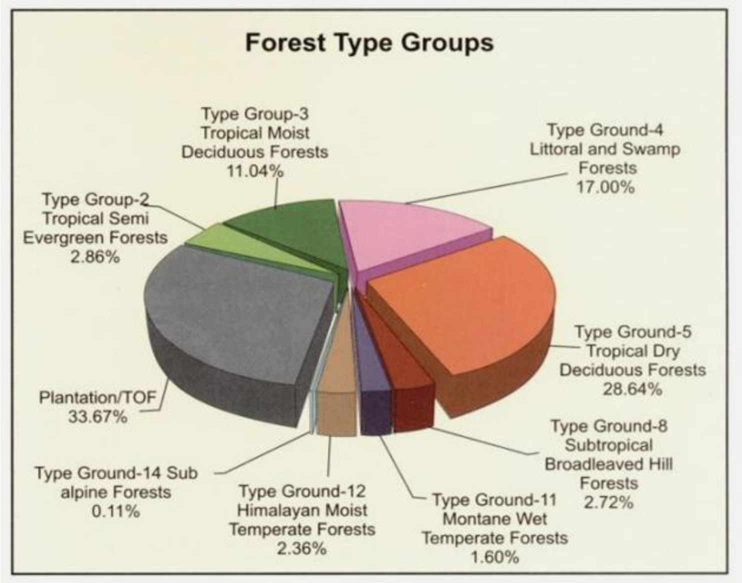
Group 3 – Tropical Moist Deciduous Forests
- **Sub-group 3C – North Indian Tropical Moist Deciduous Forests**
  - **Type 3C/C_1 – Very moist Sal-bearing forests**
    - **Subtype 3C/C_{1a} – Eastern hill Sal forest.**

5. Forest Types of West Bengal

According to assessment made by Forest Survey of India (State of Forest Report 2011 of FSI; Atlas: Forest Types of India 2011, FSI), the state of West Bengal has 30 forest types which belong to 8 forest type groups, namely, (1) Tropical Semi-evergreen, (2) Tropical Moist Deciduous, (3) Littoral and Swamp, (4) Tropical Dry Deciduous, (5) Sub-Tropical Broadleaved Hill, (6) Montane Wet Temperate, (7) Himalayan Moist Temperate, and (8) Sub-alpine forests. The extent of forest cover of the various type groups as also area under plantation/TOF (tree outside forest) is shown in the following table and the pie diagram.

Table 12.1 (Source of Figs: Atlas: Forest Types of India 2011, FSI)

Sl No.	Group	Forest	Area (sq. Km)	% of Total forest cover
1	2	Tropical Semi-Evergreen	357.50	2.86
2	3	Tropical Moist Deciduous	1376.19	11.04
3	4	Littoral and Swamp	2120.08	17.00
4	5	Tropical Dry Deciduous	3575.70	28.64
5	8	Sub-Tropical Broadleaved Hill	339.41	2.72
6	11	Montane Wet Temperate	200.31	1.60
7	12	Himalayan Moist Temperate	295.36	2.36
8	14	Sub-alpine	14.21	0.11
9		Plantation/ TOF	4202.24	33.67
		Total	12481.00	100.00



(Source : Atlas: Forest Types of India 2011, FSI)

Thus, according to Champion and Seth classification of forest types, there are eight type groups of forests in West Bengal, and the type belonging to group 5, that is, Tropical Dry Deciduous forests has the maximum coverage.

5.1. Forest cover under different forest types

Belonging to the above 8 type groups, there are as many as 30 forest types in West Bengal. The extent of cover of the various types is given in the following table.

Table 12.2 (Source: Atlas: Forest Types of India 2011, FSI)

(area in Km²)

S.No.	Forest Type	Area	% of Total Forest Cover
1	2B/2S3 Sub Himalayan Seconday Wet Mixed Forest	357.50	2.86
2	3C/C1ai East Himalayan Sal	323.67	2.59
3	3C/C1bi East Himalayan Upper Bhabar Sal	151.95	1.22
4	3C/C1bii East Himalayan Lower Bhabar Sal	126.22	1.01
5	3C/C1c Eastern Tarai Sal	326.32	2.61
6	3C/C2diii Eastern Heavy Alluvium Plain Sal	5.08	0.04
7	3C/DS1 Moist Sal Savannah	12.33	0.10
8	3C/C3a West Gangetic Moist Mixed Deciduous Forest	10.98	0.09
9	3C/C3b East Himalayan Moist Mixed Deciduous Forest	378.87	3.05
10	3C/2S2 Secondary Euphorbiaceous Scrub	6.33	0.05
11	3/1S1 Low Alluvial Savanna Woodland	34.44	0.28
12	4B/TS1 Mangrove Scrub	123.12	0.99
13	4B/TS2 Mangrove Forest	1,025.33	8.22
14	4B/TS3 Salt Water Mixed Forest	487.72	3.91
15	4B/TS4 Brackish Water Mixed Forest	313.62	2.51
16	4B/E1 Palm Swamp Forest	151.61	1.21
17	4C/FS2 Submontane Hill-valley Swamp Forest	3.26	0.03
18	4D/SS2 Barringtonia Swamp Forest	10.83	0.09
19	4D/2S2 Eastern Wet Alluvial Grassland	4.59	0.04
20	5B/C1c Dry Peninsular Sal Forest	2,732.05	21.88
21	5B/C2 Northern Dry Mixed Deciduous Forest	429.41	3.44
22	5/DS1 Dry Deciduous Scrub	84.38	0.68
23	5/E5 Butea Forest	109.97	0.88
24	5/1S2 Khair-Sissu Forest	219.89	1.76
25	8B/C1 East Himalayan Sub-tropical Wet Hill Forest	339.41	2.72
26	11B/C1a Lauraceous Forest	123.39	0.99
27	11B/C1b Buk Oak Forest	56.58	0.45
28	11B/C1c High Level Oak	20.34	0.16
29	12/C3a East Himalayan Mixed Coniferous	295.36	2.36
30	14/C2 East Himalayan Sub-alpine Birch/Fir	14.21	0.11
31	Plantation/TOF	4,202.24	33.67
	Total	**12,481.00**	**100.00**

Reference Materials:

1. L S Khanna 1999 Principles and Practice of Silviculture, Khanna Bandhu, Dehradun
2. A.B Lal 1967 Indian Silviculture, Jugal Kishore & Company, Dehra Dun.
3. Atlas: Forest types of India, 2011 Forest Survey of India.
4. Annual Report 2013-14, WB Forest Directorate

Lesson 13

1 hour

Lesson Plan

Objective:
To study

Forest types / subtypes of West Bengal

- **Type Groups**
  - Group 2 Tropical Semi-Evergreen Forests
    - Types and sub-types
  - Group 3 Tropical Moist Deciduous Forests
    - Types and sub-types

Backward Linkage: Description of forest types of WB in Lesson 12, Lesson 14, 16 and 17 of Forest Botany.

Forward Linkage: Subsequent lessons on forest types; observation of the forest types during tour

Training Materials required: Copy of Lesson 13 to be circulated beforehand

Allocation of time:

Group 2 Tropical Semi-Evergreen Forests - Types and sub-types	5 mts
Group 3 Tropical Moist Deciduous Forests - Types and sub-types	45 mts
Discussion/ Miscellaneous	10 mts

Detailed Forest types / Sub types in West Bengal

(Source: Atlas: Forest Types of India 2011, FSI, A.B.Lal 1967 Indian Silviculture, L.S.Khanna 1999 Principles and practise of Silviculture, Cowan and Cowan 1979, The trees of Northern Bengal)

The various forest types/ sub types cited in the table 12.2 in lesson 12 are now described below.

1. **Group 2: Tropical Semi-Evergreen Forests**

   Sub-group 2B: Northern Tropical Semi Evergreen Forests- It is distributed in heavy rainfall areas of Assam, West Bengal and Coastal tract of Odisha. The mean annual rainfall varies from 1500 to 3000 mm. The number of rainy days ranges from 95 to 108 whiles the number of dry months (rainfall less than 50 mm) from 4 to 5.

   Type 2B/2S3: Sub-Himalayan Secondary Wet Mixed Forest: This type exists in Jalpaiguri district; Sal comprises about 5 to 10% of forest. *Machilus gamblei* is the dominant species. Other associates are *Litsea polyantha, Dillenia pentagyna, Macaranga* spp., *Syzigium jambolonum* etc.

   A short note on *Machilus gamblei* (local name: Kawla):
   (Source: Cowan and Cowan 1929, The trees of Northern Bengal)
   An evergreen tree, gregarious on badly drained land and scattered in the Sal forest in the plains and lower hill forest (plains upto 3000 feet). Bark grey, usually with round galls, blaze reddish.

2. **Group 3: Tropical Moist Deciduous Forests**

   Sub-group 3C: North Indian tropical moist deciduous forests – It is a widely distributed formation and includes the most important Sal bearing forest of India. It is found in U.P, Bihar, Odisha, M.P, West Bengal and Assam. The mean annual temperature varies between 21° C to 26°C and the January mean varies from 13° C and 21° C. The mean annual rainfall varies from 1000 mm to 2000 mm. The number of dry months (rainfall less than 50 mm) varies from 4 to 8.

