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ЛЕСОВЕДЕНИЕ И БОЛОТОВЕДЕНИЕ

FOREST AND MIRE SCIENCE

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В учебно-методическом пособии содержатся сведения о биологии и экологии леса в целом и составляющих его компонентах, географических аспектах леса, закономерностях естественного возобновления, формирования леса, изменения его характера в пространстве и во времени, а также основы болотоведения. Издание может быть использовано студентами для подготовки к зачету и экзамену.

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PREFACE

One of the most important directions in the system of measures for creation comfortable conditions for human life in the circumstances of increasing urbanization is adaptation in cognitive and recovery purposes to the most widespread in Belarus ecosystems: forests and mires. This line has an obvious social value, and its full implementation is possible only if the training highly skilled specialists in the field of tourism and nature management is based on scientific principles of using recreational and educational functions of forests and mires.

It should be emphasized that this direction in our country, especially in connection with a current trend active of development of foreign tourism is characterized by a very significant economic component and can greatly improve the efficiency of forest production and economy of the country as a whole. In the context of the specialty “Tourism and nature management” the course “Forestry and mire science” can be regarded as a branch of science that aims at a more comprehensive and integrated approach for all forest utilities that primarily affect the improvement of physical and emotional state of people.

In developing this course, the milestone was to set the task of the comprehensive study of the natural landscape complexes of forests and mires, characterized by cognitive, aesthetic, recreational and recovery functions. This is only possible if they are in full will acquire knowledge about the causes-and-effect relations of the formation and dynamics of forest and mires of the ecosystems, learn about the regularities and peculiarities of their structure, will examine practical measures for the rational use, reproduction, conservation and protection of all components of forests and mires.

The main purpose of the course is professional training of specialists in the field of tourism and natural resources management, particularly in the use of forests and mires of Belarus as a natural tourist attraction.

A specialist can apply the acquired knowledge for the scientific organization of measures for involving the population of our country and foreign guests into investigation of forest and mire ecosystems, often representing the reference ecosystems, sometimes unique to Central and Eastern Europe.

The main task of the course is theoretical knowledge and practical investigation of basic principles of forestry and mire study in the context of the organization of tourism in forest and mire natural landscape complexes of Belarus.

As a result of studying the course a student must know:

– organization and structure of forestry in Belarus;

– components of the forest;

– characteristics of the formations of the main forest-forming species;

– patterns of forests interaction with environmental factors of reforestation, formation, growth and development of forest community;

– the main factors of formation and development of mire systems;

– the habitat of marsh plants;

– vegetation and typology of mire biocenoses;

– zoning of mires.

A student must be able to:

– distinguish in nature separate homogeneous areas (taxation units) of stands;

– identify and distinguish forest types;

– describe forest community;

– determine the individual components of forest community and define their characteristics;

– identify the main plants of mire communities;

– determine the stage of mires development;

– select the main types of mires using ecological-topological and floral analysis.

All critical comments and suggestions, which will be highly appreciated, please send to the following address: 220006, Republic of Belarus, Minsk, Sverdlova St., 13A, institution of education “Belarusian State Technological University”, Forestry Department.

1 INTRODUCTION

1.1. The concept of forestry

Silviculture is a doctrine about forest essence. Although silviculture is considered to be the natural basis of forestry, now it rightfully starts to take an independent position among natural sciences. This is due to public recognition of forest multifunctioning.

The complex nature of forest became accessible to human consciousness in the late 19th – early 20th century. The accumulated practical experience of foresters, the success of the natural sciences, requirements of time contributed to the development of forestry.

“The forest doctrine” is a fundamental study of G. F. Morozov, in which he wrote: “Forestry consists of two parts: the forest study, on the one hand, and the study of forest conversion to use it without wasting it, on the other hand. The first part introduces us to the nature of the forest, the second one presents the methods of its modification, and so on; the first introduces us to essence, the second is due”.

Forestry is a science created by G. F. Morozov at the beginning of 20th century. Its subject is forest as a natural unity of its organisms and their habitats. Unlike G. F. Morozov, M. E. Tkachenko believed that the concept of forest science cannot be limited to the first part of forestry. In his opinion, forestry “is a whole encyclopedia comprising several forestry courses and some general science, which rely on forestry”.

Thus, forestry is characterized by a certain dualism: it is integral part of silviculture, and a part of natural sciences curriculum.

Forestry studies the ecological properties of plants, the relations of tree species to environmental conditions, soil formation processes and morphology of soils to determine forest formation conditions and characteristics of reforestation.

Modern forestry should consider increasing anthropogenic impact on forests and, at the same time, the increased importance of forests for human beings not only as a source of raw materials, but also as an ecological framework and the guarantor of ecological stability in the region.

In the study of forest as the subject of multiple approaches the forest should be considered as a companion of man, as an indicator of its culture as an object of recreational use and the object of tourist industry.

If you cut down a beautiful forest, it will be recovered again only after 100 years, but using it as a tourist attraction each year, you can attract hundreds of tourists. Scientific value of forestry has increased due to the necessity of studying the nature of forest taking into account the contemporary problems concerning the environment.

The subject of forestry is not only the nature of the primeval forest, but also the nature of the forests that have been intensively managed by men.

Thus, forestry studies forest:

a) as a natural unity, based on interactions within the forest, and between the forest and the external environment as the most important component of the biosphere;

b) as the system under development, dynamics, and change not only in space but also in time. Dynamism is one of the characteristic features of the forest. Therefore, the forest as an object of research should be considered in the context of past, present and future;

c) as a process of transition from quantitative changes to qualitative changes, continuity of different stages of forest development.

Forestry is the key to silviculture. According to G. F. Morozov, forestry "allows you to turn the laws of life into the principles of good forest management".

Silviculture is engaged in growing forests to obtain timber, and other forest products; forest is used for protective, water-regulating, recovery, and aesthetic purposes.

Forestry is developing methods to increase forest productivity, to use, renew and improve the theory and practice of cutting.

Silviculture is the basis for forest management differentiation activities, for choosing the rational method of felling and reforestation, measures of care for the younger generation. Solution of these problems requires knowledge about the nature of the forest.

The development of forestry has led to the creation of forest ecology (bio-geotecnologie). The founder of forest biogeocenologie V. N. Sukachev considered the forest to be a special kind of ecosystem where flora, fauna, soil, rocks, atmosphere and moisture interact, forming the geographical complex with its special life.

The forest ecosystem, as it will be shown, is the biocenosis (phytocenosis, zoocenosis, microbiocoenosis). In the life course biocenosis modifies the soil and the atmosphere, and therefore, these components are an integral part of the ecosystem in question.

The study of V. N. Sukachev and G. F. Morozov was worldwide recognized. These scientists are constantly referred to in the books of Western European and American authors.

The idea of biogeocenosis contributed to the expansion and development of comprehensive studies on the nature of the forest.

1.2. The concept of mire study

Mires are an integral element of geographical landscape of Belarus. About 8.1% of the country is occupied by wetlands. The share of wetland and mire forests in the forest fund is 25.5%, including the species: pine (*Pinus sylvestris* L.) – 26.4%), spruce, or pine (*Picea abies* (L.) Karst) – 2.6%, pubescent birch, or white birch (*Betula pubescens* Ehrh) – 40.0%, European alder, or black alder (*Alnus glutinosa* (L.) Gaertn) – 31.0% (E. A. Dashkevich, 2004).

Belarusians mires, especially low-lying, were often associated with subjective negative meanings: these are bad, dangerous to health and life mires that occupy a huge territory (Belarusian Polesie) and are sometimes impassable even in winter, the dwelling place of devils, sprites, vampires, evil spirits and so on. Eloquent testimony to that is toponomy of some wetlands: "Dark swamp", "Terrible moss", "Black bloodwit", "Darkness", "Scupper" and others (V. P. Trybis, 1989). The classic of the Belarusian literature V. S. Korotkevich in his outstanding novel "The King Stakh wild hunting" described the landscape of one of the regions of our country: "...the darkest, most hopeless of our landscapes: peat bogs. A vast plain of a brown colour, even more brownish black, hopelessly flat, boring, gloomy" (V. S. Korotkevich, 1992, p. 408).

However, objective scientific data give a completely different view of the mires and their role in the world around us.

As it is well known, the origins of many large and small rivers and streams originate in the mires. It is important to note that water in mires, representing a kind of natural ecological filters, composed mainly of various species of sphagnum mosses, have distinguished antiseptic properties, they are significantly less contaminated than the water of the other water sources. Therefore, along with carbon depositing, mires have their very significant positive impact on the water balance of the adjacent territories, and on the quality of water supply to their natural sources.

Significant resource, and hence the economic potential of mires is defined by growing on them valuable food, honey, medicinal species, and species used as industrial raw material: swamp cranberry (*Oxycoccus palustris* Pers), bog blueberry (*Vaccinium uliginosum* L.), red bilberry ordinary (*V. vitis-idaea* L.), marsh cinquefoil (*Comarum palustre* L.), common valerian (*Valeriana officinalis* L.), sphagnum (*Sphagnaceae*), swamp ledum (*Ledum palustre* L.), heather ordinary (*Calluna vulgaris* (L.) Hull), and some other useful plants.

At present time in some regions of Belarus gathering cranberry for sale is a very substantial financial support for the local population. Considering this, the social-economic role of mires is apparent, especially for households residents located near settlements. As practice shows, careful and scientifically-informed regard to non-timber resources of wetlands increases their utilitarian role over time.

Our mires are a unique natural gene pool of plants and animals. It is preserved in hard to reach areas, which is a kind of gene pool, and you can still meet the species of either extinct from the natural flora and fauna of Europe, or those with a protected status: baeothryon alpine (*Baeothryon alpinum* (L.) Ron.), dwarf birch (*Betula nana* L.), coral root (*Corallorhiza trifida* Chatel.), sundew intermediate (*Drosera intermedia*L.), cottongrass (*Eriophorum gracile* Koch); nigritella (*Gymnadenia conopsea* (L.) R. Br.), hammarbya (*Hammarbya paludosa* (L.) O. Kuntze), iris, Siberian Iris (*Iris sibirica* L.), fen orchis (*Liparis loeselii* (L.) Rich.), heart-leaved twayblade (*Listera cordata* (L.) R. Br.), lycopodiella (*Lycopodiella inundata* (L.) Holub), bog orchis (*Malaxis monophyllos* (L.) Sw.), blunt-leaved sandwort (*Moehringia lateriflora* (L.) Fenzl), broomrape (*Orobanche pallidiflora* Wimm et Grab.), small-fruited cranberry (*O. microcarpus* Turcz. ex Rupr.), cloudberry (*Rubus hamaemorus* L.), blueberry willow (*Salix myrtilloides* L.), marsh saxifrage (*Saxifraga hirculus* L.); large spotted eagle (*Aguila clanga* Pallas), pond terrapin (*Emus orbicularis* L.) and others (M. V. Yermokhin, 2011).

Economic value of peat is very diverse; peat is a major component of mires ecosystems. Peat is used, for example, for obtaining biologically active substances; it is used in perfumery and pharmacology, as well as its direct use is in the therapeutic purposes (mud therapy, balneology). A large value of peat is used as fertilizers, in fuel industry and greenhouse farms, as bedding for cattle, and even as additive in animal feed.

The uniqueness of peat is that it can be viewed from different positions. On the one hand, this is soil; its main distinctive feature is the absolute dominance of carbon dioxide depositor as organic component presented by peat former plants decomposed to varying degrees, on the other hand, it is fossil fuel, on the other hand it is plant substance under long-term transformation into other types of resources (lignite and hard coal).

It becomes apparent that mire study is of considerable interest to researchers of different scientific disciplines: forestry and soil science, botany and its subdivisions geobotany and palynology, geography and geology, hydrology and climatology, as well as paleontology, and even history and archaeology.

The latter is due to the fact that peat is an excellent preservative substance, which is determined by the biochemical composition of sphagnum, it is main peat-producing species and the environmental conditions that adversely affect the decomposers of organic matter. By the remnants of plants (pollen, spores) and animals it is possible to restore not only the phase of development of the mire constituents, adjacent areas and the whole of the landscape, as well as a picture of climate change for a very long time (8–10 thousand years). It is also possible to get a certain pre-vision of lifestyle of the people who inhabited these placesby many human subjects found in peat depth.

