6.2 Forestry

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Abstract Forests cover about 30% of the Earth's total land area, harbouring most of the world's terrestrial biodiversity and containing almost as much carbon as the atmosphere. They have many functions, providing livelihoods for more than a billion people, and are of high relevance for biodiversity conservation, soil and water protection, supply of wood for energy, construction and other applications, as well as other bio-based resources and materials such as food and feed. The forestry sector was the first to adopt a sustainability concept (cf. Carlowitz), and sustainable use and management of forests remains an important issue to this day. Forestry is a multifunctional bioeconomic system and has an important function in securing the sustainable resource base for the present and future bioeconomy.

Keywords Forest distribution; Forest types; Natural forests; Planted forests; Forest products; Forest management

Learning Objectives
After studying this chapter, you should:

- Have gained an understanding of forests as distinct ecosystems
- Be aware of the multiplicity of functions and services which forests provide or safeguard
- Be able to explain why forests are an important multifunctional eco- and production system and how they contribute to the maintenance

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of ecosystem services, such as biodiversity protection and climate change mitigation
- Have gained an overview of the major forest types and their distinctive features
- Be aware of the characteristics and specifics of forest management
- Understand the relevance of forests for the bioeconomy

6.2.1 Forestry and Forests

Forestry is the practice and science of managing forests. This comprises the exploitation of both natural and near-natural forests. Near-natural forests are those where the original tree species composition is still apparent and the original ecosystem dynamics have been maintained, at least to some extent. The artificial establishment of forests following either recent or historical removal of the original forest cover ('reforestation' or 'afforestation') is also becoming increasingly important. This can be done with native tree species, which were part of the original forest cover, or with so-called exotic species—species from other ecosystems and often even continents. Forestry thus comprises the utilization, management, protection and regeneration of forests.

It is common understanding that forests are composed of trees. But when can an aggregation of trees be called a forest? Are trees along a road—an avenue—already a forest? Are Mediterranean olive groves or *Eucalyptus* plantations forests? Can recreational parks with scattered trees, e.g. 'Central Park' in New York and the 'English Garden' in Munich, be defined as forests? At first glance, this might not be of relevance since the purpose of such areas is obvious—they are not used, e.g. for timber production. Nevertheless, other areas covered by trees may not be defined as parks, but still fulfil similar important protection tasks or recreational purposes, such as Frankfurt's city forest (Frankfurt a.M. 2017). Therefore, a general definition of a forest could include the following criteria:

- Forests are an accumulation of trees, which are lignified, erect, perennial plants.
- They develop a 'forest climate', which differs considerably from the open land and is characterized by much more balanced temperature fluctuations and extremes, reduced wind speeds and a higher relative humidity.
- This results in characteristic soil properties with usually high-soil organic matter contents.
- The different forest types with their characteristic vertical structures provide a multitude of habitats and ecological niches supporting diverse plant and animal communities.

Since forests play an important role in the bioeconomy, for carbon storage and thus for climate change mitigation measures, a more technical definition is required, which can be used for analyses and statistics. For this reason, the FAO lay down criteria to define forests, which can be found in Box 6.7:

Box 6.7: Forest Definition According to FAO (2000) (Shortened and Simplified)

– Covers natural forests and forest plantations, including rubber wood plantations and cork oak stands.
– Land with a *tree canopy* cover of more than *10%* and an *area* of more than *0.5 ha*.
– Determined both by the presence of trees and the absence of other predominant land uses (cf. agriculture).
– Trees should be able to reach a *minimum height of 5 m*.
– Young stands that have not yet but are expected to reach a crown density of 10% and tree height of 5 m are included under forest, as are temporarily unstocked areas.

(continued)

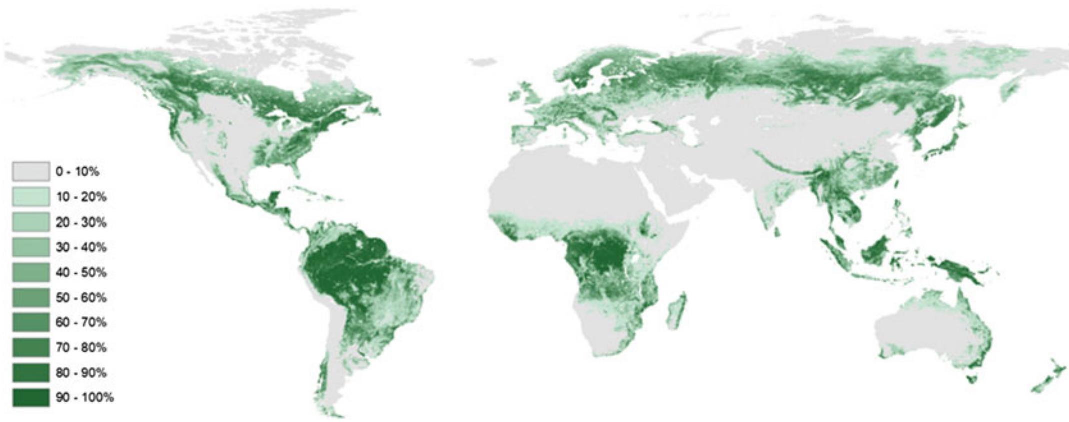

Fig. 6.15 Global extent of forest areas (based on FAO 2010)

Box 6.7 (continued)

Excludes:

– Stands of trees established primarily for agricultural production, for example, fruit tree plantations, and also agroforestry systems or short rotation coppice plantations.

Table 6.7 Global forest area and regional distribution (based on FAO 2015a)

Region/subregion	Forest area 1000 ha	Forest area % total forest area
Eastern and Southern Africa	267,517	7
Northern Africa	78,814	2
Western and Central Africa	328,088	8
Total Africa	674,419	17
East Asia	254,626	6
South and Southeast Asia	294,373	8
Western and Central Asia	43,513	1
Total Asia	592,512	15
Russian Federation (RUF)	809,090	20
Europe excl. RUF	195,911	5
Total Europe	1005,001	25
Caribbean	6933	0
Central America	19,499	0
North America	678,961	17
Total North and Central America	705,393	17
Total Oceania	191,384	5
Total South America	864,351	21
World	4033,060	100

6.2.2 Forest Distribution, Floristic Regions and Forest Types

6.2.2.1 Global Forest Distribution

Most regions of the Earth with a suitable climate (sufficient water availability and minimum length of growing season) were originally covered by forest. Since humans began to colonize the planet, forests have been exploited for resources and cleared, especially for agricultural production (cf. Albion 1926). Figure 6.15 provides an overview of the global distribution of forests, and Table 6.7 shows the forest cover by region. In Fig. 6.16, the countries with the largest forest areas are listed.