2.1 Type 3C/C$_{1a(i)}$: East Himalayan Sal Forest: It is present on the lower slopes of Mahananda Wildlife Sanctuary in Darjeeling district. As elevation increases, more of miscellaneous and some exposed area is found on the higher slopes and summits of the hills. The overwood consists of Sal with *Schima wallichii* (Chilaune) and *Stereospermum personatum* (Paruli, Parari) as characteristic associates.

2.1.1 Description of *Schima wallichii* may be seen in **lesson 17 of Forest Botany**. *S.personatum* is a deciduous tree. It is common in the Sal forest in the plains, dry mixed plain forest and lower hill forest (upto 2000 feet). Wood greyish white with numerous, narrow medullary rays, very hard and durable, but difficult to sort. Bark is dark brown with horizontal furrows.(Source: Cowan and Cowan The trees of Northern Bengal)

2.2 Type 3C/$C_{1b(i)}$: East Himalayan Upper Bhabar Sal: This type is characterised by the presence of dense *Microstegium ciliatum*. Sal is of high quality. Other associates are *Schima wallichii* (Chilaune), *Lagerstroemia parviflora* (Sidha), *Terminalia tomentosa* (Pacasaj) etc. This type is usually found in Jalpaiguri district.

2.2.1 A short note on *Microstegium ciliatum* (Source: http://www.kew.org/data/grasses-db/www/imp06339.htm)

A perennial grass. Culms rambling; 60–120 cm long; rooting from lower nodes. Culm-nodes glabrous. Leaf-blades linear, or lanceolate; 5–15 cm long; 5–15 mm wide. Leaf-blade apex acuminate. Inflorescence composed of racemes.

2.2.2 Description of *Terminalia tomentosa* syn. *T. Alata* may be seen in **lesson 17 of forest botany**. *L.parviflora* (Sidha) is a deciduous tree growing upto 60-80 feet height. The bark is buff, exfoliating in large flakes. Blaze is buff, with purple stains where the blade touches it. Wood is light brown, smooth, even green, with large pores; used occasionally for house building and for making charcoal.

2.3 Type 3C/$C_{1b\,(ii)}$: East Himalayan lower Bhabar Sal: Typical examples are found in Baman pokhari, Buxa and Jalpaiguri divisions of West Bengal. This type differs from the upper Bhabar sub type in being decidedly damper with *Microstegium* less in evidence. Overhood consists of Sal with *Terminalia tomentosa* and *Machilus* as its associates.

2.4 Type 3C/C_{1c}: Eastern Tarai Sal forest: This type is found in Buxa and Baikunthapur division of West Bengal. The overwood consists of Sal with *Michelia champaca* (Champ) and *Castanopsis* (Katus) as characteristic associates. This type is also characterised by the presence of canes and ferns.

2.4.1. Description of *Michelia champaca* may be seen in **lesson 17 of Forest Botany**.

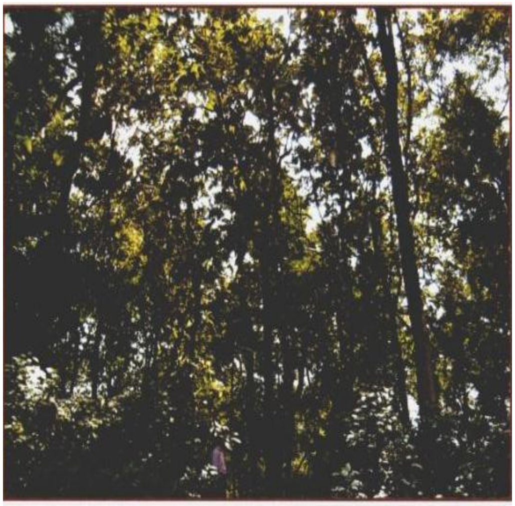
Eastern Tarai Sal

(Source: Atlas: Forest Types of India 2011, FSI)

2.5 Type 3C/$C_{2d\ (iii)}$: Eastern Heavy Alluvium Plain Sal: Generally this type occurs on yellow clayey alluvium of Malda, Uttar Dinajpur and Dakshin Dinajpur districts. Sal is dominant with low undergrowth of shrubs, with a little or no grass.

2.6 Type 3C/DS1: Moist Sal Savannah: This type is characterised by open Sal forest with heavy grass. It is found in Jalpaiguri district. Sal occurs in group with other fire hardy species like *Lagerstroemia parviflora* (Sidha), *Lannea coromendelia* (Jiol)*,Wrightia tomentosa* (Dudhi) *, Emblica officinalis* (Amlaki)*, etc.* The grasses include *Themeda arundinacea, Imperata,cymbopogon, Erianthus spp etc.*

2.7 Type 3C/C_{3a}: West Gangetic Moist Mixed Deciduous Forests : It is a closed forest of medium height having a number of dominant species intimately mixed and many second strorey trees including some evergreens. The species present are *Terminalia arjuna* (Arjun) *Tectona grandis* (Teak, Segun) *Albizzia procera* (Sada Siris) *Syzigium cuminii* (Jam) *Dalbergia sissoo* (Sissoo) *Lagerstroemia spp*. (Jarul) *Pongamia glabra* (Karanj), *Adina cordifolia* (Haldu), *Zizyphus spp* (Kul), *Acacia catechu* (Khayer), *Cassia siamea* (Minjiri), *Bauhinia variegata* etc. Undergrowth comprises species like *Clerodendrum* spp.*, Glycosmis pentaphylla* etc. This type is found in Nadia and Murshidabad district.



West Gangetic Moist Mixed Deciduous Forest

(Source: Atlas: Forest Types of India 2011, FSI)

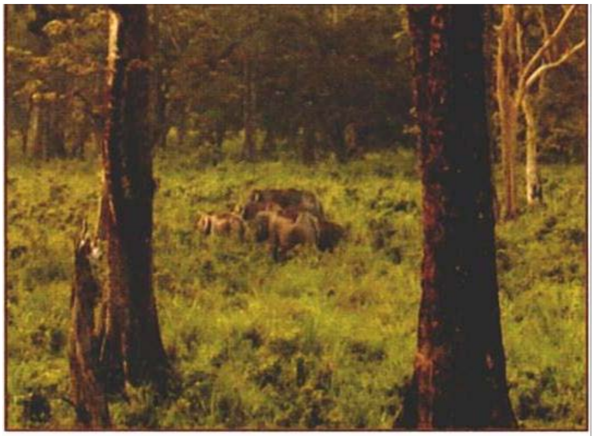
2.7.1 Description of *A. cordifolia* may be seen in **Lesson 14 of Forest Botany**, whereas that of *D.sissoo*, and *P.glabra* may be seen in **Lesson 16 of Forest Botany**, and that of *T.grandis* and *T. arjuna* may be seen in **Lesson 17 of Forest Botany**.

2.8 Type 3C/C_{3b}: East Himalayan Moist Mixed Deciduous Forest- This type occurs in Darjeeling and Jalpaiguri district. Species composition comprises *Duabanga spp.* (Lampate), *Terminalia tomentosa* (Pacasaj) *Terminalia myriocarpa* (Panisaj), *Sterculia villosa* (odal), O*roxylum indicum* (Totola)*, Bombax spp, Arundinaria maling* (Maling Bamboo), *Alstonia scholaris* (Chhatian), *Schima wallichii* (Chilaune), *Albizzia spp* (Siris), *Macaranga spp* (Malata) etc.

2.9 Type 3C/2S2: Secondary Euphorbiaceous Scrub: This type has come into existence in old village clearings in Sal forests. Dominant species comprise dense crop of *Macaranga denticulata*. This type is found in Jalpaiguri district.

2.9.1 *Macaranga denticulata* is an evergreen tree growing upto 40-60 feet height. It comes up chiefly on land which has been cleared, forming almost pure forest. Wood is white, prettily grained, but not durable and exuding a red gum when a branch is cut.

2.10 Type 3/1S1: Low Alluvial Savanna Woodland – This type is found in Jalpaiguri district in more stable riverain flats which tend to be flooded during the rainy season, but remain dry during the rest of the year. Scattered trees belonging to early series of normal succession are found with very dense tall grass. The grasses comprise *Themeda* spp, *Erianthus* spp, *Saccharum* spp etc. Also found are patches of hardy shrubs such as *Zizyphus mauritiana* (Kul).



Low Alluvial Savanna Woodland

(Source: Atlas: Forest Types of India 2011, FSI)

Reference Materials:

1. L S Khanna 1999 Principles and Practice of Silviculture, Khanna Bandhu, Dehradun
2. A.B Lal 1967 Indian Silviculture, Jugal Kishore & Company, Dehra Dun.
3. Atlas: Forest types of India, 2011 Forest Survey of India.
4. Annual Report 2013-14, WB Forest Directorate
5. Websites cited in the lesson

Lesson 14

1 hour

Lesson Plan

Objective:

To study

Forest types / subtypes of West Bengal (Continued)

- **Type Groups**
  - Group 4 Littoral and Swamp Forests
    - Types and sub-types

Backward Linkage: Description of forest types of WB in Lesson 12 and 13.