The name “mire study” implies that it is a scientific discipline which studies mire. The study of natural phenomena on the basis of biogeocenosis principle involves a comprehensive study of the components composition, their relationships, interactions with each other and the environment; it takes into account the role of anthropogenic factors, allows obtaining the most objective characteristic.

1.3. Directions of tourism development on the forest fund territory

Forest fund of our country is characterized by a significant potential of tourist activities.

The main directions of its development in the forestry sector are very diverse and according to the “Recommendations for the development of ecological tourism in forestry of Belarus" (Minsk, 2008) include:

– eco tours for groups of different ages, as well as combined by interest;

– eco tours for groups in different types of forest and mire ecosystems;

– trips, tours, tours to the most attractive parts of the landscape natural vegetation complexes. Hiking, walking, skiing, cycling, rafting on rivers and lakes, using in the latter case, rafts, kayaks or boats;

– tours of the land of wild berries and medicinal plants, mushroom plots;

– excursions by water and mires lands, in combination with fishing tours;

– game viewing of fauna and flora representatives;

– the weekend sightseeing tours of the objects that have historical, cultural and educational value (environmental paths, nature museums, open-air houses for wild animals, park complexes, dendrology), located on the territory of the forest fund.

1.4. State policy in the field of forestry

In Belarus the main state solutions in the field of forestry are outlined in the following documents:

1. The forest code of the Republic of Belarus.
2. The concept of sustainable development of forestry of the Republic of Belarus until 2015.
3. Strategic plan for the development of forestry.
4. The state program "Multi-use of forests for the period till 2015".
5. The state program "Scientific and technical development of the field for the period till 2015".
6. State program of development of forestry of the Republic of Belarus for 2011–2015.

These documents define the following objectives of forestry:

– rational, sustainable and continuous use of forests;

– providing a relatively constant forestry in forest fund for the subjects of forestry;

– implementation of ecological (nature compatible) forestry.

This should be provided by:

– optimization of the age and species composition of the forest fund;

– optimization of the assortment structure of forest fund;

– optimization of ages and cuttings;

– efficient and integrated use of wood and other products obtained from forest management;

– expanded use of forests to perform recreational potential.

1.5. Organization of forestry

1.5.1. Forest fund

The lands of the forest fund consist of forest and non-forest land. Forest land is land covered by forest, and land that is not covered by forest, but intended reforestation.

Non-forested lands comprise fallen areas, burnt areas, dead forests, woodlands, glades, clearings, the areas occupied by nurseries, rare forest crops, etc. provided for the needs of forestry.

Non-forest lands are not covered with forests, they are used for agricultural purposes, there are clearings, roads, breaks against fire, irrigation and drainage network and others, there are also ponds and other objects not for cultivation of forest land, provided for the needs of forestry, located within the boundaries of forest reserves and wetlands.

The forest fund does not include:

– protective forest belts located on the agricultural lands;

– plantings within the right of way of railroads and other roads (25 m), other transportation and communication lines and channels;

– plants on the lands with recreational facilities (except for urban forests);

– plants on lands granted for citizens to conduct collective gardening and dacha activities, private farming, construction and maintenance of residential houses.

Forests in the Republic of Belarus are the exclusive property of the state.

The Republic of Belarus has the right to possess, manage and use the forests through state authorities within their competence regarding habitat formation, water conservation, protection, sanitary, recreational and other functions of forests in the interests of the citizens of the Republic of Belarus and state interests.

1.5.2. The structure of forestry

Forestry is a multi-complex sector of the economy of Belarus. Forest management is a complex and multipurpose task. The cultivation of forests and the sustainable use of wood and other products and utilities in the interests of the society is one of the most important national issues. The task is implemented by the Ministry of forestry, which has a certain structure (table 1.1).

Table 1.1

Structure of the Ministry of Forestry

State Production Forestry Association (SPFA)	Enterprise	Institutions
Brest Vitebsk Gomel Grodno Minsk Mogilyov	RUE "Belgosles" RUE "Belgiproles" RUE "Bellesexport" RUE "Belgosohota" RUE "Belarusian forest newspaper" RUE "The Editorial Staff *Forestry and Hunting*"	SI "The Republican forest breeding cattle center" SI "Belarus forest protection" Educational institution "Republican training center for training, retraining and upgrading qualifications of forestry"

The SPFA consists of 95 state forestry agencies (SFA) or forestries. Forestry consists of forest divisions, a total of 817. Each forest division includes several logging camps, a total of 2,390. Logging camps consist of ranger districts, currently there are 10,277. The share of the Ministry of forestry has a dominant area of the forest lands of the country (table 1.2).

Table 1.2

Departmental forest distribution (according to 01/01/2013)

Department	Area of forest fund, thous. ha (%)
Ministry of forestry of the Republic of Belarus	8103.1 (85.6)
Administrative Department of the President of the Republic of Belarus	753.7 (8.0)
Ministry for emergency situations of the Republic of Belarus	216.1 (2.3)
The Belarusian production and trade concern of forestry, woodworking and pulp and paper industry	198.9 (2.1)
Ministry of defense of the Republic of Belarus	89.6 (0.9)
National Academy of Sciences of Belarus	41.4 (0.4)
Local executive and administrative authorities	38.2 (0.4)
Ministry of education of the Republic of Belarus	27.6 (0.3)
Total	9468.6 (100.0)

1.5.3. Groups and categories of forests protection

Forests are divided in groups according to the economic, environmental and social value of the forest fund, location, and the performing functions.

In the forest fund there are forests of the first and second groups. Forests of the first group perform water protection, sanitary, hygienic and recovery functions. To the forests of the first group forest reserves, national and natural parks, protected forest areas, forest, having scientific or historical significance, natural monuments, parks are also included. In the forests of the first group there are the following categories of protection: inventory classification units for the separation of forests for economic studies and social-economic value; on the basis of their place position and performing protective, environmental, and other useful functions.

Forests of the first group are divided into categories of protection:

– forest protected areas – nature reserves, national parks, reserves of national importance, nature value of national importance;

– forests that are particularly valuable forest lands having genetic, scientific, historical and cultural value;

– water protection forests. These are the prohibited forest belts and forests within the border zones along rivers, lakes, reservoirs, and other water related facilities;

– protection forests are conservation forests, protection zones along the railways and public roads;

– sanitary-hygienic and recovery forest. These are urban forests, forests of green zones around cities and other human settlements and industrial enterprises, forest sanitary protection zones of water sources, forest resorts.

All forests that are not included in the first group are the forests of the second group, i.e. operational.

In the forests of the first and second groups there can be distinguished the security areas with limited forest management regime:

– conservation forest areas along the slopes of gullies;

– the coastal strip along the banks of water bodies;

– habitat and distribution of rare and endangered wild animals and plants;

– specially protected parts of nature reserves;

– the edge of the forest on the border settlements and others.

The division of forests to groups and categories of protection, transfer them from one group or category of protection to another, distinguishing of specially protected forest areas with limited forest management regime are made on the basis of forest inventory materials or special social scientific research.

Distribution of forests by groups, as well as their transfer from one group to another are made on the basis of the decision of the governments of the Republic of Belarus, on solution of the national organization for public administration in the field of use, protection, of forest fund and reproduction of forests and the Ministry of natural resources and environmental protection of the Republic of Belarus.

Forest conversion from one category of protection to another within one group of forests, as well as a selection of specially protected forest areas with limited forest management regime are implemented on the basis of the decisions of the Government of the Republic of Belarus or the regional and local executive and administrative authorities according to the solution of the specially authorized Republican State bodies in the field of use, protection, protection of forest fund and reproduction of forests and the Ministry of natural resources and environmental protection of the Republic of Belarus.

There are "Regulations on the procedure for the distribution of forests in the group and category of protection, the transfer of forests from one group or category of protection to another, as well as selection of specially protected forest areas", approved by the decree of the President of the Republic of Belarus, dated 07/07/2008, No. 364.

Depending on the groups and categories of forests protection the procedure of forestry management and use of forest areas is defined.

1.5.4. State inventory of forest resources, state cadastral forest inventory, forest monitoring

State forestry inventory is a system of periodic single determination of quantitative and qualitative characteristics of the forest fund and its changes.

State forestry inventory is conducted by specially authorized Republican institution of state administration in the field of use, protection, protection of forest fund and reproduction of forests and its territorial bodies, legal institutions, conducting forestry.

The data of the state forest fund are used to maintain the state forest inventory. State forest cadastre contains information about the environmental, economic and other quantitative and qualitative characteristics of the forest fund.

Data of the state forest inventory are used in the state forest management and organization of its rational conduct.

Forest monitoring is a system of observation, assessment and forecast of the state and dynamics of the forest fund for sustainable forest management, sustainable use, protection and reproduction, habitat improvement, conservation, protection, sanitary, recreational and other functions of forests. Forest monitoring is an integral part of the National system of environmental monitoring (NSEM).

1.6. Principles and types of forest management

Principles of forest management in the forests of the Republic of Belarus:

– ensure continuous, sustainable and rational use of forests;

– maintaining and developing habitat, water protection, protection, sanitary, recreational and other functions of forests;

– providing conditions for the reproduction of forests;

– payment for forest use (except for the cases stipulated by the current Forest Code);

– adherence to scientifically-based standards of forest management, prohibition of over-cutting;

– maintenance of the forest integrity.

In the forest fund of the Republic of Belarus the following uses are carried out:

– timber harvesting;

– gum harvesting;

– harvesting of secondary forest resources (stumps, roots, birch bark, Christmas trees, fir hardened resins and others);

– harvesting of minor forest products (harvesting tree saps, harvesting and gathering of wild fruits, berries, nuts, mushrooms and other food forest resources, medicinal plants and technical raw materials, harvesting of moss, forest litter and fallen leaves, the distribution of bee houses and apiaries, haying, grazing, and other minor uses). The list is approved by the specially authorized Republican institution of state management in the field of use, conservation, protection of forest fund and reproduction of forests, it is coordinated with the Ministry of natural resources and environment protection of the Republic of Belarus;

– use of forest areas for hunting;
– use of forestry in the scientific research and experimental purposes;
– use of forest areas in cultural and recreational, tourism, and other recreational and or sporting purposes.

The terms, for the implementation of forest fund management can be permanent or temporary.

Permanent use of land plots of the forest fund provided for the forest management implementation is carried out without determining the use period.

Temporary use of forest areas provided for the implementation of forest management can be:
– short-term – up to one year;
– long-term – up to 15 years.

Specific terms for the implementation of short-term forest fund management are determined by the decision of the institution providing the implementation of forest management.

The amount of payment for forest use is determined by the fees. Fees for the minor forest use and harvesting of secondary forest resources, as well as for the use of forest areas in cultural and recreational, tourism, and other recreational and / or sporting purposes are established by regional executive and regulatory authorities.

1.7. Normative documents regulating the organization of tourism and wildlife management in the forests

One of the main documents are the "Recommendations for the development of ecological tourism in forestry of Belarus" adopted and put into effect from 01/08/2008, by order of the Ministry of forestry of the Republic of Belarus No. 174, dated 28/07/2008.

These guidelines determine the order of organization of ecological tourism in forestry. In particular, it is presented by the activities on the development of ecological tourism the procedure for the documentation development for tourism services is specified. The order of interaction of forestry organizations with tourism stakeholders and tourists is defined by the indices of the assessment of development of ecological tourism, the order of financing for its development in forestry; tours, routes, services, calculations, and other required information for ecotourism in forestry are presented.

In addition, “Guidelines for the development of ecological tourism in forestry of Belarus” list the types of ecological paths, which can be created in the forestry sector, and procedures of their organization. For example, the ecological path: from sowing to mature stands. Its creation requires knowledge of the age structure of the forest, stages of its development, succession of forest ecosystems, and knowledge of the actual forest typology. Recommendations determine the actual location of the ecological path, development of the route, equipment and monitoring of its condition.

The particular features of hiking, skiing, cycling, horse riding and water excursions are described. The excursions and tour around the places of growing wild berries, mushrooms and medicinal plants are presented. The procedure for flora and fauna film and game driving are presented.

The forest code of the Republic of Belarus establishes the legal foundations of rational use, conservation, protection and reproduction of forests, improvement of their ecological and resource potential.

Regulation of forest relations is carried out taking into account the concept of the forest as a complex multi-component natural system that has important ecological, economic and social importance.