6.2.2.2 Floristic Kingdoms and Forest Types

There are several approaches to distinguish and classify the natural vegetation of the Earth. A key criterion of all approaches is the floristic distinctiveness of an area. A major classification of the Earth's vegetation based on the endemicity and the presence or absence of taxa is the formulation of floral kingdoms, a concept first suggested by Good (1947) and later elaborated by Takhtajan (1986). This concept distinguishes

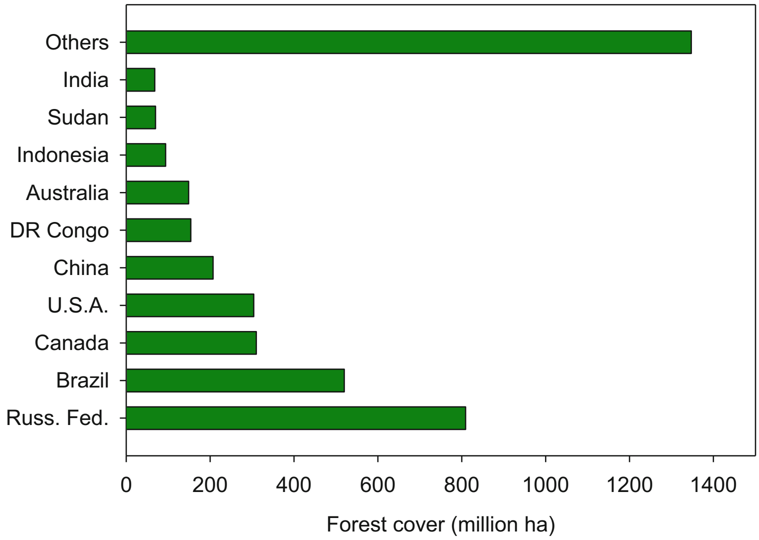

Fig. 6.16 The most important countries in terms of forest area (based on FAO 2015a, b)

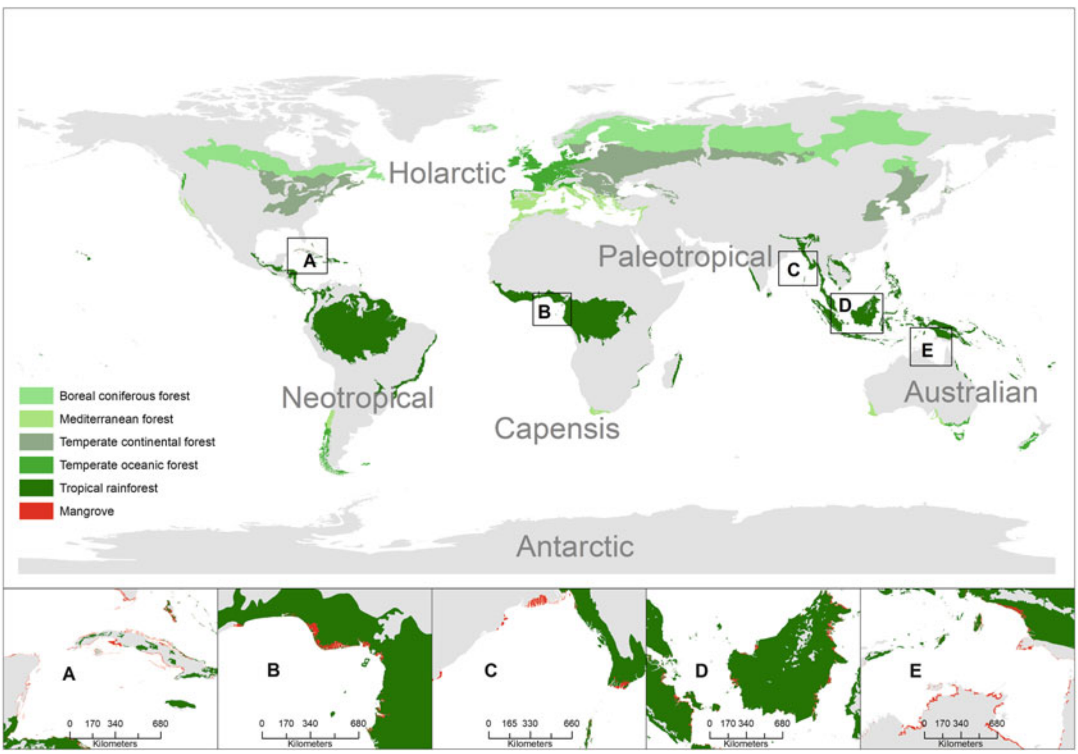

Fig. 6.17 Floristic kingdoms and global extent of important forest types (based on FAO 2010; Giri et al. 2010)

six floral kingdoms—the Holarctic, Neotropical, Paleotropical, Australian, Capensis and Antarctic kingdoms (see Fig. 6.17)—which are further subdivided into floristic regions and provinces. Since the floral kingdoms represent major species groups, they also give an indication of the general usability of the associated forests and thus reflect the bioeconomical potential.

The following overview of the floristic kingdoms lists plant groups of major economic importance together with their common use:

Holarctic

The Holarctic comprises the vegetation in the Northern Hemisphere beyond the tropics and subtropics. The forest types included are the boreal and temperate forests (see below). This huge area is characterized by representatives of important timber-tree families, such as the pine family (Pinaceae) with, e.g. firs (*Abies* spp.), spruces (*Picea* spp.), larches (*Larix* spp.) and pines (*Pinus* spp.), and several broad-leaved tree families such as the beech family (Fagaceae) with beech (*Fagus* spp.), oak (*Quercus* spp.) and chestnut (*Castanea* spp.). Other important timber families are the birch family (Betulaceae) with birch (*Betula* spp.), alder (*Alnus* spp.) and hornbeam (*Carpinus* spp.) and the willow family (Salicaceae) with poplar (*Populus* spp.) and willow (*Salix* spp.). The Holarctic is also a centre of diversity of the rose family (Rosaceae) with its cherries (*Prunus* spp.), apples (*Malus* spp.) and peaches (*Pyrus* spp.). The *Prunus* spp. in particular play an important role in a forest bioeconomy as source of valuable hardwood.