Forward Linkage: Subsequent lesson on forest types; observation of the forest types during tour

Training Materials required: Copy of Lesson 14 to be circulated beforehand

Allocation of time:

- Group 4 Littoral and Swamp Forests — 50 mts
  - Types and sub-types
- Discussion / Miscellaneous — 10 mts

Forest types / subtypes of West Bengal (Continued)

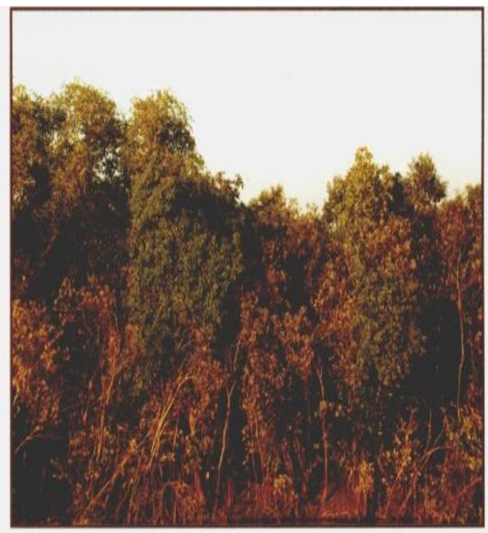
1. **Group 4 : Littoral and Swamp Forests**

(Source: Atlas: Forest Types of India 2011, FSI)

1.1 Sub-group 4B : Tidal Swamp Forests – This means a type of Littoral Forest found on sea shore below the high tide mark and thus subject to tidal influence. A major portion of this sub-group lies in Bangladesh. In India there are a few examples in estuaries of rivers. West Bengal has the following types under this sub-group.

1.2 Type 4B/TS$_1$: Mangrove Scrub: This type of forests occurs mainly in North and South 24 Parganas district. The forests have Mangrove vegetation with low average height (3-6 mts). These forests are under sustained biotic pressure. Main species are *Ceriops roxburghiana, Avicennia alba, Aegialitis rotundifolia and Acanthus ilicifolius* etc.

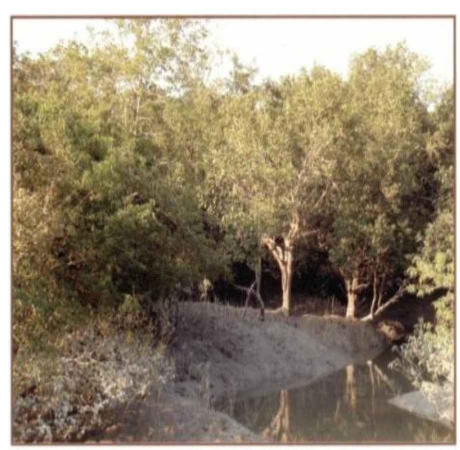
1.3 Type 4B/TS$_2$: Mangrove Forest: Typical examples are found in Sunderbans in North and South 24 Parganas districts. The type comprises closed evergreen forest of moderate height bearing trees specially adopted to survive on tidal mud. The tidal mud is permanently wet with salt water and gets submerged during every high tide. Stilt roots are very typical of the tree species. The trees are also characterised by their leathery leaves and vivipary. Main species in this forest type are *Rhizophora candeleria, Kandelia candel, Bruguiera conjugata* and *Xylocarpus granatum* etc.



Mangrove Forest

(Source: Atlas: Forest Types of India 2011, FSI)

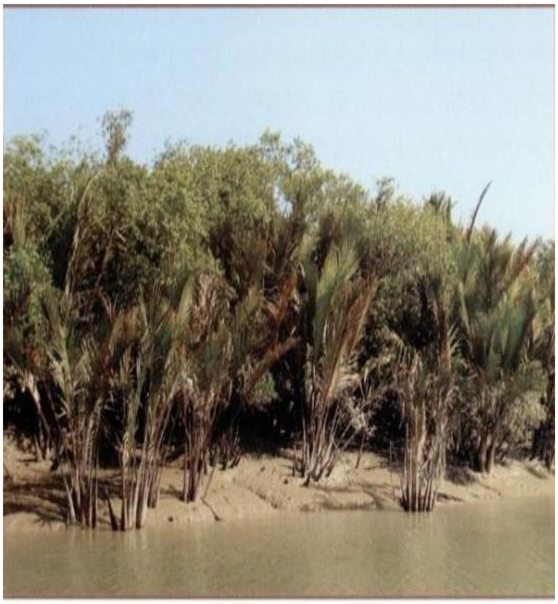
1.4 Type 4B/TS$_3$: Salt water mixed forest: The type occurs in North and South 24 parganas districts where the ground is flooded by tidal brackish water. Being situated at slightly higher levels the flooding is less frequent . The vegetation consists of *Heritiera spp*.(typically scattered), *Rhizophora spp.* (Along the edged of the river), *Excoecaria agallocha, Xylocarpus molluccensis, Bruguiera conjugata and Amoora cucullata* etc. Stilt roots are infrequent but pneumatophores are typical.



Salt Water Mixed Forest

(Source: Atlas: Forest Types of India 2011, FSI)

1.5 Type 4B/TS_4: Brackish Water Mixed Forest: It is a closed forest, over 3.3 m high, and is poorly represented in the western part of sunderbans in North and South 24 parganas district. Stilt roots are rare but pneumatophores are common. This type occupies the levels which get flooded during part of each day. Water is never very salty, and is rather fresh or slightly brackish during the rainy season. It is favoured on the ground lying between the drier banks of the larger streams and the central depressions. Main species are *Xylocarpus molluccensis, Heritiera minor, Bruguiera conjugata, Excoecaria agallocha* and *Acanthus ilicifolius etc.* **(Source:** Atlas: Forest Types of India 2011, FSI)



Brackish Water Mixed Forest

[A *short note on Heritiera fomes, syn. H.minor* –
It is a species of mangrove tree in the family Malvaceae. Its common name is Sundari. It is a major timber producing tree in the mangroves. *Heritiera fomes* is a medium-sized evergreen tree. The roots are shallow and spreading and send up pneumatophores. The trunk develops buttresses and is grey with vertically fissured bark. The leathery leaves are elliptical and tend to be clustered at the ends of the twigs. The pink or orange bell-shaped flowers form in panicles, each flower being either male or female. The fruits ripen between June and August and the seeds germinate readily.
(Source: http://en.wikipedia.org/wiki/Heritiera_fomes)]

1.6 Type 4B/TS/E_1: Palm Swamp Forest: The forest comprises a dense low growth of tufted palms upto 6 metre high. It occurs in the drier areas within the salt-water mangrove scrub or forest. The only species of this type is *Phoenix paludosa*. This type is generally found in the mangroves of North and South 24 Parganas districts.

Palm Swamp Forest

(Source: Atlas: Forest Types of India 2011, FSI)

[A short note on *P. paludosa*: Known as mangrove date palm, *P. paludosa* is classified as "near threatened" in IUCN Red list. This species is threatened by the loss of mangrove habitat throughout its range, primarily due to extraction and coastal development, and there has been an estimated 24% decline in mangrove area within this species' range since 1980. This species also occurs in the Andaman and Nicobar islands, Bangladesh, Cambodia, Malaysia, Indonesia (Sumatra), Thailand, and Vietnam. (Source: http://www.iucnredlist.org/details/178816/0)]

1.7 Type 4C/FS$_2$: Submontane Hill-valley Swamp Forest: This type of forest is generally found in Coochbehar district. The species composition comprises a dense growth of *Calamus* (Rattan) and *Ficus* species. *Alpinia* species forms the undergrowth.

1.8 Type 4D/SS$_2$: Barringtonia Swamp Forest: This type is found in Malda, Uttar Dinajpur, and Dakshin Dinajpur districts. The type normally consists of dense evergreen trees of medium height, often in pure crops, with or without thick undergrowth. Climbers are few though *Calamus* species may be many. Other species are *Barringtonia acutangula* (Hijal), *Salix* species, *Pongamia* species, *Lagerstroemia flosreginae* (Jarul) etc.

Barringtonia Swamp Forest

(Source: Atlas: Forest Types of India 2011, FSI)

1.9 Type 4D/2S$_2$: Eastern Wet Alluvial Grassland: These are grasslands bearing no tree or trees sparsely distributed, occurring in cut-off meanders of the main rivers and similar low alluvial sites mainly in Jalpaiguri district. Main species are *Acacia catechu* (Khair), *Bombax ceiba* (Simul), *Dalbergia sissoo* (Sissoo), *Oroxylum indicum* (Totola), *Emblica officinalis* (Amlaki), *Bauhinia* spp, *Dillenia* spp.etc.