The basic concepts and definitions that are used in the Forest code are next.

Forest is a combination of natural and artificially created woody and shrubby vegetation (plantations), ground shelter, animals and microorganisms, forming a forest biocenosis and used in commercial, recreational, recovery, sanitary, hygienic, research and other purposes.

Stand is a bulk of trees in the forest, with certain limited commercial and other properties.

Forest resources are timber, other components of the forest, in combination with habitat, water protection, protective, sanitary and hygienic, recreational and other functions.

Forest use is use of forest resources and forest properties in a specific order.

Forest user is legal or private person who has the right to use forest (forest resources) in accordance with the legislation of the Republic of Belarus.

Forestry is a sector of the economy, which provides the needs of the Republic in wood and other forest products; it also provides conservation and rational use of all diverse forest resources, preservation and strengthening of water protection, sanitary, hygienic, recreational and other functions of forests.

2 FOREST AS A NATURAL ECOSYSTEM. FOREST COMPONENTS. STAND DISTINCTIVE FEATURES

2.1. The forest as a natural complex and management object

The forest represents the main type of vegetation covering the Earth, it is a complex natural formation, a biological and physical geographic phenomenon, and it is an element of geographic landscape. Forests are classified as natural and cultivated.

The forest as a natural complex can be considered in a natural-historic aspect, technical, economic, agricultural, legal, historical aspects, from the standpoint of aesthetics, etc. But above all, the forest is a product of nature, a compound part of the biosphere.

Thus, the hierarchy of the forest can be represented in the following form:

1) the forest as a global integral part of the biosphere;
2) the forest as a natural-zone unit;
3) the forest as an ecosystem (ecosystem);
4) forest as planting (forest phytocenosis).

According to the Food and Agricultural Organizations of the United Nations (FAO), the total forest area of the world composition employed is approximately 4,033 billion ha or 31% of the area of the earth's land.

More than half of the world's forests are located on the territory of four countries: Russia (22%), Brazil (16%), Canada (7%), USA (6%).

Forest areas are size significant natural landscapes with a predominance of tree and shrub plantations.

The following forest zones like boreal, temperate, subtropical, tropical, sub-equatorial, equatorial zones are identified.

Forest areas are common under conditions of sufficient or excessive moisture. The most typical climate for the growth of forests is wet or humid climate. Humid climate is too wet when deposits exceed the amount of moisture coming through evaporation and soil percolation, and the excess moisture is removed by river runoff that contributes to the development of erosion landforms. There are two types of humid climate: polar is characterized by a long-term frozen state, and phreatic climate is characterized by groundwater.

Forest areas of the temperate zones of the northern and southern hemispheres include:

– taiga zone;
– zone of mixed forests;
– zone of broad-leaved forests;
– zone of monsoon forests.

Characteristic forest zones feature of temperate zones is seasonality of natural processes. Here are common coniferous and deciduous forest with a relatively simple structure and a small biological diversity. Dominating types of soil are podzol and brown. The occupied area is 0.76 billion ha in five regions of the world:

– Eastern part of North America;
– most of Europe;
– Eastern part of the Asian subcontinent;
– a small area in the middle East;
– a small area in Patagonia (Chile).

Forest as a business entity forms a special group of production funds:

– lands of the forest fund;
– wood stocks.

Production assets are at the same time function as labour objects and means. The objects of labour are revolving funds, i.e. raw materials, fuel. As raw material forest is a source of timber harvested in the process of harvesting, as well as berries, mushrooms, nuts, birch sap, medicinal and technical raw materials, honey, meat and furs of wild animals and others. Labour means are fixed assets, i.e. buildings, constructions. The main labour means in forest are plants with wood stocks. A distinctive feature of forestry is continuity of the forest production processes. For normal functioning forest industry must have stands of different age groups. Man needs wood annually, and other functions are also constant. Forestry functions normally, if one part of the forest comes into use annually, and the other one is in the production process.

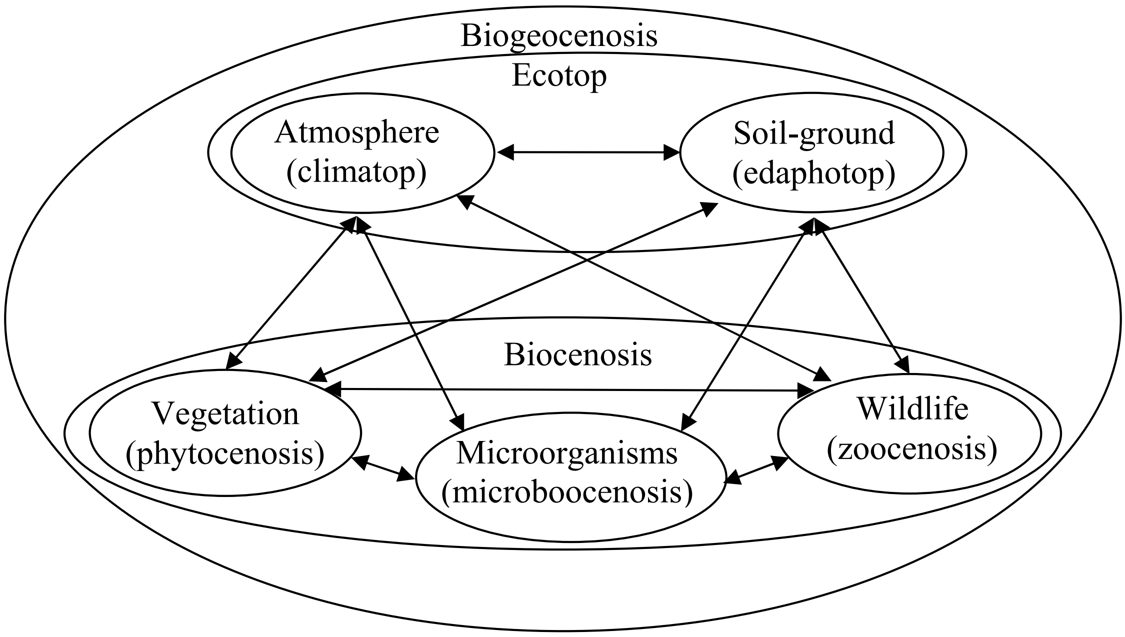
2.2. The concept of forest as a part of biogeocenosis

Foresters have long noticed the connection between growth and development of trees with the environment, especially with ground conditions. So, for example, a classic of forestry, G. F. Morozov believed soil science and the doctrine of plant communities to be closely related, he considered them to be theoretical basics of forestry.

According to V. N. Sukachev, G. F. Morozov should be considered the founder of the forest biogeocenosis. The concept of "forest" includes not only forest biocenosis, but also its environment.

Forest biogeocenosis by V. N. Sukachev (1964) is every part of the forest with homogeneous land cover, living animals, microorganisms, surface rock, hydrology, microclimate (atmospheric and soil conditions), the interactions between them, the type of matter and energy exchange between its components, and other natural phenomena. From the above definition it follows that the concepts "forest biogeocenosis" and "forest ecosystem" are synonyms.

As can be seen from figure below, which shows schematically the direction of the main interactions of the components (parts) of biogeocenosis according to V. N. Sukacheva, climatop is a complex of climatic environmental factors, edaphotop is a complex of soil, water, and ecological factors. Climatop and edaphotop together make up the ecotop, i.e. inanimate (conservative, according to V. I. Vernadsky) habitat.



Biogeocenosis components interaction according to V. N. Sukachev

The composition of the ecological community includes all living organisms, representing phytocenosis (vegetation), zoocenosis (animals) and microbocenosis (microorganisms).

They make two trophic groups: autotrophs, plants that use solar energy to create organic matter, and heterotrophs, animals, bacteria, fungi which use ready organic matter synthesized by autotrophs.

The interaction of all these components of the ecosystem in question is very different and difficult. Since all of them are interconnected and determined, the deeper is explained the essence of their relationship, the better are possibilities to manage them, which actually is a scientific basis for all silvicultural activities, i.e. forestry.

As noted by V. N. Sukachev, tree stands and other flora all the time are dependent on soil, atmosphere, fauna, and microorganisms, but affect them.

The influence of soil on vegetation. The chemical composition of soil, its moisture content and physical properties affect:

– growth and development of tree species;
– fructification;
– reproduction.

The influence of vegetation on soil. The vegetation determines physical and chemical characteristics of soil, affecting the quality and amount of organic substances in soil.

All the time between soil and vegetation there is a displacement when minerals are taken from different horizons in at-ground parts of plants, and then they are returned to the soil as litter.

Thus, there is a redistribution of mineral substances in the soil horizons. This process is usually called biological circulation of substances.

Biological cycle in a forest ecosystem is a phenomenon in which the same nutrition amount for the life-period of the tree stand repeatedly performs the cycle: soil – trees – litter – forest ground litter – soil.

It is distinguished:

– small biological cycle;
– large biological cycle.

Small biological cycle is a cycle implemented by nutrition elements contained in the leaves, needles, small branches, roots, flowers, bud scales, fruits and seeds, bark. Large biological cycle is a cycle of implemented by nutrition elements in the composition of trunk, large branches and roots and their redistribution in the soil after trees decay (during the life-time of one forest generation). It should be noted that the closed cycle of all substances within the ecosystem does not usually occur. Some elements leave this ecosystem, while the other flows into biogeocenosis outside. In this process a particularly important role is played by litter and so-called forest litter, i.e. accumulating on the surface of the actual soil layer decomposed to varying degrees leaves, small branches, bark, fruits and others, including major parts of plants (stems, branches). In the forest litter of all crop residues are mineralized.

The influence of vegetation on soil is seen in the impact on its water regime:

– in the moisture absorption of certain soil horizons and the followed transpiration into the atmosphere;

– reduction of physical water evaporation from the soil surface;

– reduction of surface runoff and increase of groundwater transition.

The influence of atmosphere on vegetation. The growth and development of vegetation depend on:

– air temperature;

– humidity;

– air movement (speed, direction);

– composition.

Wind helps and influences:

– pollination;

– distribution of seeds;

– formation of the trunks and root systems of trees;

– regulation of transpiration and assimilation.

Strong winds cause:

– windfalls;

– windbreaks;

– whipping crowns.

Sometimes whipping is underestimated. Sometimes intercrown and innercrown whipping has a negative impact on productivity and technical quality of trunks, on the development of root systems, trees rejuvenation, and hence their resistance to diseases and trees pests, fruiting.

The influence of vegetation on atmosphere. Forest vegetation has a very significant impact on a wide range of air parameters:

– composition;

– humidity;

– temperature;

– speed;

– the intensity and composition of light.

During one year period one hectare of forest plantations filters from 20 to 70 tones of dust and emit into environment various aromatic volatile compounds, which positively affect human health. Due to this fact, the number of pathogens in the forest is 100–130 times less than in city air (for more details see units 6.1, 6.2). Everyone knows the forest property to hold the wind. The flow of air rushing into the forest, soon slows down its movement, and then it quiets down. At a distance of 200–250 m from the edge of the wind speed is only 2–3% of the original. Thus, forest biogeocenosis weakens the negative impact of droughts and dry winds; it is widely used in forest afforestation (for more details see unit 6.4). Perhaps, the main influence of forests on atmospheric properties is that each forest ecosystem has its own microclimate, which is characterized by a number of properties, significantly modified by vegetation (for more details see units 3.5, 4.5, 5.3, 6.3, 6.4).

The influence of vegetation on zoogeocenosis. It is not only various in its manifestations, but it is also very significant because vegetation provides habitat for animals; it is their food source. Organic substances produced by green plants determine dependencies between plants and animals in the ecosystem, plants give rise to all food chains.

The influence of zoocenosis on vegetation. Direct influence comprises:

– vegetation as nutrition;
– trampling of vegetation;
– construction in the vegetation dwellings and shelters;
– promote pollination;
– promoting dissemination of seeds and fruits.

Indirect influence comprises:

– change of chemical properties of soil;
– change of physical properties of soil.

The influence of vegetation on the microbiocenosis. Depending on the plants species and their root extractions, the composition of microbiocenosis is significantly changed.

The influence of microbiocenosis on vegetation. The multifunctional role of microorganisms in the life of forest is manifested in particular:

– in nitrogen fixation by nodule bacteria;
– in the process of decomposition of plant residues;
– in parasitising bacteria, fungi and viruses on plants;
– in the extraction of metabolic products of microorganisms into the soil.