Neotropical

The Neotropical kingdom mainly covers Central and South America. It is of crucial importance as source of food plants such as tomato and pineapple (cf. Vavilov Centers) (Hummer and Hancock 2015). Nevertheless, it is also home to a range of highly valued hardwoods, e.g. true mahogany (*Swietenia mahagoni*) (cf. Anderson 2012), as well as the major provider of natural rubber, the Pará rubber tree (*Hevea brasiliensis*).

Paleotropical

The Paleotropical kingdom covers the huge and very diverse, mainly tropical area from Africa to Southeast Asia. It is particularly important as the origin of the Dipterocarpaceae family, a timber-tree family with several hundred species. This family is the source of important tropical timbers such as meranti, kapur, balau, etc. (Wagenführ 1996). The Combretaceae are another plant family with important timber trees including, for example, *Terminalia* spp. (framiré, limba). The Paleotropical kingdom is also the centre of diversity of the figs (Moraceae).

Australian

The Australian kingdom is the origin of important plantation-tree species, especially *Eucalyptus* spp. (Myrtaceae family). These are a crucial source of pulpwood. In addition, it is a centre of diversity of *Acacia* spp. (Fabaceae family), which also play an important role in tropical tree plantations.

Capensis

The Capensis is of more importance as source of ornamentals than for forestry. It is a centre of diversity of the heath family (Ericaceae).

Antarctic

The Antarctic kingdom includes one tree group of mainly regional importance to a forest bioeconomy, the southern beeches (*Nothofagus* spp.).

The Major Forest Types

While plant kingdoms refer to taxonomic distinctiveness and thus reflect evolutionary processes rather than habitat homogeneity, forest types reflect environmental conditions and are therefore an important classification for ecology, productivity and management options (Table 6.8).

Boreal Forests

Boreal forests cover about 13% of the Earth's land surface. They are found in the Northern Hemisphere, mainly between 50° and 70° north, and comprise the huge conifer-dominated forests of northern Europe, northern Russia, Canada and Alaska, also known as taiga. In the south, they merge with the temperate-mixed and broad-leaved forests. Climatically, they are cold-humid with annual precipitation between 250 and 500 (750) mm, mainly occurring during summer. Despite the regionally very low precipitation, the hydrological balance is usually positive due to

Table 6.8 Total biomass dry matter stock per hectare and net primary production of different forest types (cited in Richter 2001; Busing and Fujimori 2005[a])

Forest type	Dry matter stock per hectare/tonnes	Net primary production/g m^{-2} year^{-1}
Boreal forest	60–400	363–870 (1050?)
Temperate forest	150–500	1090–1775
Temperate pine forest, Oregon, USA	850	1890
Temperate redwood rainforest, California, USA[a]	3300–5800	600–1400 (only aboveground NPP)
Tropical rainforest	200–800 (1100)	3500
Mangroves	-	1700

Fig. 6.18 Large, homogenous tracts of pine forests interspersed with e.g. aspen are a typical feature of the boreal forest (left); fire plays a considerable role in nutrient cycling and forest regeneration (right) (Photos: G. Langenberger)

low evapotranspiration. The area is characterized by extreme temperature fluctuations, with permafrost soils where the average annual temperature drops below 0 °C. The vegetation period is on average 3–5 months, with a maximum of 6 months. The resulting forests are more or less single-layered with a maximum tree height of up to 20 m. It is comparatively poor on species and dominated by pine trees (*Pinus* spp., *Picea* spp., *Larix* spp., *Abies* spp.) and wind-pollinated broad-leaved trees (*Betula* spp., *Populus* spp.). The undergrowth is dominated by dwarf shrubs (e.g. *Vaccinium*), mosses and lichens. Ectomycorrhiza plays a crucial role in this type of ecosystem. Since these forests usually cover old landmasses, such as the Canadian shield, the soils are rather poor (e.g. podzols), and considerable surface humus layers (cf. the occurrence of mosses and *Vaccinium*) can be found. Fire plays a considerable role in these forests. It transforms the accumulated biomass into nutrient-rich ashes and thus initiates the natural regeneration of the forests (Fig. 6.18). Due to their homogeneity and species composition, these forests are an important resource for pulp and paper production.

Temperate Forests

Temperate forests cover about 8% of the Earth's land surface. As with boreal forest, they mainly occur in the Northern Hemisphere. They can be found between 35° and 55°, depending on macroclimatic conditions. The mountain forests of Patagonia and New Zealand can be named as examples of temperate forests in the Southern Hemisphere. Temperate forests are characterized by more balanced climatic conditions than boreal forests. They are humid with precipitation between 500 and 1000 mm/year and rainfall maximum in summer. They experience frost periods, but with much less pronounced extremes. The average annual temperature ranges between 5 and 15 °C, and the vegetation period lasts between 5 and 8 months. They show a pronounced seasonality, often with gorgeous autumn colours, e.g. during the 'Indian summer' in north-eastern USA and Canada.

Temperate forests display a high diversity of, in particular, deciduous broadleaf trees, but also evergreen trees, which can attain considerable dimensions. Tree heights of 50 m have been documented for firs, Douglas firs, oaks and beeches, even in Germany. Economically important species include oaks, beeches, maples, basswood, poplars, cherries, hickories, tulip trees, etc. Conifers such as spruce, fir and pine play an important economic role locally as planted forests. Ecologically, these forests are not only rich in tree species, but are also often characterized by a distinct shrub and herb flora. Geophytes are a typical feature of temperate forests. Two structural layers can often be distinguished. Temperate forests are not homogenous but display a high diversity of tree types depending on local site and microclimatic conditions (Arbeitsgemeinschaft Forsteinrichtung 1985). Another important difference between boreal and temperate forests is the prevailing soil types. Temperate forests mainly grow on young, post-glacial soils, often brown soils. Economically, temperate forests are still important providers of pulp wood, and especially construction timber. The production of maple syrup in eastern North America and of honey in fir forests ('Tannenhonig') can also be mentioned as specialized uses of temperate forests.

The coastal temperate rainforests of the North American West Coast represent a special case of temperate forest. They occur from Alaska down to California along the Pacific coast and its mountain ranges and are characterized by mild winters and moderate summers accompanied by high precipitation. They are dominated by conifers, comprising some of the most impressive tree species in the world including redwood (*Sequoia sempervirens*) (Fig. 6.19), Sitka spruce (*Picea sitchensis*), western red cedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*) and Douglas fir (*Pseudotsuga menziesii*). These forests are of considerable economic importance for the timber industry and are intensively exploited. Most of these species have been tested as exotics in Germany, but only Douglas fir has been established as a common component of German forests. Today it plays a considerable economic role.

