UNIT 2 FORESTRY

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2.1 INTRODUCTION

As you know, climate is defined as the weather conditions of an area which are averaged over a long time period, taking into account the weather extremes that are likely to occur. Climate change is a serious challenge for all of us. The changing climate not only encompasses rise in average global temperatures but also includes extreme weather events, affecting productivity of plants and trees, wildlife populations and their natural habitats, sea level rise and range of other impacts. The existing knowledge on the impacts of global climate change on our natural forest resources is limited.

Globally, forests cover about one third of world’s land surface and make up habitat to nearly 80-90% of the world’s terrestrial biodiversity such as plants, animals, birds and insects. More than half of the world’s total forests trees are found in just five big countries viz. Brazil, Canada, China, Russia and USA. As we know, forests and climate are intimately intertwined. Forests have played a very significant role to regulate the climate, rainfall, groundwater and soil of the earth over millennia. Forests not only provide food, fodder, fibre, fuel and shelter, but they also play a crucial role in overall environmental conservation. The forest trees act as a regulator to balance the atmospheric oxygen and carbon dioxide. It has been estimated that forests and forest soils currently store more than one trillion tons of carbon in the world, which is twice the amount present in the atmosphere. In recent times, many research studies
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have been conducted to understand various impacts of climate change on our natural environment, water resources, types of vegetation and wildlife. As you know, climate change is directly related to global emission of greenhouse gases especially carbon dioxide. As the process of climate change is a complex phenomenon, it is not easy to understand the impacts of climate change on forestry.

To understand the significance of climate change on forests due to global warming, it is necessary to know something of the forest types found on the earth. There are mainly three types of forests found around the world related to climate regimes. They comprise of the equatorial and tropical forests; the temperate forests and forests associated with colder climates.

There are many studies to indicate that Earth is warming from North Pole to South Pole. Studies indicate that the global average surface temperature has increased by more than 1.6 degrees Fahrenheit (0.9 degree Celsius) or even more in sensitive Polar Regions since 1906. The event of global climate change is a serious challenge faced by the international community. The greenhouse gases which contribute to the heating of the globe include carbon dioxide (CO₂), methane (CH₄), nitrous oxide (NO) and chlorofluorocarbons (CFCs).

According to IPCC 2007 report, the average global air temperature near the earth’s surface has been estimated to increase at the rate of 0.74 ± 0.18°C (1.33 ± 0.32°F) during the past century. Various ecosystem and climate models suggest that climate change will have a variety of impacts on the distribution of forest organisms and populations as well as impact ecosystem function and its species composition. In general, it is expected that natural habitats will shift towards the Polar Regions and move upwards in elevation. With the shift of these natural habitats, forest biodiversity will be forced to adapt and as a result, species compositions in forests is likely to change and those species and populations which are already vulnerable will potentially become extinct. Further, it has also been estimated that with climate change there will be a greater incidences of extreme climatic events, such as heavy rains, heat waves, floods and droughts. These types of extreme events will further affect forest trees, plants and animal populations and can leave forests more prone to disturbances such as frequent and intense forest fire, pests and disease outbreak. Forest ecosystems, which are expected to be particularly more vulnerable to the impacts of climate change, include mangroves in coastal zones, boreal and tropical forests.

The climatic models have predicted a 0.3 degree Celsius rise in average global temperatures per decade over the next century. This has been attributed to the increase in the amount of carbon dioxide present in the atmosphere, which has risen by about 25 per cent in the last 150 years. Since the problem of climate change is global in nature, it requires a global solution, which can be made possible by serious research, shared knowledge and engagement of people at all levels. Within climate change, particular attention needs to be paid to the unique challenges being faced by the developing countries.

The Intergovernmental Panel on Climate Change (IPCC) has projected that change in the frequency and severity of extreme climate change events will have significant impacts on the productivity of forests and agriculture. It has also projected that water scarcity will aggravate leading to increase in environmentally induced migration. The IPCC’s assessment report highlighted the potential
impacts of climate change on forest ecosystems. It has been projected that an increased surface temperature of more than 2°C above pre-industrial levels are likely to result in substantial changes in the structure and functions of forest ecosystems (Fischlin et al. 2007). In this unit, we would be discussing direct and indirect effects of global warming on forest. Further, the potential of forests as carbon sink shall be discussed.

2.2 OBJECTIVES

After studying this unit, you should be able to:

- explain the direct and indirect impacts of global warming on forest; and
- explain the CO₂ fertilization effects and net primary production.