The biogeocenosis is the interaction not only between the components, which was discussed above, but also within the components. Thus, the mutual influence of plants can be direct and indirect one, it can be intraspecific and interspecific, favorable or unfavorable for their growth and development. The direct impact is parasitism (mistletoe on pine, birch, asp, maple), rhizocollesy (nutrients for one plant can be used by another), whipping (birch whips spruce and pine).

Indirect interaction is manifested in the influence of some plants on the other by changing the environmental conditions of their growth. In particular, there is:

– weakening of the wind;
– protection from windthrow and windbreak;
– changing lighting conditions;
– changing the water regime;
– changing soil conditions due to the formation of forest litter.

The most illustrative example of indirect positive impact is interaction of secondary species and the main woody species (see unit 2.3). A classical example is usually illustrated by the relationship of pedunculate oak, or summer oak (*Quercus robur* L.) and big leaf linden (*Tilia cordata* Mill).

V. N. Sukachev identified three types of plant interaction observed in the forest:

1) contact relationship is most often associated with mechanical impacts of plants on each other (trees whipping, roots contacts);

2) trans-abiotic relationship includes competition for living conditions, lifetime extraction, dead trees remains;

3) trans-biotic relationship occurs via other organisms (nodule bacteria, mycorrhiza).

Not only vegetation interacts with components of the biogeocenosis, but its components interact with each other.

Climatop ↔ edaphotop: climatic conditions affect soil formation process, and soil processes, defining the so-called breathing of the soil (the release of carbon dioxide and other gases), change the atmosphere.

Edaphotop ↔ zoocenosis, edaphotop ↔ microbiocenosis: soil affects the fauna, not only its inhabitants, but also indirectly via flora the rest. Fauna affects the soil. V. V. Dokuchaev classifies animals as the most important soil-makers. Microbiocenosis is largely determined by the nature of the soil conditions and, in turn, affects soil-formation process.

Microbiocenosis ↔ climatop, microbiocenosis ↔ zoocenosis, microbiocenosis ↔ phytocenosis: microorganisms by their activity destroy some organic and inorganic compounds in the soil, and create new substances, including gaseous ones, thus affecting climatop, zoocenosis, phytocenosis. In turn, climate, animals and plants have a reciprocal influence on the world of microorganisms. All the above interaction between the components of the forest ecosystem is reflected in the process of exchange of matter and energy. The main source of energy is the sun, and it is basically accumulated in green vegetation. The primary materials of the forest biogeocenosis are atmosphere, the parent rock, and soil. Plants, animals, and microorganisms accumulate, transform substance and energy, exercise their transfer and exchange between living organisms and the environment. Soil and forest litter integrally reflect the results of complex biogeocenosis processes, they are the most visual expression. But, as noted by V. N. Sukachev, this is just a scheme. Each of the components of the ecosystem can be considered as material of biogeocenosis processes, and as a means of transformation and exchange of energy and matter, and as its result.

It should be noted that the more favorable combination of abiotic factors, the more developed the world of organisms. And in this case the role of wildlife in the forest biogeocenosis is dominant. However, if the complex of ecotopic factors is negative for the development (tundra), the leading value in this case will belong to the inert nature. According to V. N. Sukachev, forest as a system at the biogeocenosis level far exceeds all other types of vegetation in the accumulation of organic matter and energy in the capacity of its impacts on the biological cycle of substances. The current GOST 18486-87 provides the following definition of forest: “Forest is an element of geographical landscape, which consists of the set of trees occupying a dominant position, shrubs, ground cover, animals and micro-organisms, biologically interrelated in the development, influencing each other and the environment”.

2.3. Components of the forest

As noted above (see unit 2.2), a component of biogeocenosis is a plant or a plant community, and in our case it is a forest community. While analyzing phytocenosis, we largely get the idea of the biogeocenosis. In characterizing forest plant community, as will be discussed in this section, the following components are distinguished: tree stand, undergrowth, understory, nurse tree spiecis, live ground cover, out-of-storey plants, plant litter, litter, and rhizosphere. Studying them allows you to navigate in the structure of forest stands, to take into account special features inherent in different areas when planning and carrying forest management activities and forestry exploitation, forestry accounting, preparation of the state forest inventory, and forest monitoring (see unit 1.5).

The stand is a community of trees, which is the most important component of forest, its main part. Stands are classified as natural and artificial ones by origin. Natural stands can be formed by trees of seed and vegetative origin; sometimes they are of mixed origin. The stands can be classified by:

– form as simple and complex;
– composition as pure and mixed.

A simple stand is defined when trees are in the same layer, a complex one when there are two or more layers. Pure stand is composed of one species; a mixed one is composed of two or more species. In terms of shape and composition forest stands can be:

– simple pure – one layer one species;
– complex pure – two or more layers, one species;
– simple mixed – one layer, two or more species;
– complex mixed – two or more layers, two or more species.

According to economic value, tree species are divided into major, minor, non-desirable, prevailing. The main tree species is a species, which in certain forest and economic conditions meets in the best way the commercial requirements. Secondary species has a lower economic value than the main one. In Belarus the main forest species include pine, spruce and oak, secondary ones are European white birch or drooping birch (*B. pendula* Roth), aspen or trembling poplar (*Populus tremula* L.), and black alder. In some specific conditions secondary tree species can be attributed to the principal ones. Non-desirable forest species is a species which does not meet commercial requirements in certain forest and economic conditions.

The main species is dominant if its stock in middle-age, premature, mature and overmature stands is not less than 5/10, and for oak, common or European ash (*Fraxinus excelsior* L.) is 4/10 of total tree stock (layer). For example, in the following composition the formula is written 4O6B, not 6B4O. In a young stand, the predominant species is the main species, its share in the composition of plantations in second grade age is 1/10, and in the first age class is 2/10 less than mentioned above. So, the formula of mixed pine-birch stands of 30 years is 4P6B, and not vice versa; in a stand of 20 years it is 3P7B. It is distinguished between native and production stands. The emergence of native forest stands was not initiated by active human interference and extreme influences such as, for example, catastrophic attack of pests, diseases, fire, windthrow or breakage. Its appearance is based on natural reproduction; they are mainly due to the climate and the soil-hydrological conditions. Anthropogenic factor in the process of their development, of course, was present, but it did not significantly change their main qualities. Production stand is formed at the place of native stand as a result of human activity or under the influence of natural processes mentioned above, and having, as a rule, an extreme character.

In Belarus the native forests are: pine, fir, oak, black alder, ash, and birch stands, production forests are drooping birch, aspen, grey alder, hornbeam, maple, and linden. The concept of "stand" is often synonymous with "forest community". However, the concept of stand is narrower. As it was already mentioned above, this is only a set of trees, which are basic components of the forest. Plantation (forest phytocenosis) is a forest stand of homogeneous trees, shrubs, live ground cover. As noted by I. S. Melekhov, the term plantation, though it was in practice, it cannot be considered quite successful, as it creates the impression that it refers to an artificially created forest. Therefore, along with the term "plantation" in the same sense the term "forest phytocenosis" is also used. The young plants of natural origin grow under the forest canopy and are able to create a stand; the height does not exceed 1/4 of the height of the trees of the main canopy. The young trees are trees which are not older than two years. If their age is older than one year but not more than two years, they appeared from the seeds, it is only natural seeding. When seeding survives, it turns into the following age category, which is undergrowth. The seeding less than one year are sprouts. Undergrowth is a category of natural forest recovery, which refers to the age period of young stands. Undergrowth can comprise species, which are parts of the parent stand, as well as other species. It can be of seed or vegetation origin.

The undergrowth does not all go into the stand. A large part of it dies as a result of competitive relations. Some undergrowth may exist for quite a long time, but in a depressed state, it will never replace the parent stand.

According to the expression of G. F. Morozov, under the canopy of the forest undergrowth there is a dual struggle for existence: 1) between individual trees and undergrowth; 2) between undergrowth and the parent trees. The characteristics of reliable undergrowth are the following:

– pointed crown (it is index of good growth);
– thick needle packing;
– dark green needles.

The condition of the plants undergrowth is divided into viable (healthy), damaged, depressed, dead (rotten). For a normal existence of undergrowth there should be:

– penetration through the forest canopy the required amount of light, heat, and moisture;

– adequate soil nutrition, which can be, in particular, provided with the weakening of root competition.

Usually, undergrowth grows better where there are gaps in the tree canopy. When the stand is thick, light barely penetrates through the crown; there is no enough supply due to root competition, i.e. the undergrowth is experiencing a great depression. Sometimes it is so strong that the growth ceases and in future it will not become a basic layer. This undergrowth is called the weak or oppressed.

The characteristics of weak undergrowth are the following:

– umbrella-shaped, blunt crown (it is index of growth cessation of growth);
– thin needle packing;
– pale-green needles;
– age of several decades, and the height does not often exceed 1.0–1.5 m.

Undergrowth plays an important role in the biology of the forest, affecting neighbouring trees of the same age, and older generations (helps to clear from branches), the ground cover, microclimate. Normally developing undergrowth is characterized by gradually increasing ability to create a forest environment. Great attention should be paid to preserving undergrowth of economically valuable species when conducting forest management and forest harvesting operations. If we want to fully use all the reliable undergrowth, thinning should be conducted carefully because the young trees growing under the forest canopy are very gentle. When suddenly exposed to open space they can not immediately adapt to new conditions and often die; this does not happen with a gradual improvement of light conditions. The older the undergrowth, the longer it was shaded by the canopy of the parent stand, the less reliable it is, the less likely is the reforestation of parent stand.

The density of the undergrowth is classified as rare – up to 2,000 trees per 1 ha, medium – 2,000–8,000 trees per1 ha, thick – 8,000–13,000 trees per 1 ha, very thick – more than 13,000 trees per 1 ha.

The height of the undergrowth is divided into small – 0.1–0.5 m, medium – 0.6–1.5 m, large – 1.6 m or more.

Distributing the plants of the undergrowth according to the area there are three categories depending on the occurrence. The occurrence "C" represents a ratio of the number of plots with the presence of at least one seedling per total number of plots. If $C > 0.70$, the undergrowth distribution is even, when $C = 0.40–0.70$, it is uneven, when $C < 0.40$, it is a group distribution (group of 5–10 trees). Group undergrowth is more reliable than the undergrowth formed by separate trees. It is done little harm when it is suddenly exposed to an open place, so future growth will also be successful.

Understorey shrubs are rare trees that grow under the forest canopy are not able to create stand in specific growth conditions. Shrubs: common juniper (*Juniperus communis* L.), buckthorn brittle, or aspenlike (*Frangula alnus* Mill.), common buckthorn (*Rhamnus cathartica* L.), hazel ordinary, or hazel (*Corylus avellana* L.) honeysuckle fly, or ordinary (*Lonicera xylosteum* L.), black currant (*Ribes nigrum* L.), European Euonymus (*Euonimus europaea* L.), Euonymus warty (*E. verrucosa* Scop.), strokelinecap blackish (*Lembotropis nigricans* (L.) Griseb), English broom (*Chamaecytisus ruthenicus* Fisch. ex Wołoszcz.) Syr.), Dyer's broom (*Genista tinctoria* L.), German broom (*G. germanica* L.), Sambucus nigra (*Sambucus nigra* L.), red elderberry (*S. racemosa* L.), green broom (*Sarothamnus scoparius* (L.) Koch), Daphne ordinary or mezereon (*Daphne mezereum* L.), cherry ordinary, or bird (*Padus avium* Mill), dogberry or dorwood (*Swida sanguinea* (L.) Opiz), raspberry (*Rubus idaeus* L.), European dewberry or dewberry ordinary (*R. caesius* L.), cranberry (*Viburnum opulus* L.), roundear willow (*Salix aurita* L.), gray willow (*S. cinerea* L.), willow blackish (*S. myrsinifolia* Salisb.) and others.

Trees of the second value: ash ordinary (*Sorbus aucuparia* L.), goat willow, or sallow (*S. caprea* L.) and others. Under the forest canopy trees are usually small, and they are not much different from shrubs. Some shrubs in better conditions can be in the form of a shrublike tree. Sometimes certain shrub types of (raspberries, blackberries) belong to the sub-shrubs.