Mediterranean Forests

Mediterranean forests are defined by a set of climatic conditions rather than the locality. As such, they not only occur around the Mediterranean

Fig. 6.19 Redwood (*Sequoia sempervirens*) in a Californian national park (note the relative height of the human) and the common clear-cutting practice of West Coast forests in Oregon (Photos: G. Langenberger)

Sea but also in South Africa, California, central Chile and Southern Australia. The respective climate is characterized by mild, rainy winters and very hot, dry summers. The vegetation is sclerophyllous; the trees are evergreen. Although the forests around the Mediterranean Sea were degraded hundreds of years ago, some economically important forest products still play a role to date. The olive tree (*Olea europaea*) provides fruits and oil and is also regarded as a popular timber source. The cork oak (*Quercus suber*) not only produces cork for corking wine bottles but also for use as a very good flooring material. Cork oak stands are formally classified as forests by FAO (2000). The pine *Pinus pinea* produces the pine nuts (pignoli nuts), which are actually pine seeds, used in modern cuisine, for example, in pestos. The argan tree (*Argania spinosa*) of Morocco has recently attracted attention through its oil, which is traded as Argan oil and used in cosmetics but also as a food oil. Historically, the Lebanon cedar (*Cedrus libani*), which was already mentioned in the Old Testament, played an important role as valuable timber source in the Middle East. One of the most important plantation trees, the Monterey pine (*Pinus radiata*), actually originates from California, where it did not play a considerable role. But it proved to be a high-potential plantation species outside its natural habitat.

Tropical Rainforests

Tropical rainforests are the world's most diverse forests. While the climatic conditions in these forests are more or less similar around the world, structure, species composition and usability display distinct differences. Tropical rainforests are characterized by average temperatures between 24 and 30 °C and a minimum average annual temperature of 18 °C. Rainfall exceeds 1800 mm per year. The vegetation is dominated by a high diversity of woody plants, which can attain considerable heights of 30–50 m, sometimes even 70 m. Due to the high diversity, the density of individual species are usually very low, the exception being the dipterocarp forests of Southeast Asia. The high species diversity is also reflected in the structural diversity and associated ecological niches. A common misunderstanding is that tropical rainforests are impenetrable jungles. The opposite is the case, at least in undisturbed forests. Due to the shade created by the high and dense canopy, only little undergrowth develops, and it is easy to walk through the stands.

Three major tropical rainforests are usually distinguished: the American rainforest, mainly comprising the Amazon and Orinoco basins, the Indo-Malayan and Australian rainforest and the African rainforest. All of them are considered important timber sources.

Mangroves

Mangroves (Fig. 6.20) are forests growing in the intertidal zone of tropical and subtropical coastlines, estuaries and deltas (cf. 'Sundarbans' in Bangladesh; see also Fig. 6.17 A–E). Their adaption to regular inundation by saltwater is unique and requires tolerance to salt as well as oxygen shortage (cf. stilt roots, pneumatophores). They are found throughout the tropics and subtropics. Depending on the coastline and tidal dynamics, there can be a distinct zonation of species. Mangroves have been and, in some regions, still are a considerable source of timber, firewood and charcoal as well as tannins. They are of importance as a food source for fish and shells. With their zonation of different tree species, which often stretch a considerable distance into the sea, mangroves can protect shorelines and play an important role in coastal nutrient cycling and as spawning grounds for fish, which find protection in the shallow water and between the often impenetrable stilt roots of, for example, the *Rhizophora* trees. Due to the past heavy exploitation, these functions and services are often obsolete nowadays. Mangroves continue to be threatened by transformation into fishponds, rice fields, resorts and so on.

6.2.2.3 Natural and Planted Forests

Forests regenerate themselves naturally either through succession (cf. pioneer species) following a major disturbance (fire, storm, etc.) or less

Fig. 6.20 Mangroves are an impressive feature of many tropical coastlines (Island of Leyte, Philippines) (Photo: G. Langenberger)

obviously by the replacement of single trees or tree groups in gaps (cf. Box 6.8) after natural mortality or smaller disturbances (lightning, local storm damage, etc.). The same processes more or less apply to human-caused disturbances, such as clear-cutting and selective logging. But since the time and direction of these processes are difficult to steer and manage, they are often replaced by human intervention, and trees are replanted immediately after the harvest. This is called 'reforestation'. When a forest is re-established after a long period of other land uses, such as crop production or cattle ranching, it is called 'afforestation'.

Box 6.8: Pioneer and Climax Tree Species
Two major strategies of tree regeneration can be distinguished: pioneer species, e.g. birches (*Betula* spp.), are adapted to establish on open, often disturbed sites. They require full sun and are generally fast growing and thus especially suitable for the establishment of plantations. They produce huge quantities of volatile seeds (wind dispersal) that establish particularly well on mineral soils. Climax tree species are adapted to regenerate in the microclimate conditions of already existing forests. They are shade-tolerant in their youth, but rather slow growing and much more sensitive to climate extremes (drought, frost). They usually produce far less but larger seeds. They can regenerate under old pioneer species or in gaps in old forests. Typical examples are beech (*Fagus* spp.) and firs (*Abies* spp.).

Artificial regeneration can be practised either with 'native' or 'exotic' species. Exotic species are those that are not native to the region or country. Thus, a native species in one country can become an exotic species in a neighbouring country and vice versa (cf. teak originating from Indo-Burma and nowadays being also planted in Central America, Eucalyptus from Australia planted in Spain, Monterey pine from California planted in New Zealand). The use of exotic species in forestry is often controversially and highly emotionally discussed, in contrast to agriculture, where it is not challenged that actually all commercial crops are exotics. In Germany, there is the interesting case of the Douglas fir (*Pseudotsuga menziesii*), a tree species of high economic value, that originates from western North America. Douglas fir was native to Central Europe before the ice ages, which caused the extinction of many tree taxa in Europe which can nowadays still be found in North America. Douglas fir was successfully reintroduced to Germany at the beginning of the nineteenth century and became an important source of construction timber. It established well in the forest community and can now be classified as naturalized. It is often used to replace Scots pine (*Pinus sylvestris*), which was planted to restore degraded soils in the past, since it is much more productive. Thus, Scots pine is 'native' to Germany but never occurred naturally at the majority of sites it can be found today. Originally, these sites were occupied by broadleaf trees (especially oaks). Therefore, neither Douglas fir nor Scots pine is autochthonous (native) to these sites, and it is debatable whether, ecologically, Douglas fir is worse than Scots pine.