Reference Materials:

1. L S Khanna 1999 Principles and Practice of Silviculture, Khanna Bandhu, Dehradun
2. A.B Lal 1967 Indian Silviculture, Jugal Kishore & Company, Dehra Dun.
3. Atlas: Forest types of India, 2011 Forest Survey of India.
4. Websites cited in the lesson

Lesson 15

1 hour

Lesson Plan

Objective:

To study

Forest types / subtypes of West Bengal (Continued)

- **Type Groups**
  - Group 5 Tropical Dry Deciduous Forests
    - Types and sub-types
  - Group 8 Sub Tropical Broadleaved Hill Forests
    - Types and sub-types
  - Group 11 Montane Wet Temperate Forests
    - Types and sub-types
  - Group 12 Himalayan Moist Temperate Forests
    - Types and sub-types
  - Group 14 Sub Alpine Forests
    - Types and sub-types

Backward Linkage: Description of forest types of WB in Lesson 12, 13 and 14

Forward Linkage: Observation of the forest types during tour.

Training Materials required: Copy of Lesson 15 to be circulated beforehand

Allocation of time:

- Group 5 Tropical Dry Deciduous Forests — 20 mts
  - Types and sub-types
- Group 8 Sub Tropical Broadleaved Hill Forests — 5 mts
  - Types and sub-types
- Group 11 Montane Wet Temperate Forests — 15 mts
  - Types and sub-types
- Group 12 Himalayan Moist Temperate Forests — 5mts
  - Types and sub-types
- Group 14 Sub Alpine Forests — 5mts
  - Types and sub-types
- Discussion/ Miscellaneous — 10 mts

Forest types / subtypes of West Bengal (Continued)

1. **Group 5: Tropical Dry Deciduous Forest**

   Sub-group 5B: Northern Tropical Dry Deciduous Forest- This subgroup occurs throughout northern India except in the too moist Eastern part and too dry western part. It is found in HP, UP, Uttarakhand, Bihar, Jharkhand, Odisha, West Bengal, Rajasthan and MP. The main annual temperature ranges from 24^{o} C to 27^{o} C and the main January temperature from 7^{o}C to 20^{o}C. Main annual rainfalls varies from 750mm to 1300mm; however the typical rainfall is between 900 and 1150mm. The number of rainy days varies from 36 to 80 and the number of dry months (rainfall < 50mm) 5 to 8.The mean annual humidity varies from 46 to 74%.

1.1 Type 5B/ C_{1c} : Dry Peninsular Sal: This sub type occurs on shallow soils derived from crystalline and metamorphic rocks where soil moisture conditions are unfavourable for moist Sal. Typical examples are found in the laterite tract in West Bengal. The best Sal forest under this type are confined to the southern part of West Bengal, especially in Purulia, Bankura, Paschim Medinipur, Bardhaman, Birbhum and Murshidabad districts. Sal occurs either pure or in mixture with *Terminalia tomentosa* (Pacasaj,asan), *Terminalia bellerica* (Bahera), *Pterocarpus marsupium* (Piasal), *Anogeissus latifolia* (Dhaw), *Lagerstroemia parviflora*(Sidha), *Madhuca latifolia* (Mahua, mahul), *Diospyros melanoxylon* (Kend, Tendu), *Buchanania lanzan* (Pial), *Ougeinia dalbergiodes* etc. The under storey consist of *Combretum decandrum*, *Flacourtia cataphracta*, *Randia dumentorum*, *Zizyphus species, Gardenia gummifera*, *Holarrhena* spp, *Lantana* spp, *Eupatorium odoratum* etc.

Dry Peninsular Sal Forest

(Source: Atlas: Forest Types of India 2011, FSI)

1.2 Type 5B/C_2: Northern Dry Mixed Deciduous Forest: This type is found in the rocky and rugged steep slopes in the south western part of west Bengal, mainly in Purulia and Bankura districts. The forest is mostly devoid of vegetation with sporadic occurrence of miscellaneous species such as, *Acacia* spp, *Lagerstroemia parviflora* (Sidha), *Diospyros melanoxylon* (Kend, Tendu), *Schleichera trijuga* (Kusum), *Boswellia serrata* , *Cochlospermum gossypium* etc. Sal also occurs in this type, but in low percentage.

Northern Dry Mixed Deciduous Forest

(Source: Atlas: Forest Types of India 2011, FSI)

1.3 Type 5/DS_1: Dry Deciduous Scrub: This type occurs in Purulia,Bankura, Medinipur, Bardhaman and Birbhum districts. The species composition comprises, *Terminalia arjuna* (Arjun) , *Zizyphus* spp (Kul), *Aristida hystrix*, *Butea monosperma* (Palash), *Cassia siamea* (Minjiri) etc.

1.4 Type 5/E_5: Butea Forest: This type occurs on the lower dryer slopes, and plain and undulating land of Purulia district. Trees of *Butea monosperma* (Palash) and *Cochlospermum gossypium* are in abundance and cover the hillocks.

1.5 Type 5/1S_2: Khair-Sissoo forest- This type is found in Jalpaiguri district. The dominant species are *Acacia catechu* (Khair) *Dalbergia sissoo* (Sisso). Other associates are *Cassia tora, Holoptelia integrifolia , Erianthus munja, Grewia, Tamarix* etc.

2. Group 8: Sub Tropical Broadleaved Hill Forests

Sub-group 8B: Northern Subtropical Broadleaved Hill forests: This sub group is distributed on the lower slopes of the eastern Himalayas from 1000m to 2000m as well as in the Assam hills at slightly higher elevations. The rainfall varies from 1750 mm to 3200 mm; number of rainy days varies from 90 to 126; number of dry months from 3 to 5; mean annual humidity about 77%. The mean annual temperature ranges from 15^{o} C to20^{o} C and the mean January temperature from 12^{o} C to 16^{o}C.

2.1 Type 8B/C_1 : East Himalayan Sub-tropical Wet Hill Forest : This type is generally found in Darjeeling and Jalpaiguri district. Typical species are *Elaeocarpus lanceaefolius* (Bhadrase) , *Machilus odoratissima* (Lali kawla), *Semingtonia populnea, Engelhardtia spicata* (Mauwa), *Castanopsis spp* (Katus), *Macaranga spp, Acer spp, Michelia carkaratae, Nyssa javanica* (lekh chilaune), *Rubus* spp, fern and climbers like *Ardisia macrocarpa, Pathenocissus himalayana* etc. The shrubby growth of *Maesa indica* occurs abundantly.

East Himalayan Sub-tropical Wet Hill Forest

(Source: Atlas: Forest Types of India 2011, FSI)

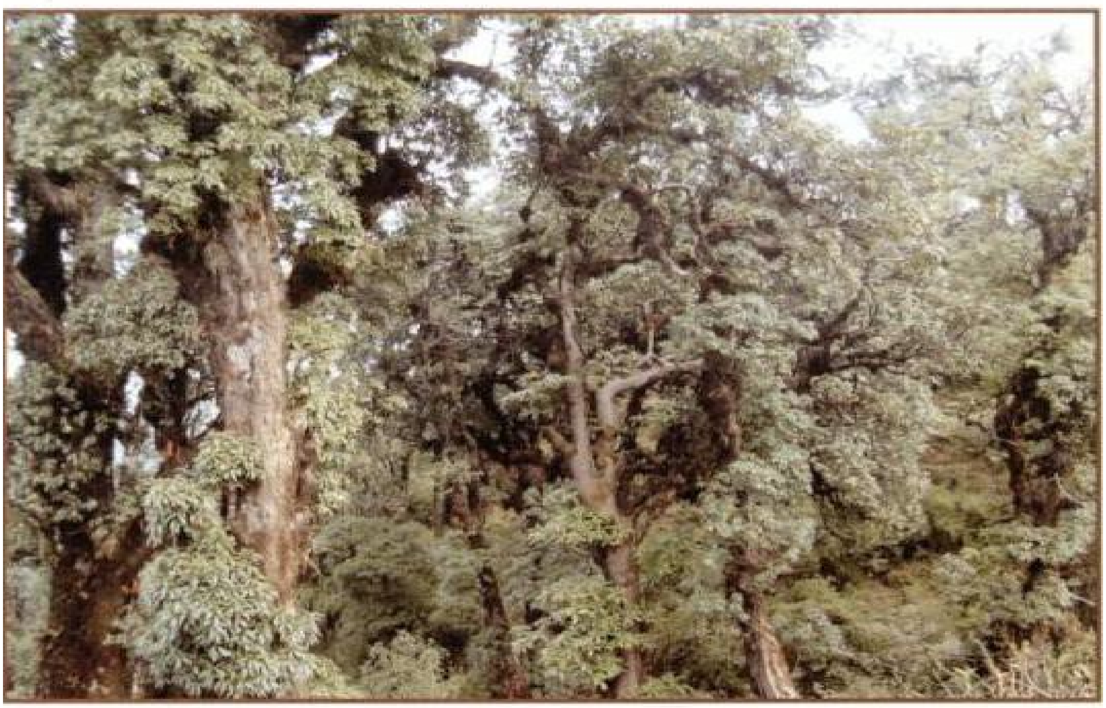
3. Group 11 : Montane Wet Temperate Forests

Subgroup 11B: Northern Montane Wet Temperate Forests – This subgroup is distributed on the eastern Himalayas at the altitude range 1800 m to 3000 m in West Bengal, Assam and Arunachal Pradesh. The mean annual temperature is about 12^{0} C and the mean January temperature about 5^{0} C. The mean annual rainfall varies from 1900 mm to 4000 mm. The number of rainy days is about 122 and the number of dry months (rainfall < 50 mm) is 4 to 5.