The trees of the first value which grow in poor or noncharacteristic conditions (climatic or soil) are the following: linden, spruce, oak, common hornbeam (*Carpinus betulus* L.). For example, linden in poor soils or in the forests on the northern border of their natural habitat does not reach large size and shelters in the undergrowth. Being well developed in the shadow, it never dies under a thick canopy of spruce and oak, but does not reach the results of these trees, and forms the undergrowth. A similar situation was observed in spruce seedlings. It becomes so oppressed that, continuing to be under dense canopy, it will never be able to reach the height of the first storey. About this undergrowth it is said that it took undergrowth form. Common jay (*Carrulus glandarius* L.), makes significant reserves of acorns under the canopy of dense pine stands, where it feels secured, contributes to the emergence of oak on poor sandy soils, where is destined to become only the undergrowth.

The positive role of the undergrowth is the following:

– prevents settling of gramineous plants;

– protects the soil from drying out and ramping after cutting; at average density it creates favorable conditions for main species reforestation;

– due to litter it increases fertility of forest soils: it creates loose, soft humus and enriches it by nutrients;

– it contributes to the accumulation of snow, minimizing runoff, prevents water erosion in thin stands;

– it acts as adjusting species. The undergrowth adjusts young trees, causes them to stretch in height, light, promotes better clearing trunks of trees from branches;

– it is a habitat and food source for fauna;

– the fruits of many species of undergrowth have nutritional value (hazel, raspberry, blackberry, cranberry, currant, ashberry, and others);

– it performs useful “guard service”: it helps the forest to decrease a large number of visitors, and thus reducing anthropogenic load.

The negative role of the undergrowth:

– thick undergrowth retards the growth of seedlings, young trees, germination and thereby prevents forest regeneration;

– fir understorey in oak forests contributes to the formation of acidic litter, holds a lot of rainfall, which adversely affects seed reproduction of oak.

When thick undergrowth is formed, it must be thinned. There is a special kind of cutting, it is undergrowth cutting. In particular, it provides the following. In young oak stands undergrowth is cut at the height which provides shading only the lower part of the crown and oak trunks. Renewal of undergrowth like stump planting or cutting at a certain height is usually done in early spring or autumn, and, if reduction of the growth intensity is necessary, it is best done in mid-summer. To enhance fruiting of hazel and other shrubs cut down old coppice shoots are periodically cut down, and 3–4 young coppice shoots are left. Before clear cutting which provide natural regeneration of the main tree species, undergrowth can be thinned or cut down completely. Undergrowth cutting can be combined, if possible, with regular intermediate cutting.

The impact of undergrowth on the environment and the biogeocenosis changes dramatically over time and becomes much more important, because it becomes the undergrowth; it becomes an integral part of the canopy. Similar effect of understory is stable during the whole period of its existence. Auxiliary tree species are trees or shrubs that contribute to growth and improvement of the form of the trunk of the main tree species. Surrounding trees, auxiliary tree species deprive lateral branches light penetration, which leads to their death and, thus, stimulates growth in height main tree species, minimizes the possibility of trunks curving, increases their solid volume. Species, slowly growing in youth and prone to expansion in branches need to a great extent being surrounded by auxiliary tree species. In conditions of Belarus, it is, for example, oak. There are species which can function as auxiliary tree species. Among wood species, they are maple, elm, linden, hornbeam and others; among bush species, they are honeysuckle, hazel, buckthorn and others. The role of auxiliary tree species (but only for a certain time) is fulfilled to each other by the trees of the main species when fast and slow growing species grow together. For example, it can be pine, when it mixes with to spruce, oak. In pine and spruce stands the role of auxiliary tree species may belong for a while to secondary species like birch, asp.

At an early age of main tree species the role of auxiliary tree species belongs to lowly shrubs, then to higher ones, and later to woody tree species. If auxiliary tree species grows much faster than the main species and its growth is not regulated, it can become the oppressor, as for example birch, and aspen in pine and spruce stands. The growth of auxiliary tree species is necessary to regulate by the removal lateral branches, tops or half tops. A certain number of trees of auxiliary tree species can be removed and, and some understory trees can be used as auxiliary tree species.

It is possible to grow highly productive stands of desired quality, regulating the height, size, composition of auxiliary tree species, taking into account the characteristics of the main species, climate, soil, and ground conditions.

The ground cover is a collection of mosses, lichens, grasses, and dwarf shrubs, which grow on forested and non-forested lands. The ground cover consists of field and moss layers. In the upper layer, e.g. field layer there are such species as bilberry (*Vaccinium myrtillus* L.), cowberry, heather. Some herbaceous plants (goutweed ordinary (*Aegopodium podagraria* L.), species of geraniums (Geranium L.), meadowsweet (*Filipendula ulmaria* L.) and others exceed far above the height of the shrubs. Others are involved in the formation of lower layer of living ground cover, for example, May lily (*Convallaria majalis* L.), bifoliate bead-ruby (*Majanthemum bifolium* (L.) F. W. Schmidt), common sorrel (*Oxalis acetosella* L.), semionic European (*Trientalis europaea* L.). Green mosses are especially common in our forests, they often form a pleasant emerald cover: pleurisy Schreber (*Pleurozium schreberi* (Brid.) Mitt.), giacomi brilliant (*Hylocomium splendens* (Hedw.) Warnst.), ptile comb (*Ptilium crista-castrensis* (Hedw.) De Not.), dykran wall fern (*Dicranum polisetum* Sw.). In some forest phytocenoses characterized by dry soils it should be noted also a significant role of lichens: Cladonia silvatica (*Cladonia alpestris* (L.) Rabh.), Cladonia rangiferina (*C. rangiferina* (L.) Weber ex F. H.), Cladonia Alpine (*C. alpestris* (L.) Rabh.).

Poor access of light, heat and wind under forest canopy causes:

– lack of flowering in many plants of live ground cover (goutweed);

– predominance of perennial plants, reproducing mainly vegetative (asexually) and having a curtain distribution; they are also characterized by a number of other changes in the morphology, anatomy, ontogeny (for more details see unit 3.4).

Live ground cover consists of:

1) plants of different life forms:

– chamaephyte (reproducing sprouts are just above the soil surface);

– hemicryptophyte (reproducing sprouts are at the level of the surface of the soil);

– cryptophyte (reproducing sprouts are at a depth of several centimeters);

– therophyte (winter buds are not reproduced);

2) plants of different ecological groups:

a) in relation to moisture:

– xerophyte (put up with permanent or temporary lack of moisture in the soil);

– mesophyte (prefer conditions with moderate humidity);

– hygrophyte (grow in conditions of excessive soil moisture);

b) in relation to light:

– light-loving (grow in the meadows, glades, in thinned stands). This group includes: ephemers (annual), ephemeroid (perennial), these are herbaceous plants with a short growing season in early spring time (before appearance of leaves on the trees). With increasing stand age, especially consisting of light-loving species, more demanding to light grass vegetation begin to develop;

– shade-enduring species (grow in dense stands).

In relation to the richness of the soil the plants of live ground cover are classified in to:

– oligotrophs (low soil fertility);

– mesotrophs (moderate soil fertility);

– eutrophs (high soil fertility).

Among the plants of the above three groups in relation to different soil characteristicsthere can be clasified:

– cryophyte (live in cold soils);

– petrophyte (live in stony soils);

– psammophyte (take econiches of sandy soils);

– halophyte (live on saline clay soils);

– acidophyle (withstand high acidity of the soil solution);

– calciphiyle (prefer soil with a high content of carbonates).

The most significant changes in surface come under the influence of cutting and especially forest fires.

Different forest communities clearly differ in the live ground cover. Therefore, foresters use it as one of the main characteristics, which determine the character of forest phytocenosis. Special attention is paid to participants in the composition of the live ground cover some species, the so-called indicators, which make a fairly accurate conclusion about the environmental conditions of a specific habitat. This opinion is proved by J. Cousens (1982) that "a more reliable guide service is provided by the ground cover in the forest than the forest layer" (p. 105). Thus, the ground cover, its composition, dominant and subdominant species (they usually are the indicators) are judged according to the forest type, forest conditions, association, the conditions for natural regeneration, and so on. Let's regard a few examples.

Grim-the-Collier (*Hieracium pilosella* L.), sheep fescue (*Festuca ovina* L.) are indicators of poor sandy soils. Heather indicates similar conditions as the previous species, but its presence in the live ground indicates good conditions for natural reproduction of pine, due to the loosening effect of root systems of theshrub.

Fireweed, or French willow (*Chamerion angustifolium* (L.) Holub), raspberry, big sting nettle (*Urtica dioica* L.), celandine (*Chelidonium majus* L.) are indicators of soil nitrification (formation of salts of nitric acid during aerobic biochemical processes), which increase its fertility. Hepatica, or liver-leaf hepatica (*Hepatica nobilis* Mill.), lily-of-the-valley, Grim-the-Collier, Solomon's seal, or drug Solomon's seal (*Polygonaum odoratum* (Mill.) Druce), Paris herb (*Paris quadrifolia* L.), wood sorrel, goutweed, beadruby are indicators of soft, boggy humus (Mull), characterized by high fertility. Blueberry, Labrador tea, common hair-cup moss (modern name is polytrich common (*Polytrichum commune* Hedw.), sphagnum (*Sphagnaceae*) are indicators of raw, peaty humus (raw humus), unfavorable for natural regeneration. Blueberries are indicators of fresh and moist sandy soils (more details see unit 8.6), having, as a rule, gleyed layer, showing periodic significant rise in groundwater levels. Cranberries are indicators of relatively little moist sandy soils. Marchantia polymorphic (*Marchantia polymorpha* L.) is an indicator of soil compaction and the beginning of the process of eutrophication. Common hair-cup moss is an indicator of increased soil moisture, its compacting and further swamping, acidic environment and poor living conditions for reforestation. The sphagnum is an indicator of further swamping.

Forestry function of live ground cover is determined by its significant influence on soil, hydrology, and temperature regimes, and all components of forest, represented by vegetation, litter, and wildlife, fire conditions in forests, conditions for reforestation.

1. Impact on soil drying and swamping. The most powerful factors of drying up soil are grains; the least powerful plants are mosses. In this regard they can be compared to litter. Forest mosses cause soil compaction, reducing its permeability, reducing evaporation. Due to anatomical structure, sphagnum mosses cause excess of moisture in dry valleys, thus initiating the development of swamping (for more details see units 13.2, 13.3, 14.2).

2. The effect on the temperature regime. In the presence of live ground cover the temperature range is smaller, which is good for the development of seedlings and natural regeneration of woody species.

3. Impact on the distribution of fauna. Live ground cover shelters mice, which destroy the seeds of forest species. There also live pests, which destroy the insects.

4. Impact on forest fire distribution. Dried residues of herbaceous plants are an ideal fuel for fires, they most often occur in early spring. On the contrary, in summer actively vegetating, juicy above-ground plant organs of live ground cover are likely to reduce the emergence and spread of fires.

5. Impact on natural regeneration. A thin growth of moss-grass-shrub layer creates favorable conditions for the emergence of a new generation of forest, but when it is powerfully expanded it becomes an obstacle to the reproduction of woody species.

Non-layered vegetation is a set of vines, lichens and other plants that grow in different parts of the forest (hops common (*Humulus lupulus* L.), common ivy (*Hedera helix* L.)). Plant litter (fresh litter) comprises fallen leaves, needles, branches, twigs, fruits, and bark. Forest litter is a soil layer, which is formed from forest plant litter of varying degrees of decomposition. The name "forest litter" historically emerged due to the fact that in the past the peasants gathered the surface layer of fallen pine needles, foliage, small branches for use on bedding for cattle. Initially, there was no difference in terms of litter and fallen leaves. They were synonyms for a long period. Soil and forest litter reflect the results of complex biogeocenosic processes and represent the most clear and complete results of the interaction and mutual influence of the components of the forest ecosystem. There are three main types of forest litter. Mull humus is soft, quick humus, loose litter, which consists of a litter of broad-leaved trees and shrubs. It is rich in nitrogen and ash substances, contains up to 10% of humus in the upper horizon, it has a crumbly structure and a neutral reaction. This type of litter is identical to the modern concept of the term humus. Moder is a moderately coarse litter of an intermediate type; its thickness is 3–5 cm. It is the most common type of litter in the forests of Belarus; it is common under normal deciduous plants or in mixed coniferous-deciduous forests.