6.2.3 Forest Services and Functions

Forests have accompanied human development from time immemorial. They provided shelter, wood for fire, tools and construction purposes, as well as fruits, mushrooms and meat. And this has not really changed to the present day. But what has changed is the intensity of usage, the sophistication of products manufacture and the improved understanding and greater importance of forests for human wellbeing. Forests have played a special role in the development of mankind due to a complex set of societal perceptions and expectations (cf. Harrison 1992). Nowadays, in addition to the sustainable production of physical goods, forests are expected to provide a multitude of services. This has resulted in restrictions in management practices that far exceed those of agricultural production, including tree species selection, mode of management, forest protection, application of agrochemicals and even mode of harvesting. This section gives an introduction into the modern usage of forests, distinguishing between their traditional function as physical resource provider and the contemporary function of non-physical service provider.

6.2.3.1 Products from Forests

The Tree as Major Source of Forest Products
A tree is defined as an erect, lignified plant composed of three major functional units, namely, root system, trunk and crown (Fig. 6.21). Thus, it comprises a below-ground and an above-ground component, which is of importance when calculating biomass and carbon sequestration potentials. The main tree parts that are used for economic purposes are the stem and major branches. Stump and roots, minor branches and leaves usually remain in the forest to maintain organic matter and nutrient cycling, since the majority of forests are not fertilized, in contrary to forest plantations.

The root system anchors and stabilizes the tree in the soil. It ensures the provision of water and nutrients, usually supported by a symbiosis

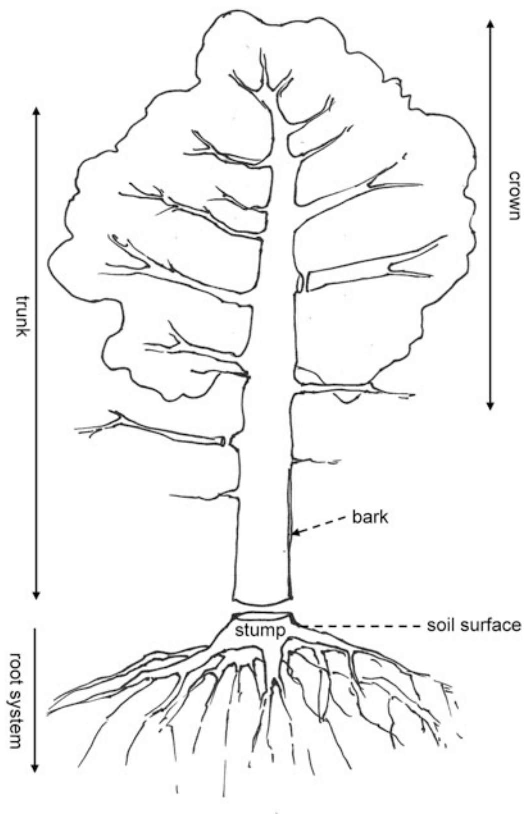

Fig. 6.21 The major components of a tree (from Young et al. 1964, simplified)

between the tree and fungi referred to as 'mycorrhiza', which is specific to the tree species. The trunk merges via branches into the crown and connects the root system with the leaves, which serve as photosynthetic units. It transports the water and nutrients absorbed by the root system in its central, woody part, the xylem, via the branches to the leaves. In return, the assimilates produced by the leaves are transported downwards in the phloem, which is located in the inner side of the bark. These assimilates are used for tree growth, including root growth and regeneration, and to provide food for the mycorrhiza. The tree crown usually begins where the trunk starts to divide into a hierarchy of branches, at the ends of which the leaves are found. This is however strongly dependent on the age and position of the tree in the population. While the crown of young trees reaches down to the soil, old trees often have a long straight bole without any branches, especially in dense forests. Solitary trees can retain their low branches throughout their entire lifespan. The tree root system needs to be flexible in order to adapt to different site conditions. Three major types of root system can be distinguished: the taproot system, heart-root system and sinker root system (Fig. 6.22).

The taproot system is based on a central, dominant root supplemented by side roots. This system provides very stable anchorage and is typical for oaks, firs and pines, but also the Neotropical rubber tree *Hevea brasiliensis*. The heart-root system does not have a clear root hierarchy, but rather spreads homogenously in the soil. It is fairly typical for a wide variety of species, such as birches and beeches. The sinker root system is characterized by a dominant horizontal root system near the soil surface from which vertical sinker roots develop that can reach considerable depths. Since the sinker roots are sensitive to waterlogged and compacted soils, they are often not well developed, erroneously leading to the perception that the root system is generally flat. Spruce trees display a typical sinker root system.

Wood

The major physical resource provided by a tree is its wood. The ability to make fire altered the course of human evolution and the energy source involved was wood. This did not change for hundreds of thousands of years, until 'recently' coal and then oil replaced wood. In the wake of the recent renewable energy boom, wood is currently experiencing a renaissance as an energy

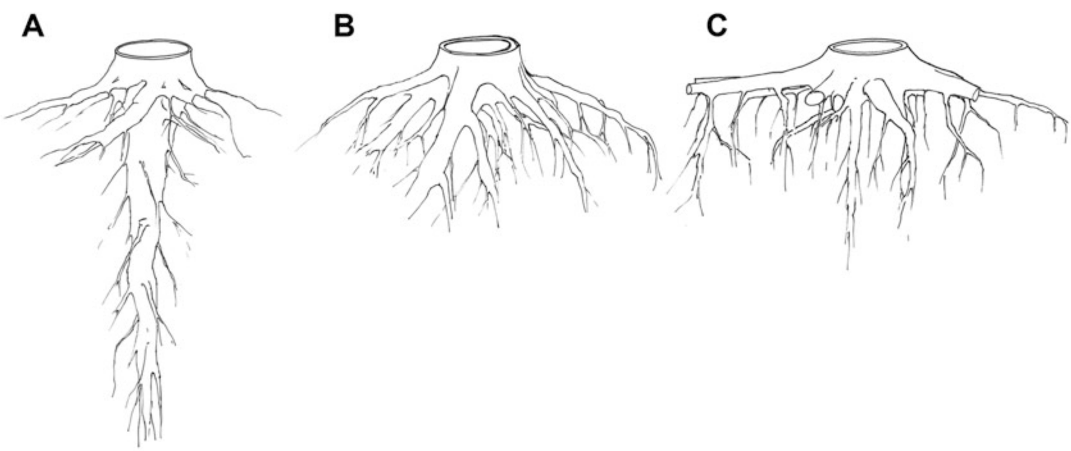

Fig. 6.22 The major root systems of trees: taproot system (left), heart-root system (middle), sinker root system (right). The actual development and structure depend strongly on site and soil conditions. Soils with a high water table can lead to a very shallow and flat root system (even in pines) © Ulrich Schmidt

source, either as raw wood or wood chips or pellets. Additionally, wood serves as raw material for tools, furniture, a wide variety of construction purposes and paper production.