3.1 Type 11b/C_{1a}: Lauraceous Forest: This type is found in Darjeeling district. Composition of the crop varies with altitude, aspect and rainfall. Edaphic and biotic factors also influence the species composition. Main species are *Quercus pachyphylla* (Sungre Katus), *Quercus lamellose* (Buk), *Quercus lineata* (Phalant) etc. Other associating species are *Rhododendron* spp, *Acer campbelii* (Kapasi), *Arundinaria maling, Alnus nepalensis* (Utis), *and Evoidia* spp.

3.2 Type **11b/C$_{1b}$: Buk Oak Forest:** This type is found in Darjeeling district. The crop composition comprises *Quercus pachyphylla* (Sungre Katus)*, Alnus nepalensis* (Utis)*, Bucklandia spp, Quercus spp*, *Castanopsis* spp, *Symploco* spp, *Acer* spp, *Elaeocarpus* spp etc. The undergrowth comprises *Rubus* spp, fern, *Polygonum*, *Berberies*, *Ageratum conyzoides, Eupatorium* spp etc.

3.3 Type 11B/C$_{1c}$: High level Oak Forest : This type is found in Darjeeling district. In the altitude zone 2100- 2400 m, Oak occupies the top canopy. The main species are *Quercus lamellosa* (Buk), *Quercus lineata* (Phalant), *Acer campbelii* (Kapasi), *Arundinaria maling, Alnus nepalensis* (Utis), *Evodia* spp etc. Rhododendron species is comparatively more at the elevation range 2400 m-2800 m associating more with the species like *Viburnum erubescens*.



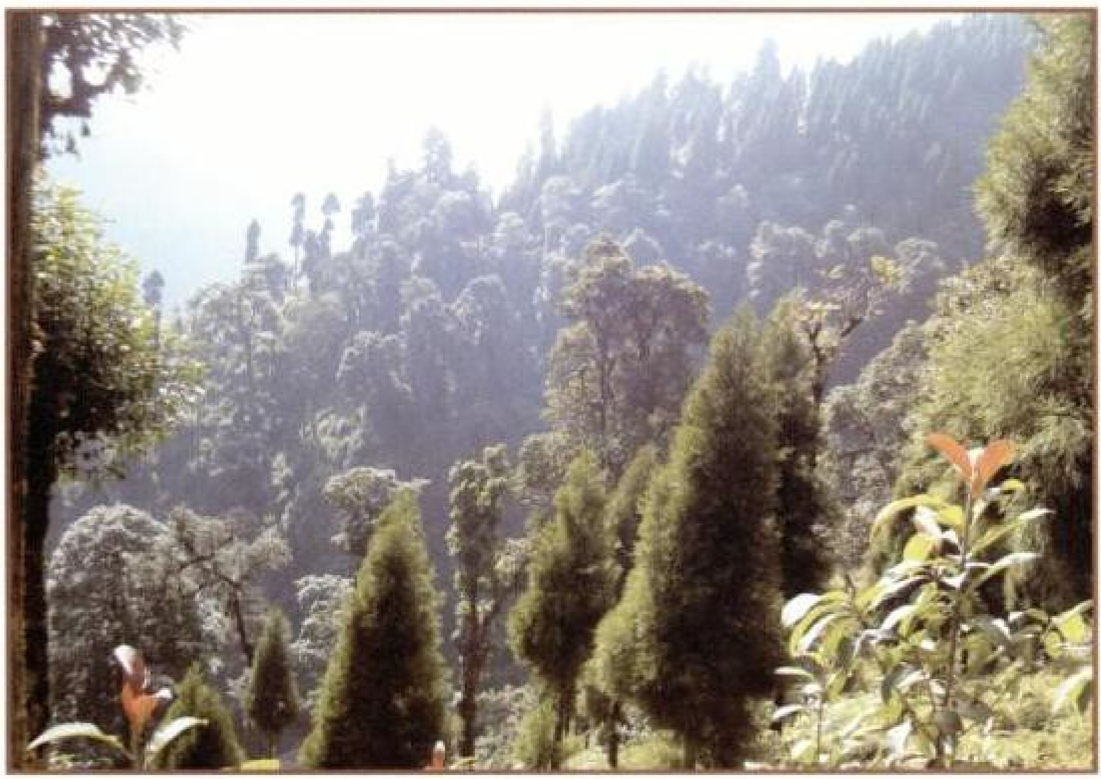
High Level Oak Forest

(Source: Atlas: Forest Types of India 2011, FSI)

4. Group 12: Himalayan Moist Temperate Forest

This group occurs throughout the length of the Himalayas at altitude between 1500 m and 3300 m, the limits varying with aspect and configuration. It is found in Kashmir, HP, U.P, Sikkim and West Bengal (Darjeeling district). The mean annual temperature ranges between 13^0 C and 16^0 C, and the mean January temperature between 1^0C and 6^0C. Except the north west the rainfall varies from 1100 mm to 2500 mm, and most of it is received from the south west monsoon.

4.1 Type 12/C_{3a} : East Himalayan Mixed Coniferous Forest : This type is present at an elevation ranging from 2300 to 3000 m in Darjeeling district. The dominant species are *Tsuga dumosa* (Hemlock), *Rhododendron* spp, *Abies densa*, *Arundinaria maling etc.*



East Himalayan Mixed Coniferous Forest

(Source: Atlas: Forest Types of India 2011, FSI)

5. Group 14: Sub Alpine Forests

This group is the top most tree forest in the Himalayas adjoining Alpine scrub or grassland. It is found on the altitude zone of 2900m to 3500m and above. The main annual temperature varies from 2^oC to 6^oC and the mean January temperature from -16^oC to -7^oC. The mean annual rainfall varies from 80mm to 650mm. The number of rainy days varies from 11 to 57, and number of dry months (rainfall <50mm) from 6 to 12. Snowfall is a regular feature and may accumulate to 3m or more.

5.1 Type 14/C_2: East Himalayan sub alpine Birch/Fir forest: It is found in Darjeeling district. The species namely *Tsuga dumosa* (Hemlock), *Rhododendron* spp., *Abies densa* (Gobre salla, Silver fir) are found in moderate numbers with *Betula utilis* (Birch, Bhuj patra). In some places of Darjeeling district, this type occurs as dense evergreen forest. The undergrowth is sparse and mostly consists of *Berberis aristata* (Daru haridra) , *Rosa sericea*, *Cotoneaster* spp.etc.

Reference Materials:

1. L S Khanna 1999 Principles and Practice of Silviculture, Khanna Bandhu, Dehradun
2. A.B Lal 1967 Indian Silviculture, Jugal Kishore & Company, Dehra Dun.
3. Atlas: Forest types of India, 2011 Forest Survey of India.
4. Websites cited in the lesson

Lesson 16

1 hour

Lesson Plan

Objective:

To study

- **Growth of forests and crown differentiation**
- **Tree Classification**
  - Dominant
  - Dominated
  - Suppressed
  - Dead or moribund
  - Diseased
  - Canopy cover and Canopy closure
- **Tending**
  - Definition and Need
  - Weeding
  - Cleaning

Backward Linkage: Lesson 10 and 11 on Plant Succession
Lesson 8 on Forest Protection

Forward Linkage: On the job Training

Training materials required: Copy of lesson 16 to be circulated beforehand.

Allocation of time:

- **Growth of forests and crown differentiation** 5 mts
- **Tree Classification** 20 mts
  - Dominant
  - Dominated
  - Suppressed
  - Dead or moribund
  - Diseased
  - Canopy cover and Canopy closure
- **Tending**
  - Definition and Need 5 mts
  - Weeding 10 mts
  - Cleaning 10 mts
- **Discussion/Miscellaneous** 10 mts

1. Growth of Forests and crown differentiation

A forest begins its life with aggregation of seedlings. In an even aged or regular forest, the seedlings are more or less of the same age. At the seedling stage, the number of plants per unit area is too many. Each plant gets ample growing space, and unless the site is too inhospitable, each of them also gets optimum water and food. With increasing age the plants grow in size and their requirement for water and nutrients also increases. Before long the individual trees develop crowns of moderate size, which tend to touch and overlap each other. The competition for space and light sets in. Soil moisture and nutrients, available in limited quantities at a site, get shared among the plants, but the division is not equitable. Depending on the nature of a species and its suitability on the site in question, growth of certain species becomes more than others. Again within the population of a species the individuals who are genetically superior grow taller and healthier than others. Thus through the process of struggle and competition for space and other inputs, some of the individual trees grow faster and their crowns form the uppermost canopy of the forest. The less vigorous remain in the intermediate position and the weakest occupy the lowest position. Thus the competition for survival and growth leads to **crown differentiation**.

1.1 Trees forming the uppermost canopy also have variation in crown height and thus within the top canopy also there is crown differentiation. The process of differential growth and the phenomenon of crown differentiation are well manifested in a regular forest. With time individual trees may move from one crown class to another. Some of the trees in the middle crown class may get relegated to the lowest class. Some of the trees in the lowest class may die in the competition for light and food.