Needle litter (mora) is coarse, acidic, peaty, dense, poorly decaying litter. It is formed mainly under coniferous plants in conditions of lack of oxygen and high moisture. As a result of slowing down the process of decomposition of litter it is increased and peaty. It is typical for pine forests with bilberry, ledum. The above-described components of the forest are not always found in forest at the same time as a complete set. Sometimes, there is no undergrowth, or nurse tree species, or understory, auxiliary species. There may be the lack of several components, for example, young trees and understory, undergrowth and underbrush, etc. There is always a live groundcover. The exception is high close pine forests, especially spruce forests, in which the ground cover is a dead litter. All components of the forest, located above the earth's surface, conventionally comprise its aboveground part. The underground part is the rhizosphere.

The rhizosphere is a layer of soil where root system is located. It can be limited by the upper horizons of the soil (in the early development of trees) or covers the entire volume, which are the roots of the plants. Thus, the rhizosphere is a part of the soil, directly related to roots. In the rhizosphere favorable conditions are created for microbial growth, due to high content of nutrients due to root pruning, extraction of live roots. For example, the roots of oak, ash, pine and some other species are known to produce phosphorus, potassium, ammonia nitrogen, calcium, magnesium, and various enzymes. The root extractions may contain toxic substances for microorganisms.

The role of rhizosphere increases for some herbaceous plants after tree cutting. Nitrifying bacteria appear in the rhizosphere of fireweed in a significant number. Some bacterial species, primarily nodule settle on the roots of some plants and absorb nitrogen from air. These are pea family (Washington lupin (*Lupinus polyphyllus* Lindl.)), the black and grey alder (*Alnus incana* (L.) Moench). Introduction of these plants in forest phytocenosis is an effective way of enriching soil with nitrogen and increasing its fertility. The founder of biological amelioration of forests with lupine is Professor B. D. Zhilkin, and a group of his followers, who worked at the Department of forestry at the BSTU.

2.4. The main distinctive features of forest stands

Origin: the stands are formed, originating from seeds or vegetatively. They can be of natural (seed, vegetative, mixed) or artificial (planting, seeding) origin (see unit 10). The shape of the stand is the indicator that characterizes the form of crowns. The shape of the stands can be simple (one layer) and complex (two or more layers). A simple stand is characterized by horizontally closed crowns. Despite the difference in the height of individual trees, their crowns together still constitute one common layer.

Complex forest stand is characterized by a vertical tree crown cover, i.e. tree height is split into separate layers. A layer of the stand is a set of plants occupying a certain limited position in its vertical structure and having the appropriate environmental conditions. Any extreme conditions such whether deficiency or excess of some factor in the environment, lead to the formation of simple stands. As an example, we give a single layer, even-aged pine stands on dry, sandy soils. As a rule, no other tree species grow there. Another example is represented by sparse growth of sphagnum pine forests, characterized by excessive stagnant moisture. Complex stands are formed in rich conditions, especially in areas with favorable climate. The moist stands of tropical and sub-tropical forests are most expressed characterized by multiple layers. In Belarus fast-growing, light-demanding species, which occupy the first layer contribute to the formation of complex stands. Eco-niche of the second and third layers belongs to shade-tolerant species, growing slowly in the first years of life. Examples of two-layer stands:

– common on sandy loams, where the upper layer is formed by pine, the lower one is formed by fir; the upper is formed by birch or aspen, the lower one is formed by fir;

– oak forests, in which the upper layer is represented by oak, sometimes involving ash, second by maple, or platanoides (*Acer platanoides* L.), elm (elm small, or smooth, Scotch elm (*Ulmus minor* Mill.), or elm (*U. scabra* Mill.)), linden, hornbeam.

Two-layered stand may be formed by one tree species, if the tree stand is represented by two sharply different age categories: elder trees in the first (top) layer, young trees in the second (bottom) layer, i.e. the complicated form of the tree stand may also be determined by age structure. The tree stand composition is a sign of mixed species in the stand. According to the tree stand composition there are pure and mixed species. The pure tree stand consists of one species, or admixture of other species does not exceed 5% of the total stock. Mixed forests consist of trees of several species.

The tree stand composition:

1) is characterized by a list of tree species with indication of the share of each of them in the growing tree stand stock;

2) is determined for each storey of the tree stand;

3) is expressed by the formula, which is abbreviation of the names of species and their share in the composition. The sum of coefficients should be equal to 10. The first place in the formula takes the predominant species. In young stands up to 10 years, the composition is characterized by the ratio of the number of stands.

The complication of the tree stand form occurs simultaneously with enrichment of the composition. The complicated tree stands are usually mixed, and most simple tree stands are pure. Thus, a conclusion can be made that the simple and pure tree stands formation is due to the same reasons, as well as the complex and mixed tree stands also naturally arise in certain similar combination of conditions of forest community. On dry, poor sands, on high-moor peats there are pure, of a simple form pine forests, on low-moor peats there are one storey black alder forests, possibly with a small admixture of other species. At the same time on fertile loamy and clayey soils there are mixed multiple stands of oak with linden, aspen, maple, elm, ash, hornbeam and others. Mixed stands are stable, they better use environment conditions: soil, light, moisture, better withstand the strong winds, suffer less from pests, diseases and fires and temperature fluctuations. The admixture of soil-improving species (linden, maple, birch, aspen, alder) to species that tend to form acid ground litter and compact the soil (spruce), contributes to the maintenance and increases soil fertility.

When the species are properly mixed, it can significantly increase the productivity of the forest, its protective and water conservation properties. And yet, giving preference to the formation of mixed tree stands, it should be remembered that pure forests also have some advantages. They are easier to take care of; it requires less effort and expense. On sandy soils, characterized by dryness and low fertility, pure pine stands are more appropriate. Age is a sign that indicates the relative or absolute age of the stand. The essence of this property is revealed by using the following concepts. Class age is the period of time during which a stand is considered to be commercially homogeneous. Its value depends on genetically determined growth of certain tree species and their origin. The duration of the class age for coniferous and hardwood stands of seed origin are 20 years old, for small-leaved and deciduous stands of vegetative origin are 10 years. If the age of the trees in a tree stand varies in a range of the same class, it is even-aged, if the age of the tree stand covers more than one class, it is considered to be multiple-aged. For example, in the composition of forest stands there are pine and birch in the age of 50 and 30 years, respectively. In this case, it is the even-aged stand, because the forming species have the same third age class. Absolutely even-aged stands are formed by simultaneously conducted planting or sowing, after a fire in the year an abundant harvest of seeds.

The group of stand age is a classification unit of a tree stand, which depends on the determined for the given species the age of the main cutting and corresponds by terminology and definitions to the age periods of the formation of forest stands (see more details unit 11.1).

The groups of stand age are young, middle-aged, premature, and mature, overmature, indicate the relative age of the stand. In Belarus it is adopted the following age of the main cutting according to the species: group II of forests (see unit 1.5): pine, spruce of 81 year old and more; oak, ash of 101 year old or more; hornbeam of 71 year or more; birch of 61 years and more; black alder of 51 years and more; grey alder, aspen of 41 years and more. In the first group forests (see unit 1.5) the cutting age for all species, except for aspen, is one age class higher. The young growth stands are in the age of their closure (I age class) until the end of the second age class. Middle-aged stands are stands of all age classes between the age groups of young stands and maturing stands. Maturing stands are stands of the preceding maturing age class. Mature stands are stands of two age classes (age class of main cutting and following it). Overmature stands are all the stands after mature stands. Forest appraisal index is a criterion of tree stands production. It characterizes the growth rate of trees and is determined with the tables of Professor M. M. Orlov in accordance with average height, age and origin (vegetative or seed).

Depending on the conditions of climate and soil at the same age stands are of different heights. The more favorable climatic and soil conditions, the greater the growth of trees in height, the thickness (and hence volume), and the higher is the yield (forest appraisal index) of the tree stand. In young stands up to the age of 10 the forest appraisal index is based on the conditions of the habitat (forest type).

There are seven basic classes of forest appraisal index from I^a (the highest productivity) to V^a (the lowest productivity). Occasionally, it is distinguished I^b (the highest productivity) and V^b (the lowest, worst productivity) classes of forest appraisal index.

The stands of II and higher classes are called the stands with a high forest appraisal index, III and IV classes are called the stands with a medium forest appraisal index, V class is called the stand with a low forest appraisal index, V^a and V^b classes are distinguished as unproductive classes.

The class of forest appraisal index is not constant, once and always fixed for a given forest stand. The soil largely determining the forest appraisal index varies with time. Changes can be caused by podzol formation processes, processes of eutrophication and others. The forest appraisal index undergoes some changes in the course of time, respectively. Positive changes in quality can be achieved by draining wetlands of forest land.

When presenting silvicultural characteristics it should be correlated to the forest appraisal index and forest types and forest conditions. Forest density is the indicator that characterizes the density of treestand and is determined by the ratio of the sum of squares of the cross of tree trunks at a height of 1.3 m to the total area of cross sections of a normal stand of the same age and the same height.

The relative density is determined for each species of the stands. The total relative density of the stand is determined by summing the densities of its constituent species. For example, $D_t = D_s + D_b + D_a$ and so on, where $D_s + D_b + D_a$ are relative density of spruce, birch, aspen, respectively.

For young tree stands, density is calculated according to the degree of closeness of the canopy, and for the stands which have not reached the closeness of stands, it is the ratio of the number of woody plants per 1 ha to 10,000. The unit of density corresponds to 10,000 trees per 1 ha. Density is expressed in tenths of a unit. Stands with a density 0.8 or higher are considered to be highly dense, with a density 0.6–0.7 are medium dense, with a density 0.3–0.5 are low dense, with a density 0.2 and below the stands are sparse. Absolute density is expressed in square meters per 1 ha. The closeness is the feature that characterizes the density of the closeness of tree crowns.

Within the limits of the same forest appraisal index, the same composition and age, stands may vary according to the degree of closure of the canopy. The stand may be closed, if there are few gaps in the canopy, the stand is little or sparse, rare, if there are many gaps. The closure of the canopy is expressed in tenths of units (as well as density) and is determined by the ratio of the sum of squares of the projections of tree crowns to the total area occupied by the stand. High density of tree stands does not always mean high closeness of the canopy. In some conditions, for example, when, unproductive and low valued pine forests are formed in the high-moor bogs and there are no closeness of the crowns, the stands, however, are normally full.

In young stands, the closure is usually higher than the density in middle-aged and maturing stands they are approximately the same, in mature and overmature stands the density is higher than the closeness. Density is a characteristic that is determined by the number of trees per 1 ha of forest area. Above we discussed the density of trees which characterizes the degree of density of standing trees. As you can see, these concepts are close. However, it should be noted, they do not always coincide. Let us analyze the following example. There are two tree stands; the amount of trees in the first stand is more than in the second one, i.e. the density is different. But in the first tree stand is thin, the second is thicker. And the sum of the areas of the cross sections in both tree stands, and hence the density can be approximately the same, i.e. at a different thickness it is observed the same density, and the same densities there are different diameters and the nature of the crowns of the trees. All this is manifested in various biogeocenosis differences: resistance to windthrow, peculiarities of natural reforestation, and others. Ultimately, this is reflected in the differences (sometimes quite substantial) of silvicultural approaches: the intensity of the main cutting, their frequency, type and method of main cutting and others.

Merchantability is a criterion of economic category ofthe stand quality, which is determined by the yield of the wood commodity or commercial wood. There are 4 classes of merchantability (for more details see case study 2). The classes of merchantability are defined in maturing, mature and overmature stands for each element of the forest. A certain species that is a constituent part of the given stand is regarded as an element of the forest. The class of merchantability of the stand is determined by the dominant species.The tree belongs to commercial or fuel wood depending on the technical validity (quality):

a) commercial wood are trees, in which the length of the commercial part of the basis part is 3 m or more;

b) fuel wood are trees with a length of basis part is less than 3 m.

3 FOREST AND LIGHT

3.1. The importance of light in the life of the forest

Light is the most important environmental factor for forest, the main source of energy in forest biogeocenosis. On the Earth radiant energy of the Sun is converted into heat. The light and heat of the Sun caused life on the Earth.