2.3 FOREST BIODIVERSITY

A warmer climate and higher concentration of CO₂ in the atmosphere will affect the growth, development, survival and reproduction of forests trees, perhaps even changing the nature and extent of forest cover. Many people think of global warming and climate change as synonyms, but scientists prefer to use “climate change” when describing the complex shifts now affecting our planet’s weather and climate systems. The event of climate change encompasses not only rising average global temperatures but also extreme weather events.

The term ‘biodiversity’ refers to the variety of living organisms at all levels of organization (flora, fauna, microorganisms, etc.), ranging from species through gene, to higher taxonomic levels, including the variety of habitats and ecosystems, as well as the processes occurring therein. Forest biological diversity is a broad term that refers to all life forms found within the forested areas and the ecological roles they perform to maintain ecosystem balance. As such, forest biological diversity comprises not only a variety of forest trees, but also the multitude of plants, animals and micro-organisms that inhabit the forested areas and their associated genetic as well as specific diversity. The most biologically diverse and complex forests are tropical rainforests, which produce nearly 40% of Earth’s oxygen and store more than any other land-based ecosystem.

In the Indian sub-continent, forest vegetation is distributed mainly in four distinct geographical zones- the Himalayas, the Vindhyas, and the Western and Eastern Ghats. India is also considered as one of the 12 mega-biodiversity rich countries having a very wide variety of flora and fauna. It has almost 7% of world’s biodiversity and support 16 major forest types, varying from mangroves in the coastal regions, alpine pastures in the Himalayas to temperate, sub-tropical and tropical forests.

It has been estimated that over the past 150 years, deforestation has contributed to an estimated 30 percent of the atmospheric build-up of CO₂. It is also a very significant driving force behind the loss of genes, species, and ecosystems. It is expected that due to global warming, there would be large scale shifting of forest biomes throughout India. A study on ‘Investigating Climate Change in India’ (2005) was conducted under a joint project of Department of Environment, Food and Rural Affairs (DEFRA), UK and MOEF, India to understand the climate change scenario for India. The studies suggest that as much as 85% of the India’s forests will change due to climate change by 2030-
The highest impact is expected to be on the teak and sal forests of central and eastern regions and the temperate Himalayan region. Nearly 85% of the forest grids of the country would change their type. Forest cover in the Western Ghats and forests of the Northeast region would be impacted comparatively less.

Climate change is predicted to result in a large scale shifting of forest biomes throughout India. It has been estimated that forest cover in India, is dominated by the tropical dry forest type (nearly 37.2%), followed by dry savanna type (nearly 33%) and moist savanna types (nearly 32.5%). It has been projected that tropical dry forest and tropical seasonal forest types (28.4%) becoming dominant forest type. Xeric scrubland, to a smaller extent, is set to decrease in area and xeric woodland is expected to increase in the drier regions. The forest types in the colder regions, boreal and temperate conifer coverage is projected to decrease while temperate deciduous and temperate evergreen coverage increases. This projected shift in forest vegetation may lead to large-scale forest dieback and loss of rich biodiversity especially during the transition between forest types.

Forest biological diversity can be considered at different levels, including the ecosystem, landscapes, species, populations and genetics. Complex interactions can occur within and amongst these levels. In biologically diverse forests, this complexity allows organisms to adapt to continually changing environmental conditions and to maintain ecosystem functions. In the annex to decision II/9, the Conference of the Parties (COP 2) to Convention on Biological Diversity recognized that: “Forest biological diversity results from evolutionary processes over thousands and even millions of years which, in themselves, are driven by ecological forces such as climate, fire, competition and disturbance. Furthermore, the diversity of forest ecosystems (in both physical and biological features) results in high levels of adaptation, a feature of forest ecosystems which is an integral component of their biological diversity. Within specific forest ecosystems, the maintenance of ecological processes is dependent upon the maintenance of their biological diversity”.