2. Tree Classification

(Source: L.S Khanna 1999 Principles and Practice of Silviculture; http://www.uky.edu)
Based on crown differentiation or crown class, trees are classified into the following categories. These classes are generally met with in an even-aged forest.

(1) Dominant Trees – All trees which form the uppermost leaf canopy and have their leading shoots free are called dominant trees. The dominant trees are further subdivided into following categories.

- **(i) Predominant Trees –** They comprise all the tallest trees which determine the general top level of the canopy and are free from vertical competition. Predominant trees have crowns extending above the general level of the crown cover and receiving full light from above and partly from the side.
- **(ii) Codominant Trees –** They comprise the rest of the dominant trees falling short of and averaging about $\frac{5}{6}$th of average height of predominant trees. Codominant trees have crowns forming the general level of the crown cover and receiving full light from above but comparatively little from the sides.

(2) **Dominated Trees** – They do not form part of the uppermost leaf canopy, but the leading shoots **are not** definitely overtopped by the neighbouring trees. Their height is about 3/4 th that of the tallest trees. They are further classified into
   (i) Trees with normal crown development and good stem form, and
   (ii) Trees with defective crowns or stems.

(3) **Suppressed Trees** – Trees which reach only about 1/2 to 5/8 of the height of the best trees, with their leading shoots **definitely overtopped** by their neighbours or at least shaded on all sides by them.

(4) **Dead and Moribund Trees** – This class also includes bent over or badly leaning trees usually of the whip type.

(5) **Diseased Trees –** Trees which are infected with parasites to such an extent that their growth is seriously affected and they pose a danger to the neighbouring trees.

3. Canopy cover and Canopy closure

(Source: Korhonen, L., Korhonen, K.T., Rautiainen, M. & Stenberg, P. 2006. Estimation of forest canopy cover: a comparison of field measurement techniques. Silva Fennica 40(4): 577–588.)

Forest canopy cover, also known as **canopy coverage** or **crown cover**, is defined as the proportion of the forest floor covered by the vertical projection of the tree crowns. Estimation of forest canopy cover has recently become an important part of forest inventories. First, canopy cover has been shown to be a multipurpose ecological indicator, which is useful for distinguishing different plant and animal habitats, assessing forest floor microclimate and light conditions, and estimating functional variables like the leaf area index (LAI) etc. Finally, **the international definition of a forest is based on canopy cover**: the United Nations Food and Agricultural Organization **(FAO) has defined forest as land of at least 0.5 ha with potential canopy cover over 10% and potential tree height of at least five meters (FAO 2000).** To ensure compatibility of international forestry statistics, forest canopy cover needs to be included in national forest inventories.

3.1 It is, however, necessary to understand the **difference between the concepts of canopy cover and canopy closure.** *Canopy cover*, defined as the *proportion of the forest floor covered by the vertical projection of the tree crowns*, should be distinguished from ***canopy closure*,** which is defined as the *proportion of sky hemisphere obscured by vegetation when viewed from a single point* (Fig. 16.1). The difference between these concepts is clear: if canopy is measured with instruments that have an angle of view (i.e. measure a larger area than just a vertical point), like cameras or spherical densiometers, the results are estimates of canopy closure. In other words, canopy closure is just a percentage figure describing the fraction of non-visible sky within a certain angle, whereas canopy cover describes the fraction of ground area covered by crowns.

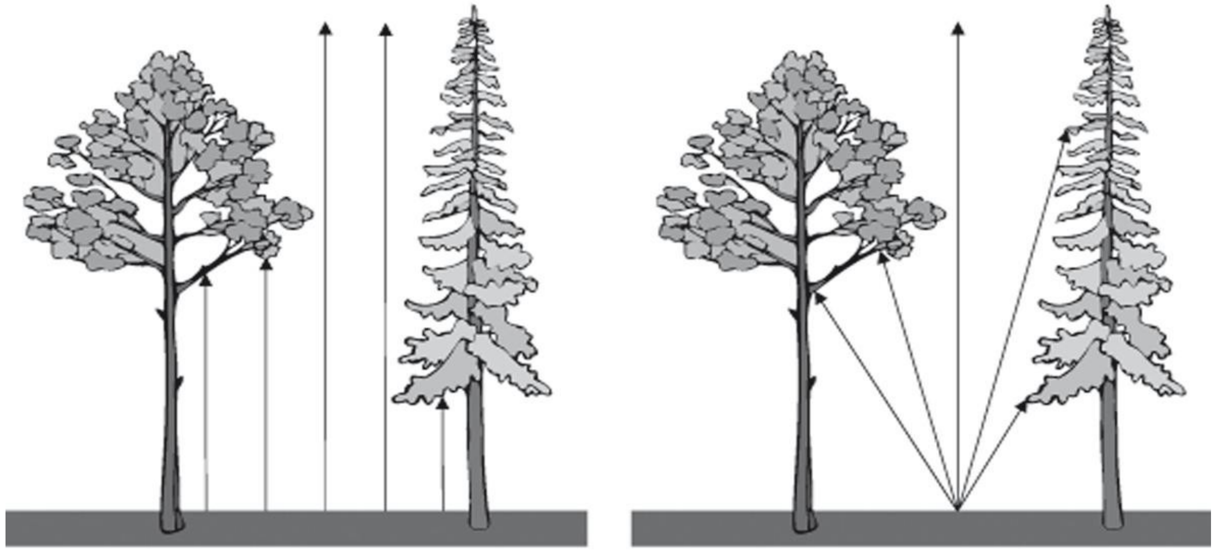


Fig.16.1. Canopy cover (left) is always measured in vertical direction, whereas canopy closure (right) involves an angle of view.
(Source: Korhonen, L., Korhonen, K.T., Rautiainen, M. & Stenberg, P. 2006. Estimation of forest canopy cover: a comparison of field measurement techniques. Silva Fennica 40(4): 577–588.)

Tending

4. Introduction

Throughout its life cycle forest crop needs food, light and water. With age, crop's requirement of these essentials increases. As explained above, the individual members of a plant community engage themselves in a struggle or competition for these essential inputs in order to survive and grow. The competition is not restricted among the members of desired species alone. Trees of the desired species also compete for food and light with the member of unwanted species. If this competition is not restricted, or in other words, if trees of the desired species do not get optimum quantities of essentials, their growth is adversely affected. The object of tending operations, as part of forest management, is to contain the degree of competition for essentials (i) between the desired species and the undesired ones and also (ii) between the trees of the desired species.

5. Definition and Need

Tending is defined as an operation carried out for the benefit of a forest crop, at any stage of its life between the seedling and the mature stages (L S Khanna 1999). It covers operations both on the crop itself and on the competing vegetation. Tending includes–

- Weeding
- Cleaning

- Thinning
- Improvement felling
- Pruning
- Climber cutting
- Girdling of unwanted growth
- Coppice thinning

However, tending does not include regeneration felling, and ground operations like soil working, drainage, irrigation, and controlled burning.

5.1 Need

By reducing the competition among the plants, tending facilitates provision of larger share of essentials for the desired individuals. Tending aims at creating best conditions of growth for the forest crop. It helps in producing high quality timber and optimizing returns of forest produce in the desired form. Tending is thus an important silvicultural operation.

6. Weeding

Any unwanted plant that interferes or tends to interfere with the growth of the individuals of favoured species is called a **weed**. In all regeneration areas, natural or artificial, weeds generally appear profusely earlier than the desired species. If not restricted, the weeds tend to smother and kill the main forest crop. **Weeding** is defined as a tending operation done in the **seedling stage** in nursery or in a forest crop, which involves removal or cutting back of all weeds. (L S Khanna 1999).

6.1 Objects of weeding

- **To reduce root competition and water loss due to transpiration –** Weeds are generally more in number and they get established faster than the main crop. If left unchecked, they take a larger share of soil moisture for their growth than the main crop, and also cause, through normal physiological function, moisture loss by way of transpiration. By eliminating or containing the weeds, the operation of weeding reduces the root competition for moisture and nutrients, and also cuts down the water loss due to transpiration. Weeding thus makes more of water and nutrients available for the tiny seedlings of the main species and facilitates their growth.
- **To improve light conditions –** Weeds restrict the sunlight reaching the forest floor. If tall and dense, weeds may cut off the light to a large extent. Weeding improves light condition and help the seedlings of the main crop in the process of chlorophyll formation and photosynthesis.

6.2 Season and frequency of weeding

Growing season is the guiding factor to decide when weeding should be done. In general, weeding should be done (i) before the weeds begin to suppress the seedlings, and (ii) during the growing season of the seedlings. After the growth period the seedlings may require protection from frost or browsing, or during drought water loss due to evaporation from the soil surface may require to be contained, and presence of weeds may be helpful in such conditions. In practice, weeding is done in plantation during the rains and stopped by the end of September. However, in nurseries where the object is to produce planting stock as quickly as possible and conditions of light and humidity can be manipulated, weeding is done as often as necessary. The number of weeding to be done in a plantation in a particular year depends on the rate of growth of the weeds vis-a-vis seedlings. In an afforestation programme. a plantation generally undergoes four to five weeding / cleaning in the first year, that is, year of creation, and further weeding, fewer in number, in the next couple of years as part of creation of the plantation.