Depending on the wavelengths in the solar spectrum the following partsare distinguished:

a) visible radiation (wavelength 0.40–0.76 μm);

b) ultraviolet radiation (less than 0.40 μm);

c) infrared radiation (more than 0.76 μm).

The share of visible and infrared radiation constitutes about 50% of all incoming to the Earth radiant energy, ultraviolet part of the spectrum is about 1%. There is the concept of “physiologically (photosynthetic) active radiation” (PAR), which is directly used in the process of photosynthesis. A significant part of the PAR is in the range of 0.38–0.71 μm and is part of the visible spectrum. In the course of physics, the following types of flows of solar radiation are known:

1) direct;
2) diffused;
3) reflected;
4) total (1 + 2).

About 45% of solar radiation, the rest is reflected, absorbed, diffused in the atmosphere reaches the surface of the Earth. The amount of solar radiation falling on the Earth, depends on the following conditions:

1) latitude (altitude of the Sun above the horizon);
2) the ratio of direct and diffused radiation;
3) transparency and circulation of the atmosphere;
4) landforms, slopes exposition and others.

In silviculture there are the following types of radiation, which differ from the types of radiation flows:

– direct radiation reaches the earth's surface directly from the Sun in the form of parallel rays;

– diffused radiation comes from the sky because of diffused sunlight from the atmosphere, clouds.

In southern latitudes in the total light flux, the ratio of direct and diffused light is 70 to 30%. In northern latitudes there is an inverse proportion. Optimal proportion of scattered light for plants is 50–60% of the total;

– bottom light is reflected from the soil, the live ground cover, water. That is why it is so important for the life of the lower crown parts of tree canopy, especially plantations with live ground cover, bright color lichen, growing on the banks of reservoirs;

– lateral light enters a forest stand from the open space (technology corridors (portages) created by thinning). Impact on vegetation at a distance of 20–40 m, resulting in a better survival rate for seedlings, increased decomposition of forest litter, causes increased growth of trees.

As noted by V. N. Sukachev, light participates in all vital processes in the forest:

1) photosynthesis is the fundamental process of the biosphere; K. A. Tymiraysev compared plants with "true Prometheus, who stole fire from heaven and gave it to people";

2) the breath goes in parallel with photosynthesis, the lack of light respiration dominates over photosynthesis;

3) transpiration is a physiological evaporation of water from plant varies, depending on light.

4) photoperiodism is change of daily and seasonal lighting modes, it is an important signaling factor, it calls a reaction from plants of the forest ecosystem, which is manifested in the change of morphological, biochemical, physiological properties and functions of plants;

5) photomorphogenesis is light that has a direct impact on the growth and development of plants, the processes of differentiation in cells and tissue levels, organs formation;

6) reproductive function is activated in the time of flowering and fruiting when trees are better lit, their fruits and seeds are more regular and more abundant, there are more seeds by weight and have a better crop quality than shaded plants;

7) the germination of conifer seeds is the most actively occurs in the red rays, slowing down in green and blue rays;

8) the growth of seedlings and sowing as a normal process occurs at necessary 1,000–2,000 Lux;

9) the formation of plantations and habitus of trees in the forest, depending on the needs in the light play a certain role in a vertical structure and form characteristic appearance of this type. The trees grown in forest differ in morphology of stem and crown from free-standing specimen.

Periodic plurannual change in solar activity is repeated, according to I. S. Melekhov, in 11, 22, 33, 35, causes changes of climatic factors and thus effects:

1) on the frequency of fruiting tree species and natural reproduction, resulting in the formation of cyclic uneven-aged stands;

2) on the breeding cycle of pests;

3) on the growth of trees; with increasing solar activity it increases, i.e. it is a periodic variation in the width of annual rings.

3.2. The relation of tree species to light

Tree species are divided into heliophilous and shade-tolerant ones. Manifesting different needs in light, they all need it, even shade-tolerant, i.e. to a greater or lesser extent, all species are light-demanding. Therefore, as noted by I. S. Melekhov, in forestry until the mid-19th century there was a division of tree species into light-demanding and shade-loving; now it is recognized as incorrect. In forestry the negative reaction of plants to shading is understood as photophily. The ability to maintain relatively high activity of photosynthesis in shading is defined as shade-tolerance. Understanding of the relationship of tree species to light can be obtained on the basis of the following external features and biological characteristics:

1) the thickness of foliation and the degree of crown thickness. A thick lowered crown proves a shadow-resistant species; a thin, open highly elevated crown is a sign of photophily;

2) leaf orientation. Shade-tolerant tree species are characterized by mosaic foliage type. Due to the different length of the petioles of the leaves on the shoots, they are in the same plane located perpendicular to the flow of light, which contributes to more effective light absorption;

3) the rate of removal stems from knots. Heliophilous species of stems are removed from knots faster, shade-tolerant species preserve in the shade live branches for a long time;

4) the nature of the canopy of the forest. There are no, as a rule, young trees of heliophilous species under canopy of forest or there are some young heliophilous species in a depressed state;

5) the presence and condition of the seedlings under the canopy of the stand – undergrowth of light-demanding species under the canopy, usually absent or presented in small quantities and is in a depressed condition;

6) the growth rate of heliophilous species are characterized by fast growth when they are young, shade-tolerant species are characterized by slow growth when they are young;

7) the intensity of natural thinning is more intense for heliophilous species and slower the shade-tolerant species;

8) seed size, frequency and abundance of fruiting. Light-demanding species (birch, aspen), in contrast to shade-tolerant, are characterized by small seeds, much more frequent and abundant fruiting;

9) thickness and nature of the bark. The bark of light-requiring species is thick and rough (oak, pine, birch, aspen), the bark of shade-tolerant species is slim and smooth (spruce, hornbeam);

10) relation to frost and sun – unlike shade-tolerant species, photophilous species are not afraid of negative effects of abiotic factors, therefore they quickly populate open space of forest lands;

11) the character of the live ground cover and the rate of decomposition of forest litter in forests. In the stands of photophilous species there is a quick formation of a grass layer, the process of forest litter- and tree waste decomposition is activated.

Relation to light of forest plants of the same species varies substantially depending on various factors:

1) age. Tree species of different ages have different light requirements: young plants are more shade-tolerant, mature plants exhibit increased photophily;

2) origin. Seed stands are less shade-tolerant than sprouting trees. The latter have inherited a powerful root system that facilitates adaptation to the conditions of the environment, including the lack of light;

3) climate. The same tree species are more light-demanding in the north. The better is the climate, the less light-demanding are the plants. Apparently, it is explained by increased heat amount;

4) altitude above sea level. The higher is a level above sea level, the greater is photophily, because there is less heat availability;

5) soil fertility. The more fertile is the soil, the less is photophily, and vice-versa;

6) seasonality. After the peak of active growth of plants, this is observed in the middle of the growing season, the need in natural light decreases.

3.3. Photophily scales of tree species

In different geographical areas there are different photophily scales of tree species. Classical one is the scale of M. K. Toursky. It is based on set of features, though without regarding age-related stages of tree species development. M. K. Toursky was the first among foresters who made up the scale of distribution of forest species depending on their demands to light (at the age of maturity, under average conditions). The scale is a series in which the first place is given to the most light-demanding species, and followed in a descending order by less photophilous ones: larch, birch, pine, aspen, willow, oak, ash, maple, alder, elm, Crimean pine, grey alder, linden, hornbeam, spruce, beech and fir. For Belarus the photophily scale was proposed by N. D. Nesterovich and G. I. Margaylick (1969):

1. Light-demanding species: pine, Murray and Banks, Siberian larch, European larch, black locust, willow, European bird cherry, Siberian pea shrub, Manchurian walnut, weeping birch, aspen, Italian poplar, grey alder, white birch.
2. Relatively light-demanding species: Austrian black pine and Eastern white pine, Douglas fir, Amur corcktree, ash ordinary and Pennsylvanian, Padus maackii, walnut grey, canoe birch, silver maple, English oak, mountain ash.
3. Intermediate or medium light-demanding species: blue spruce, hazel spruce, sycamore maple, black alder, horse chestnut common.
4. Relatively shadow-tolerant species: Siberian fir, common spruce, Norway maple, common hornbeam, lime large-leaved and small-leaved.

3.4. Relation to light of the plans of the lower layers of the forest

Because growing conditions under the forest canopy are characterized by varying degrees of light availability, live ground cover, young trees, undergrowth developed a number of adaptations that allow them to grow and develop with a lack of solar radiation or in some way compensate limited effect of this environmental factor.

1. Plants ephemers and ephemeroids pass a development cycle in early spring, before frondescence of shading foliage (European wood anemone (*Anemone nemorosa* L.), hepatica (*Hepatica nobilis* L.), lungwort (*Pulmonaria obscura* Dumort.), bitter pea vine (*Lathyrus vernus* (L.) Bernh.), and others).

2. Some species prefer forest type with slightly dense pine stands for the normal development (Heather).

3. In order to catch a small amount of light penetrating under the canopy, and use it more efficiently, a separate representatives of the living ground cover:

a) form a significant amount of leaf blades, which are placed in the same plane, not shading one another (wood sorrel, beadruby, starflower);

b) contain large amount of chlorophyll.

4. Preservation of leaves of evergreen (cranberry, copperleaf (*Pyrola rotundifolia* L.), Pyrola secunda (*Orthilia secunda* (L.) House), north twinflower (*Linnaea borealis* L.), and others) and wintergreen (wood sorrel, wood rush and others) plants is an original way to extend their growing season. Thus the lack of light is refilled.

5. Saprophytic nutrition. Some plants (hypopitys common (*Hypopitys monotropa* Crantz), toothwort (*Lathraea squamaria* L.), birds nest orchid (*Neottia nidus-avis* (L.) Rich) and others) change to nutrition by organic substances.

6. The white color of the flowers of the plants composing the live ground cover is better visible for pollinating insects in the darkness under the canopy (wood sorrel, starflower), or self-pollination as generative reproduction begins to dominate.

7. Due to the low seed productivity associated with a lack of lighting and the need for preservation plants of herbaceous-shrub layer, vegetative reproduction is dominated by rhizomes (cranberry, goutweed, coltsfoot (*Asarum europaeum* L.), Paris herb), causing them to grow in groups.

8. The lack of lighting in the undergrowth determines the formation of lateral shoots, resulting in the umbellate form of the plants (spruce).

At very high degree of closeness of stands of shade-tolerant species such as spruce, when lighting amounts to several percents, and sometimes it is up to 1% or less, a forest with a dead shelter is formed. It consists of fallen leaves or needles. This is the so-called dead soil types that cause visitors of ecological trails to fall into a special psycho-emotional state of seclusion, isolation from the outside world and clearly illustrating the determined (edificios) influence of forest on the formation of a microenvironment in forest biogeocenosis.

In the life of sowing and seedlings it is distinguished the so-called "shadow period" which is required for the gradual adaptation of the young generation of plants to environmental conditions. Its duration is first 1–2 years of life for birch, aspen; 2–3 years for pine; 4–5 years for oak; 8–10 years for spruce. After the end of the specified period, the need for light sharply increases, and the shortage of solar radiation cause the death of undergrowth (pine, birch, aspen) or it acts as undergrowth (oak, spruce).

With a sudden exhibiting to full light of understory conifers (spruce), it may cause its death. Under the influence of the direct solar lighting it can also cause burn and death of shoots and seedlings. In low light stool shoots of hardwood or root suckers (aspen) are less intensive.

3.5. The impact of forest canopy on a number of physical parameters of solar radiation

The forest is a kind of optical system, consuming, transmitting and reflecting solar radiation. Its radiation balance exceeds the balance of other ecosystems (meadow, field, marsh, and others), because the forest absorbs more solar energy and reflects less. This is because the surface area of the leaves or needles of the canopy of the forest stand which is directly perceived, it is 4–8 times greater than the area occupied by the actual planting. Radiation under the canopy is not only thinned, but it also changes its spectral composition, i.e. it changes qualitatively. In particular, light under the forest canopy, is depleted by physiologically active radiation (PAR). According to I. S. Melekhov, for example, if in an open area the proportion of physiologically active rays accounts for 50%, under the pine canopy it is about 30%, and in the young oak forest it is about 10%. Qualitative changes in solar radiation of forest ecosystem depend on the composition, shape, site quality, age of wood, density of plantings.