### 2.4 DIRECT AND INDIRECT EFFECTS OF GLOBAL WARMING

According to Koch and Mooney (1996), the direct effects of global warming on forest ecosystems will be more complex than the direct effects of increased CO$_2$ concentration because temperature fluctuations influences all the physico-chemical and biological processes in any ecosystem, whereas the direct influence of CO$_2$ is almost entirely limited to leaves (photosynthesis, stomatal aperture, and perhaps respiration). For both rising temperature and increasing CO$_2$ concentration, however, the greatest obstacles to understanding the effects lie in the web of indirect effects resulting from interactions among various processes affected directly by environmental changes. These interactions lead to feedbacks that are sometimes positive and sometimes negative. Therefore, the responses to changing temperature or CO$_2$ concentration due to climate change can be expected to vary among different ecosystems both in terms of magnitude and direction depending upon the properties of the dominant species, interactions among various species, and the initial physical and chemical environmental conditions.
The impacts of rising temperature on the carbon budget of an ecosystem provides an example of this complexity. The Net Ecosystem Production (NEP) is defined as the overall carbon balance of an ecosystem over a period of time and it has two major components, Net Primary Production (NPP) and Heterotrophic Respiration ($R_h$). Net Primary Production (NPP), the principal input of carbon to the natural ecosystem, is the net result of CO$_2$ fixation by the process of photosynthesis and loss of CO$_2$ through plant respiration. The product of NPP is new organic matter in the plants, which gets accumulated initially in plant parts as living biomass and is eventually transferred to soils as litter and to animals and decomposer organisms as food. Heterotrophic respiration ($R_h$) represents the loss of carbon from the ecosystem by respiration of animals and decomposers; the products of $R_h$ include CO$_2$ and other inorganic carbon products (e.g., CH$_4$). The process of NPP and $R_h$ both are directly affected by temperature change. In response to temperature, both are usually increased by warming, although $R_h$ often increases more rapidly in the short term. In addition, rising temperature could also affect NPP and $R_h$ indirectly by altering the ecosystem’s moisture regime, nitrogen availability, length of its growing season, or species composition. The climate change induced changes in the “soil moisture”, “nitrogen availability”, or “species composition” may cause effects on processes such as “litter quality and quantity”, and eventually causing carbon loss either through forest fire or leaching.

In case of many ecosystems, the indirect effects of increases in temperature on “carbon dynamics” are likely to be significant than the direct effects of temperature increase. For instance, northern forests, and tundra forests which are constrained for nutrients are reported to be more responsive to “changes in nutrient availability” particularly in the short term. In case of dry ecosystems, high temperature increase the evaporation rate and water loss; and eventually limit soil and plant processes. Further, the temperature increase have potential to disturb the interaction between the species, and consequently influencing the “carbon turnover”, “NPP”, and “$R_h$”. Global warming is expected to affect essentially all ecosystem processes and pools of organic matter in the forests but at different rates. As the processes occurring within the ecosystem and the organic pools are linked through cycles, the magnitude of the ecosystem change may vary with time.

2.4.1 Negative Impacts of Climate Change

It has been reported that the increase in global average temperature may bring in changes in spatial distribution of forest trees, changes in species composition, forest productivity, health, biodiversity richness and life of forest trees. There are ample evidences in the fossil records to show that plants and trees have undergone significant range shifts in response to changing climates in due course of time. If the change in climatic condition is gradual, the tree species could respond through adaptation and migration. However, anthropogenic induced climate change occurs over a relatively short time period of few decades and is not gradual. Therefore, so many forest tree species may not be able to respond to the climate change and ultimately may become extinct. The situation is quite alarming given the fact that the earth has witnessed an increase of 0.74 °C temperature in the last century. It has also been projected that the climate change could alter the frequency and intensity of forest disturbances such as insect outbreak, invasion of exotic species, wild forest fires and severe storms. These disturbances could lead to reduction in forest productivity and may cause
alteration of distribution of plant and tree species in the forests. In some cases, forest can recover from such disturbances. In some other cases, existing species may shift their range or die out due to climate change, leading to a new forest type due to growth and development of new vegetation.

In a favourable atmospheric temperature, increasing concentration of CO$_2$ increases the growth of plants subject to availability of sufficient soil nutrients and water in adequate quantity. For example, since the high altitude areas of the Himalaya region are generally poor in soil nutrients, climate change may have a negative effect on the rate of photosynthesis in such areas leading to lower productivity. The change in vegetation distribution and species composition of forest may not guarantee a shift in the companion plant and animal species. The climate change is assumed to have more effect on the less mobile fauna.

Recent studies have indicated that the negative impacts of global climate change on forests may be more severe than previously believed and that the potential positive impacts have been overestimated. The negative impacts of climate change will include biome redistribution, increased occurrence of forest fire and accelerated infestation of wild weeds and other pests and insects.