Box 6.9: Chemical Composition of Wood
Carbon (50%)
Oxygen (43%)
Hydrogen (6%)
Nitrogen (1%, incl. minerals)

To understand the relevance of wood in a bio-economy, it is crucial to be aware of its composition and features. The major components of wood are cellulose, hemicelluloses and lignin. Wood is often compared to a concrete construction, with the cellulose fibres representing the steel reinforcement which give the construction elasticity and the lignin representing the concrete which provides stability. Additionally, wood contains fat, starch and sugars as minor components, as well as resins, tannin agents, colour agents, etc. From a chemical point of view, wood is composed of carbon (C), oxygen (O), hydrogen (H), nitrogen (N) and minerals (see Box 6.9).

Since the molecular weight relation of carbon dioxide to carbon is 3.7 to 1, it is easy to calculate the carbon sequestration potential of wood from its species-specific dry weight. It should be mentioned that there is a traditional distinction between so-called hard woods (broad-leaved trees) and soft woods (conifers). Hard woods are usually heavier and have a shorter fibre length than soft woods. The latter is of importance, e.g. in paper production. Table 6.9 shows the average dry weight and bulk density of common timber species. Bulk density is the mass of dry matter in relation to the volume of the freshly harvested wood. It is an important parameter for the calculation of, among others, the carbon dioxide equivalents stored in trees. For example, a balsa tree with a volume of 1 m^3 has a dry matter wood content of about 120 kg. As the proportion of carbon is 50% (Box 6.9), this gives 60 kg carbon. The molecular weight of carbon dioxide is 3.7 times that of carbon. Thus 1 m^3 of balsa wood stores

Table 6.9 Density figures of some common tree species (all data from Knigge and Schulz 1966)

Tree species	Average dry density in g cm^{-3a}	Boundary values of dry density in g cm^{-3a}	Bulk density in kg m^{-3a}
Balsa	0.13	0.07–0.23	120.8
Spruce	0.43	0.37–0.54	377.1
Poplar	0.37	0.27–0.65	376.8
Pine	0.49	0.30–0.86	430.7
Maple	0.59	0.48–0.75	522.2
Oak	0.64	0.38–0.90	561.1
Beech	0.66	0.54–0.84	554.3
Pockwood	1.23	1.20–1.32	1045.5

[a]There is a small but relevant difference between the dry density, usually measured in g cm^{-3}, and bulk density, measured in kg m^{-3}. This is due to the fact that wood shrinks during the drying process. The bulk density relates the fresh volume of a wood sample or tree to the respective wood content. The dry density relates the volume of an oven-dried, shrunken wood sample to its weight. The latter figure is therefore higher, since the reference volume is smaller

60 kg × 3.7 = 222 kg of carbon dioxide (CO_2). The same calculation for a beech tree with a bulk density of 554 kg m^{-3} results in a figure of 1025 kg and for a pockwood tree 1935 kg.

Dry wood has a calorific value of 5–5.2 kWH kg^{-1}, and, depending on the species and its wood density, one m^3 of piled hardwood can replace around 200 l of fuel oil given a wood moisture of about 15% (air dry).

Due to its chemical and physical composition, wood has some unique features which distinguish it from other materials, resulting in a wide spectrum of applications. It is comparatively light, flexible, easy to work and often even very ornamental. It is thus used for construction purposes such as houses and boats; for flooring, furniture, carvings and tools; as well as for the production of paper and semi-natural fibres including viscose and modal. Wood also serves food industry applications, e.g. as artificial vanillin produced from lignin and as xylose, a sugar produced from wood.

Globally traded forest products are recorded in a standardized form. Table 6.10 shows the major trade categories with associated volumes for the year 2015.

Table 6.10 Global production of forest products in 2015 (FAO 2017a)

Product[a]	Unit	Production in 2015
Roundwood	million m^3	**3.714**
Wood fuel	million m^3	1.866
Industrial round wood	million m^3	1.848
Wood pellets	million tonnes	**28**
Sawnwood	million m^3	**452**
Wood-based pannels	million m^3	**399**
Veneer and plywood	million m^3	171
Particleboard and fibreboard	million m^3	228
Wood pulp	million tonnes	**176**
Other fibre pulp	million tonnes	**12**
Recovered paper	million tonnes	**225**
Paper and paperboard	million tonnes	**406**

[a]For definitions see FAO (1982, 2017b)

Table 6.11 Bushmeat provision of forests and agricultural land together[a] in Germany, hunting year 2015/2016 (only hoofed game) (DJV 2017)

	Amount in tonnes[b]	Value in mio €[c]
Red deer	4865.51	21.9
Fallow deer	2157.33	10.8
Wild boar	23,908.82	95.6
Roe deer	12,330.29	61.7
Total	43,261.95	190.0[d]

[a]Hunting districts are not delimited along land-use boarders but are based on ownership. The overall hunting area in Germany amounts to 32 mio. hectares
[b]Animal with skin
[c]Price for whole animal with skin and bones ('primary value')
[d]The monetary value given in the table does not take into account the associated value chain and added values due to processing

Other physical goods that can be obtained from forests (e.g. fruits, mushrooms) are referred to either as 'non-wood' or 'non-timber forest products' (NWFP, NTFP). Depending on the region of the globe, these may provide important contributions to the population's livelihood or be used for recreational activities. Since Mediterranean cork oak stands are classified as forests, the cork produced can also be classified as a non-wood forest product, as can the natural rubber produced in the millions of hectares of rubber tree plantations in Southeast Asia.

A special case with considerable regional importance is the meat provisioning service. So-called bushmeat is a source of protein in many African regions. In some Southeast Asian countries, e.g. Vietnam, forest species are being hunted to extinction to feed the insatiable hunger for exotic meat of the region's new rich. Bushmeat hunting and trade is usually illegal and uncontrolled and has considerable negative impacts on the affected species' populations. However, hunting practices in North America and Europe, for example, show that it is also possible to use forests as a sustainable source of considerable amounts of meat. Table 6.11 shows the case of Germany, where about 380,000 persons currently own a hunting licence.