7. Cleaning

Cleaning is defined as a tending operation done in a sapling crop with the object of freeing the main species from competing growth of undesirable form or inferior species which are actually or potentially overtopping the main species. It involves the following operations –

- Cutting back of shrubs and herbs interfering with the growth of the saplings of the desired species;
- Cutting back of individuals of inferior species;
- Cutting back of the malformed and diseased individuals of the desired species;
- Climber cutting.

Cleaning is concerned more with the regulation of light conditions than with minimising root competition.

7.1 Objects of Cleaning

- **To improve light conditions** – The primary objective of cleaning is to improve the light conditions. A growing sapling needs more light than a seedling.
- **To reduce root competition and water loss due to transpiration – A**s a secondary objective, cleaning reduces root competition and facilitates better growth of saplings of the desired species. Further, removal of foliage reduces the transpirational water loss from the soil.

7.2 Season and frequency of cleaning

As a rule, Cleaning should be done during the season which is the growth period of the favoured species. Thus in practice, cleaning should be done during the rains. However, cleaning may be done in summer and winter also, if undesirable species are found to interfere with the main species. Frequency of cleaning depends on the density and rate of growth of the shrubs on being cut back. In a plantation, cleaning is done normally four to five times in the first year, and fewer times in the subsequent years. Ideally, cleaning should be done every year throughout the sapling stage of the crop so that the saplings may grow into healthy poles.

Reference Materials:

1. L S Khanna 1999 Principles and Practice of Silviculture, Khanna Bandhu, Dehradun
2. A.B Lal 1967 Indian Silviculture, Jugal Kishore & Company, Dehra Dun.
3. Korhonen, L., Korhonen, K.T., Rautiainen, M. & Stenberg, P. 2006. Estimation of forest canopy cover: a comparison of field measurement techniques. Silva Fennica 40(4): 577–588
4. Websites cited in the lesson

Lesson 17

1 hour

Lesson Plan

Objective:
To study

- **Thinning**
  - Concept and Definition
  - Objects
  - Basic principles underlying thinning
  - Kinds of thinning In regular crops
    - Mechanical Thinning

Backward Linkage: Lesson 16 on Tending

Forward Linkage: On the job Training

Training materials required: Copy of lesson 17 to be circulated beforehand.
Allocation of time:

• **Thinning**	
➢ Concept and Definition	10 mts
➢ Objects	10 mts
➢ Basic principles underlying thinning	10 mts
➢ Kinds of thinning in regular crops	5 mts
- Mechanical Thinning	15 mts
• **Discussion / Miscellaneous**	10 mts

Thinning

1. Concept and Definition

A forest stand, whether natural or man-made, in its initial stage, has a large crop density, that is, a large number of seedlings/saplings per unit area. As root competition and competition for light sets in, the crop gets differentiated into several classes like dominant trees forming the uppermost canopy, and dominated or suppressed trees forming lower layers of canopy. The dominant trees are those which have vigorous growth potential and are best adapted to the site. The dominated and the suppressed are the weak ones which are left behind in the competition. As the stand grows with age, the competition for food and light becomes more intense. Under this situation, the weak and less vigorous trees keep dying due to limited availability of food and light at a given site. Thus the forest stand over time undergoes what is called natural selection and the crop density gradually reduces and ultimately attains a more or less stable value at maturity. Notwithstanding the fact that this process of natural selection favours the trees of superior growth, the forest stand if left to natural selection, allows retention of more stems per unit area than would have been optimum for growth of the desired trees. In other words, without silvicultural intervention, the density of the stand would remain high and would adversely affect the growth of even the dominant trees. It is thus necessary that the number of trees per unit area is reduced as the stand advances in age.

1.1 Definition

Thinning is an operation of felling carried out in an immature stand where the main objective is to reduce the density of trees in the stand, improve the quality and growth of the remaining trees and produce a saleable product. Thinning, strictly speaking, is carried out in pure, even-aged, or relatively even-aged crops.

2. Objects of Thinning

(1) **To distribute the growth potential of a forest** - Total volume of timber to be produced by a stand is governed by its site. Whatever be the degree of thinning, the total volume production per unit area for a given site quality and for a given age is the same. However, by thinning, that is, by manipulating the crop density, the total volume of timber to be produced by a stand can be distributed among an optimum number of superior trees selected on the basis of their form, quality and future growth potential. Thus thinning can have total growth potential of a stand distributed over an optimum number of trees of desired size and form.

(2) **To increase net yield of timber and money value** – Though the volume of timber to be produced by a stand cannot be increased by thinning, the thinned material, which otherwise would have perished in the natural struggle for existence, can be salvaged,

resulting in increase in net yield of timber. The money value of produce is also increased due to (i) increase in net yield and (ii) higher market price for timber of better quality and size.

(3) **To obtain earlier returns of investment** – Thinning can fetch early returns of investment by (i) utilization of thinned material, and (ii) shortening the rotation. Thinning is primarily aimed at increasing the rate of diameter increment of the crop and reaching the exploitable diameter in shorter period. It thus shortens the rotation and fetches early returns.

(4) **To maintain hygienic condition of the stand** – Thinning helps regulate the hygiene of the crop by getting rid of dead, dying and diseased trees.

(5) **To choose the right type of trees of the desired species as future crop**

(6) **To obtain timber of the desired quality and mechanical strength** - Thinning facilitates growth of superior trees of good quality by removing the trees of inferior quality.

3. Basic principles underlying thinning

- Reduction in the number of stems per unit area for the benefit and growth of future crop.
- At the same time keeping optimum stocking for development of better bole and maintaining soil fertility.
- One should have clear idea about (i) which trees are dominant and promising for future growth, (ii) production potential of a site, and (iii) number of trees per unit area to be retained to make full use of the site.
- The integrity of the leaf canopy should be maintained. Creation of lasting gaps in the canopy may lead to reduction in soil fertility.

4. Kinds of thinning in regular crops

Thinning depends on the nature of the crop. In a **regular crop**, following types of thinning are employed.

1) Mechanical thinning
2) Ordinary thinning
3) Crown thinning
4) Free thinning
5) Maximum thinning, and
6) Advance thinning.

The **first three kinds** of thinning which are commonly employed are described hereafter.

4.1 Mechanical thinning – It is defined as a thinning in which the trees to be cut are selected by some rule-of-thumb, e.g trees in alternate diagonals or rows, alternate trees in alternate rows or every second, third, fourth, etc line or a minimum spacing gauged by a standard stick (stick thinning. (L.S Khanna 1999).

4.1.1 Mechanical thinning is carried out in the young stage before the crown differentiation has taken place. Thus the tree classification which is normally the basis of thinning is not applicable in the case of mechanical thinning. As all the trees in the plantation are more or less of the same vigour, the thinning consists in providing uniform and enlarged spacing to the trees by removing a certain number of trees mechanically. However, even in mechanical thinning, the diseased, damaged and malformed trees are removed.

4.1.2 The rule-of –thumb applied for removal of trees may be empirical, viz. alternate trees in each row or trees in alternate rows or diagonals etc. or, may follow some formula based on the studies of various natural crops. Some of the formulae are as follows.

For Sal: $D = 1 - d$ (Warren's formula)

For Teak: $D = 1.5\ (d+4)$ (Sagreiya's formula)

$D = 2\ (d+3)$ (Sagreiya's formula)

For Sissoo, $D = 2d$ (Howard's formula)

Where, D = spacing of trees in feet,

d = average diameter of trees in inches.

4.1.3 When the purpose of mechanical thinning is to create a spacing equal to a prescribed length (that of a stick), it is called **stick thinning**. The length of the stick depends on the average diameter of the crop and the species. For example, the following table shows the stick length used for Sal.

Table 17.1

(Source: L S Khanna 1999 Principles and Practice of Silviculture)

Species	Average Diameter in cm	Length of stick in metres
Sal	2.5 to 6.25	0.90
	6.25 to 10.00	1.20

4.1.4 An example of mechanical thinning in Teak Plantation

(Source: L S Khanna 1999 Principles and Practice of Silviculture, A.B Lal 1967 Indian Silviculture)

A Teak plantation which started on a spacing of 1.8 m x 1.8 m (6 feet X 6 feet) is subjected to first mechanical thinning when the crop height is 7.5 m to 9.0 m (25 feet to 30 feet). In this thinning, alternate plants are removed in each row (in other words, alternate diagonals are removed). Fifty per cent of the stems are thus removed, bringing the spacing to 2.5 m X 2.5 m

(8.5 feet X 8.5 feet). After 5 years, another thinning is carried out in which alternate rows are removed, reducing the number of plants by 50% and leaving the spacing about 3.6 m X 3.6 m (12 feet X 12 feet).