2.4.2 Poleward Shift in Vegetation

A change in climate would be expected to shift plant distribution as species expand in newly favorable areas and decline in increasingly hostile locations. The global climate change resulting due to increasing temperature and subsequent changes in the resource availability may shift tree species poleward in latitude and upwards in elevation. Research studies have shown a typical pattern in species distribution, which include northward range shifts during the last two 20th century warming periods (1930-45 and 1975-99), and southward shifts during the intervening cooling period (1950-70). Many studies suggest that global warming is driving species ranges poleward and towards higher elevations at temperate latitudes, but evidence for range shifts is scarce for the tropics, where the shallow latitudinal temperature gradient makes upslope shifts more likely than poleward shifts.

2.4.3 Pest and Disease Outbreak

It is also expected that the global climate change could significantly contribute to an increase in the severity of future insect outbreaks. Since insects feed on leaves, insect outbreak often leads to trees defoliation, and subsequently killing a large number of forest trees. Rise in temperatures may promote and enable some insect species to reproduce, grow and develop faster, alter their seasonal life-cycles, and expand their ranges northward. Invasive plant species can also displace and replace important native vegetation species because the invasive species often lack natural predators. It is expected that the climate change would benefit invasive wild plants that are more tolerant to changed environmental conditions resulting from climate change than the native plants species.

2.4.4 Wildfire

The events of fire in any forested area, whether wildfire or controlled burning, has an important role to contribute to the global warming. Forest fire causes
immediate release of a large quantity of CO$_2$ and smaller amounts of other gases, including methane, a much more potent greenhouse gas than carbon dioxide. Destruction of forest stands due to forest fire will also reduce the total amount of photosynthesis and therefore, contribute to an increase in atmospheric concentration of CO$_2$. Forest fire is a major disturbance factor and common phenomenon in most of the forests. Availability of large quantity of ignition sources and flammable materials in the forests facilitate the frequent occurrence of forest fire in vegetated areas in all ecosystems (Omi 2005). The event of global climate change is projected to increase the extent, intensity and frequency of wildfires in certain forest areas. Warmer spring season and high summer temperatures, coupled with decreases in water availability, accumulation of dried leaves and woody materials in forests can increase the risk of wildfire. Forest fires can also contribute to climate change, since they can release large quantity of CO$_2$ in the atmosphere in a very short time.

Some forest ecosystem are naturally adapted to forest fire and require it for nutrients recycling and creating favourable conditions for germination and growth of certain native species (FAO 2010; IUCN and WWF 2000). Fire on the other hand is also considered as one of the major drivers of deforestation and forest degradation and one of the major sources of emission of greenhouse gases; forest fire has a big share in forestry sector’s 17.4 % of the total global emissions of greenhouse gases. Although, 63 % of the global forest area witnesses fire every year and forest fire, particularly uncontrolled, causes substantial loss to forest biomass, soil, air, water, and forest functions and services.

2.5 CO$_2$ FERTILIZATION EFFECT AND NET PRIMARY PRODUCTION

The Earth’s atmosphere is a composition of many gases. The water vapour and carbon dioxide are the two most abundant greenhouse gases in the atmosphere. Both are transparent to visible incoming sunlight, while each traps heat outgoing from the Earth’s surface, although the responses of ecosystem to temperature increase are diverse and complex. It is reported that increase in atmospheric carbon dioxide concentration through carbon dioxide fertilization effect increase production and productivity of forests. Long term Free-air CO$_2$ enrichment (FACE) studies reported that under 2 x CO$_2$ climate scenario, the average net primary productivity (NPP) increased by 23% in young tree stands (Kirilenko and Sedjo, 2007). It is an established fact that increasing CO$_2$ concentration increases plant growth (Graves and Reavey 1996). Forest productivity is generally higher in warmer, and moist climates. Carbon dioxide is required for photosynthesis, the process by which green plants uses sunlight for their growth and development. In a condition when sufficient water and nutrients are available, an increase in atmospheric CO$_2$ may enable trees to be more productive, which may also change the distribution of tree species. Growth of trees will be highest in nutrient rich soils with abundant water and will decrease with decreasing fertility and water supply.

The effect of CO$_2$ on the plant productivity may be influenced by some factors, such as availability of soil nitrogen, plant acclimatization and availability of water. Under low nitrogen conditions, plants will have difficulties to transform elevated CO$_2$ into production of organic matter. Moreover, in the long term, elevated CO$_2$ condition may cause the accumulation of carbohydrates in the plant tissues.
which may reduce the photosynthetic rates or decrease photosynthetic response to elevated CO₂.