In addition to the monetary value of the meat, annual hunting fees can also constitute a considerable source of income for forest owners and often exceed the annual income from wood production. Expenditure on hunting equipment is another economically relevant factor.

6.2.3.2 The Protective Role of Forests

Forests fulfil important protective functions. In mountainous regions, they protect settlements, farms and infrastructure from avalanches and rockfalls. Due to the specific forest climate, which maintains soil humidity and thus enhances water infiltration rates, forests usually reduce surface runoff and erosion. The root network stabilizes the soil and acts as a buffer against landslides.

Along streams, forests stabilize river banks and often serve as water (and sediment) retention areas during periods of flooding. In the tropics, mangroves have a protective role on shorelines, serving as wave breaks and also as spawning ground for fish, safeguarding the livelihood of fishermen.

Forests are also crucial for the hydrological cycle and as water protection areas. In urban centres, forests play a considerable role as air filters and oxygen providers. On a global scale, forests are crucial for carbon sequestration and serve as long-term carbon sinks.

6.2.3.3 Forests for Recreational Activities

Forests are important for recreational activities. In Germany in particular, it is said that people have a very close affinity to their forests. For this reason, forests are open access, and generally people are allowed to enter without permission. Hiking, jogging, biking and mushroom collection are common recreational activities. But hunting, which is practised nationwide, should also be mentioned.

6.2.3.4 The Socio-economic Importance of Forests in a Bioeconomy: A Case Study—Germany

Germany is a highly industrialized country with a land surface of nearly 360,000 km^2, of which 32% are classified as forest. Centuries of intensive use, degradation, reforestation and afforestation mean that today the forests are mainly production forests and only parts can be defined as near-natural. Despite this intensive use and exploitation in the past, the forests have largely maintained their original level of biodiversity, with the exception of large carnivores and predators, which historically competed with humans and have been hunted to extinction. These include bear, wolf, lynx and large birds of prey, such as eagles and vultures.

Without human interference, German forests would be characterized by broadleaf trees, mainly beech. Beech-dominated forests would cover around 74% of the total forest area, followed by oak forests with 18%. Through historical developments, however, German forests are nowadays dominated more by conifers, which cover 60% of forest area, with broadleaf forests only covering 40%. One main reason for this development is that conifers are easier to propagate and establish than broadleaf trees, especially on open lands, and in the past were often the only viable option to ensure the re-establishment of forests. As a result, the currently dominant tree species are as follows: 28% spruce (*Picea abies*), 23% pine (*Pinus sylvestris*), 15% beech (*Fagus sylvatica*) and 10% oaks (*Quercus robur/petraea*).

Table 6.12 Forest ownership structure in Germany (from BMEL 2017)

Forest ownership	Share of forest/%
Private[a]	48
Federal states	29
Corporations	19
Federal government[b]	4
	100

[a]About 50% of private forests are smaller than 20 ha
[b]Especially military training grounds

In recent years, there has been a trend towards the return to the original site-adapted species composition, mixed stands and abandonment of clear-cuts. This has been mainly triggered or accelerated by devastating storm damage, especially—but not only—in spruce monocultures (e.g. hurricanes Vivian and Wiebke in 1990 and Lothar in 1999). To date, around 73% of German forests are classified as mixed forests, composed of different tree species.

Forest distribution and ownership within Germany varies greatly between the federal states. Rhineland-Palatinate and Hesse have the highest forest cover at 42% each, while Schleswig-Holstein has only 10%. The ownership structure is quite heterogeneous (Table 6.12) and dominated by private owners. The private sector, that is, private and corporate forests together, accounts for 67% of the total forest area and around two million owners.

Forests and their associated value chains are of considerable socio-economic importance. On average, each hectare of forest has a timber stock of 336 m^3 and an annual timber growth of around 11 m^3, resulting in an annual timber production of more than 120 million m^3. The forest sector as a whole has an annual turnover of 170 billion euros, providing nearly 1.3 million jobs (BMEL 2017).

6.2.4 Forest Management

The management of forests has some peculiarities which need to be understood to properly assess their potentials and restrictions in a bioeconomy. One major difference compared to all other biological production systems is the time horizon. In forestry, we are dealing with decades or even centuries—in contrast to the short rotation time of modern agriculture. This requires much more foresight. In agriculture, a wrong decision might result in the loss of an annual crop. In forestry, a wrong decision with regard to tree species may reveal its disastrous consequences only after some decades. For example, a single exceptional summer or winter season can ruin the entire long-term investment in one blow, which is particularly bitter in times of high interest rates. This long-term perspective together with the necessity of food production is the main reason that, in the majority of developed countries, forests have been pushed back into less productive or difficult-to-manage sites and replaced by agriculture on good soils.

As a consequence, forest investments focus on short rotation plantations, while the management of natural or near-natural forests is practised in state-owned or traditionally privately owned forests.

6.2.4.1 The Exploitation and Use of Forests

The first use of forests was exploitative—the desired products (meat, wood, other non-wood products) were harvested without considering their regeneration. Soon, people discovered that an overuse can result in a shortage of supply. For this reason, the majority of rural tribes around the world have use restrictions, even though these may not be written down or documented as they would in a modern society.

However, forests were often cleared to create open space for crop production. This form of agriculture can still be found in the tropics, where it is called 'shifting cultivation' or 'swidden agriculture'. The use of fire is a key element in this practice, and, in the course of time, vast areas can be deforested, even with very primitive tools. The forest is cut down during the dry season and the dry matter burned at the beginning of the rainy season. The open land is used for crop production for 2–3 years. After that time, it is abandoned, and the forest can re-establish and regenerate into a secondary forest.

The great onslaught on tropical forests in particular, but also boreal forests, stems from technical developments, especially the chain saw and related heavy machinery such as bulldozers, skidders and nowadays harvesters. With these tools, it was and still is possible to extract timber at an unprecedented speed. Although usually only the most valuable trees are harvested, the damage to the remaining forest can be tremendous, due to the heavy machinery and the lack of technical (felling) skills. In addition, lack of regulations and non-implementation of existing rules and corruption have led to the degradation and disappearance of large tracts of tropical forests.

In sustainable forestry, two major approaches can be distinguished: *clear felling* and *selective logging*, i.e. the targeted removal of single trees.

Clear felling is the most simple and straightforward practice. All trees on a given area are harvested. This has considerable advantages from a production point of view. First, harvesting can be conducted very efficiently, and a huge amount of biomass can be made available. Clear felling allows site modifications such as stump extraction and ploughing which requires large machinery, but also facilitates artificial regeneration. This type of forest usage and regeneration is typical in plantation forestry (cf. *Eucalyptus*, *Acacia*, *Pinus* spp.), where the fast production of a single commodity is the main objective.