Reference Materials:

1. L S Khanna 1999 Principles and Practice of Silviculture,Khanna Bandhu, Dehradun
2. A.B Lal 1967 Indian Silviculture, Jugal Kishore & Company, Dehra Dun.
3. Thinning Practice, A silvicultural Guide by Gary Kerr and Jens Haufe, Forerstry Commision at http://www.forestry.gov.uk/pdf/Silviculture_Thinning_Guide_v1_Jan2011.pdf)

Lesson 18

1 hour

Lesson Plan

Objective:

To study

- **Thinning in regular crops (Continued)**
  - ➢ **Ordinary thinning**
  - ➢ **Crown thinning**
- **Thinning in irregular crop**
  - **Selection thinning**

Backward Linkage: Lesson 17 on thinning

Forward Linkage: On-the-job training

Training materials required: copy of lesson 18 to be circulated beforehand

Allocation of time:

• **Thinning in regular crop(Continued)**	
➢ **Ordinary thinning**	25 mts
➢ **Crown thinning**	15 mts
• **Thinning in irregular crop**	
➢ **Selection thinning**	10 mts
• **Discussion/Miscellaneous**	10 mts

Thinning (Continued)

1. Thinning in regular crops (continued)

1.1 Ordinary thinning

When a forest crop having passed its early stages manifests crown differentiation, mechanical thinning loses its value. By this time the stand shows which are the dominant individuals and should be retained to generate maximum value at maturity. This is when silvicultural thinning is called for and it aims at removing those trees which have been left behind in the social struggle.

1.1.1 Definition

Ordinary thinning, also called 'Low thinning' or 'German thinning' is defined as the method of thinning in common use that consists in the removal of inferior individuals of a crop, starting from the suppressed class, then taking the dominated class, and lastly some of the dominants. (L S Khanna 1999)

1.1.2 Basic principles of Ordinary thinning

- The trees which have fallen behind completely or partially in the struggle for existence do nor perform any useful function and are likely to retard the growth of future stems by accentuating the root competition.
- The suppressed and dominated class which constitute the weaker individuals of the population are liable to attack by insects and fungi which might ultimately affect the better stems.
- The retention of suppressed and dominated trees is likely to increase the fire hazard and damage by climbers.
- Removal of trees starts from the lowermost class, i.e the suppressed class, and gradually works upwards through the dominated and the dominant class. The maximum number of trees is taken out from the suppressed class, the least from the dominant class.
- Ordinary thinning follows nature in which the reduction in the number of stems takes place through gradual mortality of trees from the lower canopies.

1.1.3 Grades of Ordinary thinning

A **thinning grade** refers to the relative extent to which a crop is opened up in thinning. (L S Khanna 1999). Five grades are recognized in ordinary thinning.

(1) **A Grade (Light thinning)** – Thinning is limited to **removal of dead, dying, and diseased** trees in all canopy classes as well as **suppressed trees**. "A" grade thinning does not make any difference to the increment of future crop. This grade of thinning is basically a hygiene operation and is concerned with burying of the dead as well as those which are likely to die soon (A B Lal 1967).

(2) **B Grade (Moderate thinning)** – In addition to the trees removed in 'A' grade thinning, dominated trees with defective stems or crowns, whippy dominants as well as dominants with very defective stems and crown form are removed. This grade is also of little use in ordinary practice as it has very little bearing on the growth of the remaining trees.

(3) **C Grade (Heavy thinning)** – In addition to the trees removed in 'B' grade, all the dominated trees plus the less promising trees in the dominant class are removed. Some suppressed trees might be left as soil cover in the gaps created by the removal of the dominant trees. This is the standard grade usually applied in practice and corresponds to normal stocking as recorded in the ordinary yield tables.

(4) **D Grade (Very heavy thinning) –** In addition to trees removed in 'C' grade, some of the good dominant trees are removed in favour of the more promising dominants. Some suppressed and dominated trees might be left as cover wherever there are big gaps in the canopy. This grade makes considerable difference in the light conditions of the dominant trees.

(5) **E grade (Very heavy thinning) –** This is heavier than 'D' grade thinning involving the removal of a larger number of dominant trees compared to grade 'D', subject to the condition that no lasting gaps would be created in the canopy. Some suppressed and dominated trees are left as soil cover. Formerly, this grade was applied for research purpose, but is now being used for some species.

1.1.4 Stocking in various grades of ordinary thinning

Assuming 'C' grade as normal stocking, the stocking of other grades of thinning are –

- B Grade – 1.1 to 1.3
- C Grade – 0.9 to 1.1
- D Grade – 0.7 to 0.9
- E Grade – 0.5 to 0.9

1.1.5 Application of ordinary thinning

Ordinary thinning is applied under the following conditions**.**

- It is generally applied to light demanders such as Chir, Sal , Teak, Sissoo etc., because in the case of light demanders the suppressed and the dominated do not retain power of recuperation and are likely to die.
- Where there is market for small sized timber
- Applicable for areas infested with climbers and where there is danger of crown fire.
- Applicable for sites where there is little danger of soil deterioration as a result of removal of suppressed and dominated trees.

1.2. Crown thinning

In ordinary thinning the primary focus is on removal of suppressed and dominated trees, some of which are also retained to afford soil cover. However, the beneficial effect of ordinary thinning on the remaining dominant trees remains doubtful. Therefore, another system of thinning has evolved where growth of dominant trees is facilitated by removing inferior trees from among the dominant class, ignoring the dominated and suppressed class. This is called crown thinning as it involves removal of trees mostly from the upper crown classes.

1.2.1 Definition

Crown thinning is defined as a method in which thinning is primarily directed to the dominant trees in a regular crop, the less promising ones being removed in the interest of the best available individuals; the dominated and the suppressed stems are retained unless they are dead, dying or diseased.

1.2.2 Basic Principles of Crown thinning

- Better individuals in the dominant class which promise good value as future crop should be facilitated immediately by felling inferior trees in the dominant class.
- The heaviest felling is in the dominant class; only those suppressed and dominated trees are felled which are dead, dying or diseased, or interfering with the growth of good dominant.
- As compared to ordinary thinning, crown thinning results in more rapid diameter increment of future crop, with considerable shortening of the rotation period.
- A higher cash return is obtained through the felling of big-sized trees.
- The vertical closure of the stand resulting from the retention of lower canopy classes affords maximum protection to the soil.

1.2.3 Grades of Crown thinning

The following two grades of crown thinning are recognized.

(1) **Light Crown thinning (L.C Grade)** – This grade involves removal of dead, dying and diseased trees in all the canopy classes, defective dominants and some better dominants in favour of the more promising dominant individuals. Suppressed and dominated class are left intact. This is very similar to D grade ordinary thinning, except that it retains the suppressed and dominated class.

(2) **Heavy Crown thinning (H.C Grade) –** In addition to trees removed in L.C Grade, a still larger number of dominant trees is taken out leaving the best selected dominant stems uniformly distributed over the area.

1.2.4 Application of Crown thinning

This thinning is suitable and applicable in the following cases.

- Crown thinning is suitable for shade-bearing species, because such species in the dominated class continue to grow and retain the power to respond to improved light conditions later.
- This thinning is suitable for localities where there is danger of frost, snow, drought, wind damage etc. If some of the dominant trees die, their place can be filled in by the trees in the dominated class.
- It is applicable for drier and arid regions where there may be danger of site deterioration. In the case of crown thinning, retention of suppressed and dominated class ensures vertical closure of the stand and minimizes the danger of soil deterioration.
- It is suitable for localities where there is a market only for relatively big-sized timber.

2. Thinning in irregular crops - Selection Thinning

The thinning carried out in an irregular forest is called **Selection Thinning**. It is defined as a method of thinning directed to obtain and /or maintain selection composition in a crop, with all diameter classes adequately represented. (L S Khanna 1999). It is one of the most difficult thinning operations. It requires a high level of technical skill as all age classes are present on every unit area and there is no crown differentiation like what is visible in a regular forest.

2.1 Selection thinning is carried out in **all canopy classes** removing trees of the following classes.

- Dead, dying and diseased trees;
- Inferior trees which restrict the development of their neighbours from all sides;
- Less valuable stems in favour of more valuable stems of the same species;
- Trees of less valuable species in favour of the more valuable species, provided the less valuable species are not required for the purpose of getting a suitable mixture;
- Groups of advance growth wherever they occur will be thinned and freed from overhead suppression.

Reference Materials:

1. L S Khanna 1999 Principles and Practice of Silviculture, Khanna Bandhu, Dehradun
2. A.B Lal 1967 Indian Silviculture, Jugal Kishore & Company, Dehra Dun

Lesson 19 & 20

2 hours

Lesson Plan

Objective:

To undergo On-the-job training

On

Tending (weeding-cleaning) and Thinning

Backward Linkage: Lesson 16, 17 and 18

Forward Linkage: Nil

Training materials required:

- Copies of Lesson 16, 17 and 18
- Implements and materials to demonstrate tending and marking for thinning

Allocation of time:

On-the-job training

- **Tending (weeding-cleaning)** **45 mts**
- **Thinning** **1 hr 15 mts**

The trainees may visit

- some young plantations and have on-the-job training on the methods of tending operations like weeding and cleaning.
- Some regular forest stands, yet to be thinned, and have on-the-job training to identify trees to be removed on some prescribed grade of thinning.