While deforestation is responsible for about 20 percent of greenhouse gases, overall, forests currently absorb more carbon than they emit. The problem, according to scientists, is that this critical carbon-regulating service of forests could be lost entirely if the earth heats up to 2.5 degrees Celsius or more relative to pre-industrial levels, which is expected to occur very soon, if emissions are not substantially reduced. Further, higher temperatures due to global warming, along with the prolonged drought periods, more intense pest invasions, and other environmental stresses that could accompany climate change, would lead to considerable forest destruction and degradation (Seppala, et al 2009).

Check Your Progress 1

Note: 1) Use the space given below for your answers.
                          2) Check your answers with those given at the end of this unit.

1. What is the Net Primary Production?
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2. What is Heterotrophic Respiration?
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2.6 FOREST AS A CARBON SINK

Carbon dioxide (CO₂) is produced by the combustion of woods, fossil fuels and other materials. It is also a principal by-product of the respiration of all living organisms on the earth including trees. In the nature, carbon dioxide is naturally captured from the atmosphere through physical, chemical or biological processes. Naturally, forest trees and plants help by removing carbon dioxide from the atmosphere and converting it into carbon compounds, during photosynthesis, which they store in the form of wood and vegetation, a process referred to as carbon sequestration. In other words, carbon sequestration is the process involved in carbon capture and the long-term storage of atmospheric carbon dioxide or other forms of carbon to either mitigate or defer global warming and avoid dangerous effects of climate change. It has been proposed as a way to slow the atmospheric and marine accumulation of greenhouse gases, which are released by burning of fossil fuels. After oceans, forests are the world’s largest storehouses of carbon, and are known as carbon sinks because they absorb the greenhouse gases that cause climate change.

The world’s forests collectively form a major locus of photosynthetic activity and therefore play a very significant role in regulation of earth’s carbon cycle and in the global warming equation. As a tree increases in size, it accumulates
more and more CO₂ from the atmosphere, converting it into the organic compounds in wood. As long as the tree is alive and growing, that carbon will remain in storage; hence the description of forests as a “sink” or reservoir for atmospheric carbon. Trees are generally about 20% carbon by weight. The amount of carbon stored or absorbed by forests is basically dependent upon the species of trees and their age. The overall biomass of forests trees also acts as a carbon sink with the organic matter stored in forest soils – such as the humus produced by the decomposition of litter, leaves and dead plants. Forest soils store even larger amounts of organic carbon than do forest stands. There are also large areas of peat deposits, which are rich in organic carbon, throughout the northern coniferous forest zone.

The trees and soils of the world’s forests are storing more than a quarter of the world’s carbon emissions. India is having over 100 million hectares of wasteland and degraded forests, hence, carbon emission mitigation through the forest sector and afforestation seems like an attractive option.

However, using forest trees as carbon sinks has been a contentious issue. As forests are lost or degraded, they can become sources of harmful greenhouse gases instead of carbon sinks. Creating new forest areas would require the creation of entire ecosystems. It is also criticized for being a quick fix that doesn’t tackle the root causes effectively and doesn’t lead to, or promotes actual emissions reduction.

### 2.7 FORESTS UNDER PRESSURE

Deforestation and forest degradation are the largest sources of CO₂ emissions after the combined emissions from all automobiles such as cars, trucks, trains, planes and ships in the world. Changing agricultural practices and increasing urbanization, due to increasing population and change in food habits, is responsible for most of the world’s deforestation. Illegal and unsustainable wood logging, usually resulting from the rising demand for cheap wood and paper, is responsible for most of the degradation of the world’s forests. The threats are so severe that in the last 25-30 years alone, the world has lost a forested area almost equivalent to the size of South Africa. The biggest forest area loss in the last two decades has been in the tropical regions, particularly Africa and South America.

It has been estimated that more than 80% of deforestation is likely to happen in just 11 places between 2010 and 2030. If the present scenario continues as usual, more than a quarter of the Amazon forests could be treeless by 2030, and we could see a global loss of forest cover equivalent to the size of Germany, France, Spain, and Portugal combined. The amount of wood we take from forests and plantations each year may need to be tripled by 2050 to meet the world’s growing demand for wood, forest products, timber, etc. placing additional pressure on our natural forests.