Selective logging targets individual trees of high value, with the intention of maintaining forest structure and functions. It is often practised in mixed, near-natural forests. One selection criterion is a preset minimum diameter. This management practice is highly demanding and involves all aspects of management. First of all, the identification of the right trees requires the forest manager to know his forests very well. Harvesting logistics need to be worked out before logging begins to reduce the impact on the remaining forest stand. This requires the establishment of a skidding infrastructure and related felling schemes (cf. directed felling).

Fig. 6.23 Clear-felling system in conifer forests of the western USA (Photo: G. Langenberger)

Good logging skills are necessary to implement the felling scheme and minimize felling damages. The concept as a whole aims at the production of single but high-value trees. This kind of logging is usually accompanied by natural regeneration.

However, in practice, the situation is much more complex and diverse than described above, and the two approaches are often mixed, depending on local circumstances. Thus, small clear-cuts can be used to promote light-demanding species, and the natural regeneration is sometimes assisted by artificial planting either to support stagnant regeneration or to change species composition. Figure 6.23 shows the common clear-felling practice of conifer forests in the western USA. Large tracts of forests are clear-cut, but blocks of forest are maintained in between as a source of seeds.

6.2.4.2 Management Cycles

Generally, five natural development phases can be distinguished in the lifetime of a tree:

- Establishment phase: This comprises the establishment of a tree seed at a given site.
- Youth phase: The time between the establishment and maturity (seed production) of a tree.
- Optimal phase: Adult stage with regeneration.
- Stagnation phase: Decreasing vitality.
- Natural decay: die-off and replacement.

The length of each stage is species-specific and, as a result, different species are used in different management schemes. For all production forests, the stagnation phase and natural decay are eliminated by prior harvest.

Two major tree types can be distinguished based on their life strategy: the *pioneer species* and the *late-successional* and *climax forest* species (see Box 6.8). Typical *pioneer species*, e.g. birch and pine, all share a similar strategy. They produce large quantities of wind-dispersed seeds, prefer mineral soils for regeneration and require full sunlight to establish and grow. Plantation forestry uses species from this group, as they show tremendous growth in their youth but soon reach a culmination in increment, allowing for short rotations. Their natural lifespan is comparatively low (Table 6.13).

The majority of *late-successional and climax forest species* are adapted to regeneration inside the forest, in shady conditions or small light gaps. The seeds are usually larger (e.g. beech) than those of pioneers, and the seedlings can often not tolerate full sunlight exposure or temperature

Table 6.13 Life expectancy of selected tree species and production figures[a]

Tree species	Potential max. age in years	Rotation period in years	Average annual increment[b] in m^3/ha
Broadleaf trees			
Alder (*Alnus glutinosa*)	150	90	4.5–8
Ash (*Fraxinus excelsior*)	200	120	4.5–6.1
Beech (*Fagus sylvatica*)	300	150	4.2–8.6
Birch (*Betula pendula*)	120	80	3.6–4.9
Eucalyptus (*E. camaldulensis*) (plantation)	1000	7–15	2–30
Oaks (*Quercus petraea*, robur)	800	200	3.6–6.4
Teak (*Tectona grandis*)	>200	80	0.6–14.8
Conifers			
Douglas fir (*Pseudotsuga menziesii*)	1000	100	9.4–17.1
Fir (*Abies alba*)	500	150	7–12.8
Larch (*Larix decidua*)	500	140	4.1–7.2
Pine (*Pinus sylvestris*)	600	140	1.2–7.0
Spruce (*Picea abies*)	600	120	5.6–11.9

[a]Different sources: Schütt et al. (1992), Schober (1987), Lamprecht (1989), Jacobs (1955)
[b]The annual increment strongly depends on site quality and thinning concept; the values given for temperate-zone species refer to the highest rotation length given in yield tables. If rotation length is reduced, average annual increments can be higher

extremes. The establishment of these species in open spaces poses considerable problems. Therefore, such species are more often used in permanent mixed forests. They usually have slower growth in their youth than pioneer species, but maintain a considerable level of increment up to a high age and can grow quite old (Table 6.13).

Once trees have been established, either as a monoculture or within the framework of a natural regeneration concept, they need to be tended. Fertilization is common practice in forest plantations. The risk of fire should be taken into consideration in plantation schemes, but also competition from grass, which can make weeding necessary. Lianas are often reported as a serious problem hampering natural regeneration in selectively logged forests (especially in the tropics). Here, growth regulation and competition control is necessary after the establishment of the young trees, for example, misshapen and damaged trees, and trees of low vitality are removed. As the trees grow taller and start to differentiate, thinning is required, that is, the promotion of trees which fulfil quality and growth expectations by the removal of competitors. This is the first management step which can lead to positive economic returns through the marketing of wood. Depending on the management scheme, several thinning rounds need to take place before final harvest.

6.2.4.3 Forest Certification and Sustainability Initiatives

Sustainability has recently become a buzzword with as many meanings as it has advocates. The 'invention' of the term by Carlowitz in 1713 originally aimed at the provision of a permanent timber source for industry. Since then, the meaning of the term has evolved, based on scientific progress and ecological understanding, and has now taken on an ecosystem-oriented connotation, comprising the protection of species diversity and ecosystem functions. While forest management regulations in the temperate-zone and industrialized countries are usually well developed and implemented, forest use in the tropics has been and often still is pure exploitation, leading to forest degradation and finally transformation, sometimes intentionally to expand agricultural land. As a reaction to the tremendous forest losses in the tropics in the second half of the last century, environmentalists and other civil society organizations came together to consider options to change this development using market pressure. As a result, forest certification schemes were developed, probably the most prominent being the 'Forest Stewardship Council', better known as FSC (https://ic.fsc.org/en). As FSC was initiated by environmental and human rights organizations (in particular WWF, Greenpeace, etc.), forest owners and the forest industry reacted by creating their own, more user-friendly certification scheme, the 'Programme for the Endorsement of Forest Certification' (PEFC: https://pefc.org/). There are other certification schemes, each with somewhat different criteria and focus, e.g. that of the organic farming label 'Naturland' (http://www.naturland.de/en/).

Review Questions

- What are the specific features of forests?
- Distinguish between the different forest types.
- How do they contribute to mankind's needs and to the bioeconomy?
- What is the relevance of forests in meeting global challenges such as the mitigation of climate change?
- What is sustainable forest management?