### 2.8 REDD AND REDD+

The concept of Reducing Emissions from Deforestation and forest Degradation (REDD) was first discussed in Conference of Parties 11 (COP 11) to the United Nations Framework Convention on Climate Change (UNFCC), 2005. India being one of the participating countries proposed the concept of “Compensated...
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Conservation” which is intended to compensate the countries for maintaining and increasing their forest cover as carbon pools.

REDD+ provides a kind of solution to address the drivers of forest loss in developing countries. The framework has been created under the UNFCCC, intended to offer financial incentives to developing countries for reducing carbon emissions from deforestation and forest degradation (REDD), as well as to conserve and enhance their carbon stocks and sustainably manage their forests (the plus in REDD+). But REDD has several significant inbuilt flaws, in particular, it permits the replacement of natural tropical forest with tree plantations; and it would increase net emissions of carbon to the atmosphere, if carbon offsetting were involved.

Besides, the big corporate players, who are responsible for many a problem related to large scale commercial logging, extensive mining, pushing monoculture plantations and crops, etc., take advantage of such schemes and incentives to present a “clean” front, many of their objectionable activities hidden behind a Clean Development Mechanism (CDM) driven carbon sink projects.

The available scientific technologies does not enable prediction of exactly how much quantity of carbon is being absorbed by a country’s forest sinks and whether the carbon moving into forests or soils will actually stay there. Besides this, we also know that trees fixes carbon only during growing periods and after reaching maturity become carbon neutral, hence reforestation seems only as a temporary solution.

Lastly, commodifying forest carbon is inequitable, since it discriminates against the native people who previously had free access to the forest resources. Carbon sink projects and REDD, refocus attention on a key dilemma – to whom do forests belong to? And who has the rights to sell forest carbon credits? And how does one quantify and put value to what forest-dwellers do i.e. protect forests? Since forests act as a sink for greenhouse gases, it helps to mitigate the effects of climate change.

In the Millennium Ecosystem Assessment report, it has been reported that the amount of carbon stored in the world’s forests is somewhere between 335-365 billion tons. However, land use change (largely resulting from deforestation) is hindering the carbon sequestration abilities of forests. As forest ecosystems are important sinks for carbon, their loss has serious implications for climate change. Many aspects related to climate change such as increase in temperature, changes in rainfall pattern, and increased CO$_2$ concentration, are likely to affect growth, development and productivity of forests trees. The climate change has direct and indirect effect on the growth and productivity of forests through changes in temperature, rainfall pattern, weather condition and other factors.

### 2.9 LET US SUM UP

Climate change is a serious challenge for all of us. The changing climate not only encompasses rise in average global temperatures but also includes extreme weather events, affecting productivity of plants and trees, wildlife populations and their natural habitats, sea level rise and range of other impacts. Forests and climate are intimately intertwined. Forests have played a very significant role to regulate the climate, rainfall, groundwater and soil of the Earth over millennia. As forest ecosystems are important sinks for carbon, their loss has
serious implications for climate change. Many aspects related to climate change such as increase in temperature, changes in rainfall pattern and increased CO$_2$ concentration, are likely to affect growth, development and productivity of forests trees. The climate change has direct and indirect effect on the growth and productivity of forests through changes in temperature, rainfall pattern, weather condition and other factors. In this unit, we have discussed the direct and indirect effects of global warming on forests. Further, the potential of forests as carbon sink was discussed.

### 2.10 KEYWORDS

- **Carbon dioxide (CO$_2$)**: The enhancement of the growth of plants as a result of increased atmospheric carbon dioxide (CO$_2$) concentration.

- **Fertilization**: Any process, activity, or mechanism that removes a greenhouse gas, an aerosol, or a precursor of a greenhouse gas or aerosol from the atmosphere.

- **Sink**: The upper limit of tree growth in mountains or at high latitudes. It is more elevated or more poleward than the forest line.

### 2.11 SUGGESTED FURTHER READING/REFERENCES


2.12 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress 1

1. The Net Primary Production (NPP), the principal input of carbon to the natural ecosystem, is the net result of CO$_2$ fixation by the process of photosynthesis and loss of CO$_2$ through plant respiration. The product of NPP is new organic matter in the plants, which gets accumulated initially in plant parts as living biomass and is eventually transferred to soils as litter and to animals and decomposer organisms as food.

2. Heterotrophic respiration (R$_h$) represents the loss of carbon from the ecosystem by respiration of animals and decomposers; the products of R$_h$ include CO$_2$ and other inorganic carbon products (e.g., CH$_4$).