The fluxes of solar radiation are substantially redistributed by forest plantations, resulting in prevalence of scattered radiation under the canopy. In Belarus, the amount of reflected radiation is 4–12% for coniferous forests; 10–20% is for deciduous forests. Thus, coniferous forests actively accumulate solar energy; this is also because they have more long-term period of photosynthesis, starting already at –5...–8°C. Infrared radiation is mainly reflected from the surface of the forest, thus preventing overheating of leaves. The canopy absorbs 35–70% of solar radiation. The canopy of 20–40-year-old tree stands absorbs the least amount of solar radiation. Different species of woody plants reflect and transmit the light in varying degrees, so the light modes in phytocenosis differ. Thus, the amount of light passing under the canopy, formed by certain species amounts:

– pine up to 50% of the total flux of the solar radiation;
– birch up to 44%;
– oak up to 18%;
– ash up to 17%;
– spruce up to 13%.

4 FOREST AND HEAT

4.1. The value of heat in the life of the forest

Heat is the direct environmental factor; it is of great importance in the life of forest ecosystems. As a physical concept, heat is a form of kinetic cooling energy which can be transformed into other forms of energy and transferred from a hot body to the cold one. There are three ways of such conversion or transfer: radiation, heat transfer, convection. Every region and every sector of the forest has its own heat resources. It is established that the Northern border of distribution of forests coincides with the July isotherm of +10°C. For forest plants (like all others) and plantations, heat provides the following processes.

1. Photosynthesis (table).

Influence of temperature on photosynthesis rock-forming species

Species	Low limit	Optimum	High limit
Conifers	–5...–8°C	+10...+25°C	+30...+40°C
Decidiuos	–3...–1°C	+15...+25°C	+40...+45°C

2. The respiration. The optimum temperature for this process is in the range from +4 to +30…+40°C. At higher temperatures respiration falls sharply. The lower limit of the temperature is –20°C. Needles, buds of conifer and deciduous species which winter in the snow, breathe in winter.

3. Growth. The predominance of photosynthesis over respiration provides the accumulation of organic matter and, ultimately, the growth of plants. With increasing temperature from 0 to +35°C growth processes are enhanced; in the range of +35...+40°C they are reduced; at temperatures above +45°C leaves die. The beginning of the growth of roots of Scots pine is observed at temperature +4...+6°C, and Siberian larch, Siberian stone pine and Siberian spruce starts the growth at temperature about 0°C. Optimum temperature for root growth is +17...+19°C. The maximum efficiency of photosynthesis and growth of trees is observed in the range from +15 to +20°C.

4. Transpiration. When average monthly temperature is up to +4...+10°C the relationship between transpiration and temperature is expressed by a linear dependence, but at the level +10...+12°C and above it can be graphically represented as a curve that goes up steeply to a temperature of +25...+30°C, and then falls sharply.

5. Mineral and water nutrition, the activity of soil biota, which determines the decomposition of organic matter of forest litter, with increasing air and soil temperature naturally increase. This is Vant Hoff, according to which activity of biochemical reactions and metabolic processes with increasing temperature by 10°C increases in 2–3 times. In Northern regions, for example, under the lack of heat decomposition of forest litter runs 3–4 times slower than in the South.

6. The germination of seeds. The best conditions for seed germination of woody species are formed within +18...+30°C. In many species it starts at the temperature slightly above 0°C. Though oak is thermophilic, acorns start to germinate at a temperature +1.5 to +2.0°C, and the seedlings grow already at +5...+7°C. Typically, the wider is the range of species, the greater is the temperature interval of seed germination.

7. Flowering and fruiting. The flowering of many woody plants begins when the average daily temperature is +4...+15°C. The more consistent temperature of specific growing season to climatic norm in the region, the more abundant flowering and higher yield, the less is the damage of seeds by fruit pathogens and pests; edible fruits having the best biochemical composition.

4.2. The relation of tree species to heat

According to I. S. Melekhov, to establish relations of tree species to heat there are fewer scientific indices than, for example, to their shadow-tolerance. Woody plants relate differently to heat, frost, spring and autumn frosts, summer heat, and in this regard they are subdivided into the following groups:

1. Thermophilic: for the full cycle of development during the growing season temperature above +10°C is required; optimum temperature is +30…+40°C. (The period from the leaves before they get yellow is called vegetation. Conventionally, it is determined by the average daily air temperature, considering the beginning and the end of days with temperatures above +10°C. A similar soil temperature index is +5°C).

2. Cold-resistant: capable for a long time resist low but positive temperatures. Plants in this group stand lower temperature, respectively, 0…+5° and +25…+31°C than the thermophilic ones. The cold resistance is characteristic for species of temperate climate. It largely varies depending on the stage of individual development of an organism and organ of the plant. For example, young plants suffer more from low temperatures than adult plants; the flowers are more sensitive than fruits and stems, leaves and roots are less resistant to cold than the stems.

3. Frost-resistant: they are resistant to effect of negative temperatures. Frost resistance is largely determined by the life form of plants. In a temperate climate species with unprotected kidneys (*phanerophyte*), as a rule, are more resistantthan the species with covered winter buds (*hamephyte*, *hemicryptophyte*). Among deciduous tree species the most frost resistant is Siberian larch (*Larix sibirica* Ledeb.), able to withstand a complete freezing of tissues and temperatures down to –62°C. In species, the range of which is restricted to areas with a mild climate, frost-resistance is reduced. In the centre of the area frost-resistance of species is more pronounced; it is determined by the strategy of evolutionary development and general regularities of species formation. That is why continental species and their population are more frost-resistant.

Frost resistance and resistance to frost are similar concepts, but not identical. It is established that the resistance of trees to autumn and spring frosts is usually associated with bark thickness and relation to light. Thin bark species (spruce) are more sensitive to frost than thick bark ones (pine, aspen, birch). Shadow-tolerant plants are more susceptible to negative frost effects than photophilous ones. It is especially clearly manifested at young age and during exposure them to open place.

4. Heat-resistant and drought-resistant plants are plants of climate zones with high temperatures, which are properly adjusted to the environment. Among the adjusting features are thinning of lamina, the method of intensive transpiration, the orientation of leaves in the vertical direction, the whitish colour of the surface of the assimilatory organs, their pubescence, a significant concentration of carbohydrates in the cytoplasm, and low contents of water and others. Plants in the temperate zone are damaged at the temperature +40...+55°C.

4.3. The thermophily scale of tree species

Classification of thermophylic tree species, according to G. F. Morozov (beginning from thermophilic plants to cold-resistant ones):

1. Chestnut	6. Maritime pine	11. Birch
2. Oak	7. Pine Austrian	12. Fir
3. Ash	8. Pine	13. Spruce
4. Elm	9. Rowan	14. Cedar
5. Hornbeam	10. Alder	15. Larch

The scale of thermophylic plants made by P. S. Pogrebnyak (1963) regards geographic distribution, the start and end of the growing season in relation to the conditions of the Central forest-steppe of the CIS.

1. Highly thermophylic: eucalyptus, Maritime pine, cypress, oak, cork, cedars, saxaul.
2. Thermophylic: chestnut seed, walnut, acacia, poplar, silver and others.
3. Mid-thermophylic: oak, hornbeam, maples, elms, basswood, beech, alder, Amur velvet.
4. Low thermophylic: aspen, grey alder, Rowan, birch, spruce, fir, pine, larch, balsam poplar.

In the conditions of Belarus A. A. Chakhovski highlights the following environmental groups of woody plants according to the degree of frost resistance.

1. Highly frost-resistant plants stand temperatures below –40°C: spruce, pine, birch and white birch, aspen, grey alder, mountain ash, willow goat.
2. Frost-resistant plants stand temperatures from –35 to –40°C: European larch, English oak, elm, spruce, maple, small-leaved lime, and black alder.
3. Moderately frost-resistant plants stand temperatures from –25 to –30°C: North oak, horse chestnut common lime.
4. Low frost-resistant tolerate frosts –20 to –25°C: beech, hornbeam common.
5. Frost-susceptible plants withstand frosts from –10 to –15°C: these are mainly subtropical species that perish or can be severely injured in our country.

V. G. Nesterov determines the following classification according to tolerance of tree species to frost:

1) very sensitive – ash, oak, spruce;
2) less sensitive – maple, larch, pine;
3) tolerant – alder, birch, Rowan, aspen, chestnut ordinary.

4.4. The impact on forest extremely low and high temperatures

The factors and phenomena that are harmful due to the low and high temperatures:

– absolute minimum;
– alternation of strong frost and thaw;
– long period of low temperatures;
– late spring and early autumn frosts;
– hot winds;
– fires.

Negative impact on forest low and high temperatures:

– damage of shoots, leaves, flowers by frost, and, as a consequence, the reduction of fruiting, growth, formation of the wood with defects, the spread of diseases and death of plants;

– squeezing the roots of young plants, seedlings, sowing, when soil water expands when it is frozen, resulting in the soil elevation together with the roots of young plants. During thawing it falls, and the roots are partially broken but due to these movements they remain bare on the surface;

– death from severe frosts caused irreversible cells damage at low temperature caused by the formation of ice in the intercellular spaces. Ice draws water from the cells, dehydrates the cells, resulting in proteins coagulation, and mechanical pressure on the cells. The proteins coagulation is greatly changed as a result of formation of various protective substances, mainly sugars. With the gradual onset of cold weather plants form sugar from starch, and thereby they prepare for the frost. At a sudden frost in spring and autumn, even at a relatively small low temperature up to –1...–2°, and more at –5° plants are heavily frosted and can even die;

– crown freezing leads to the death of buds, needles, cones of stem growth;

– frost cracks are formed during severe frosts with species having cleavable wood, especially oak. This is due to the fact that the outer part of the wood is cooled earlier, and it bursts, compressing around the inner part, which changes the volume to a less extent. This reduces its commercial value, causes fungal infection, and reduces growth. There is no effective means against frostcracks yet;

– sunny frosty bake of the stem, branches and needles leads to side-dry stem, the drying of branches and needles cast;

– winter desiccation. If during the cold season air temperature exceeds the soil temperature, the plants lack water, which is lost by above-ground parts as a result of transpiration. Water loss is particularly enhanced by intense winter insolation and frequent winds;

– burn of leaves and bark leads to abscission of leaves and reduced growth, while burn of the crust observed in adult trees, is the local extinction of cambium; species with a smooth, thin bark, spruce, hornbeam suffer more. The dark color of the crust increases the danger of burn;

– bark is also burnt under the influence of a forest fire, and fire injuries are formed;

– root-collar scorch is observed at a temperature of approximately +60°C, the most sensitive woody plants are those in the younger the age, the damage is characterized by cambium lesions at the bottom of the stem is at soil level.

4.5. The influence of forests on temperature

In summer, forest causes the following changes in the thermal conditions of air and soil to open space.

1. The average temperature in the forest is lower than in open space. In pine forests this difference is 0.2–0.5°C, in spruce forests it reaches 0.7–1.5°C.

2. The temperature amplitude, both of air and soil in the forest is less. The absolute maximum is reduced, and the lower temperature level increases. For example, the temperature amplitude of the air is reduced by 10–12°C. The average summer soil temperature during vegetation period at a depth of 50 cm in May it is less than 8.4°C, in June it is 6.7°C, in July it is 5.6°C, in August it is 3.7°C in open space. In hot years, the difference reaches 10–12°C. Thus, the soil covered with forest plants, heats up slower and weaker than the open space, but it is not cooled so quickly and not as strong as open space.

3. In forest late spring frosts cease earlier, and early autumn frosts come later, therefore, the vegetation and frost-free periods last longer in forest.

4. The number of cases with very low and very high temperatures is reduced. In summer the thermal influence of forests on adjacent open space reaches up to 50–100 m. In winter:

1) the average temperature is always 0.2–0.5°C above comparing to open space;

2) soil temperature at different depths is 0.1–0.6°C higher in comparison with the open space;

3) the number of cases with very low temperature is reduced.

So, the forest has a cooling effect on the environment in winter, it has a warming effect in summer. However, the average annual air temperature in forest comparing to open space is less by 0.1–0.7°C, soil – 1.0–1.7°C.

5 FOREST AND MOISTURE

5.1. The importance of moisture in the life of the forest

Moisture is a direct environmental factor, without which the existence of living organisms is impossible. It is constantly present in woody plants, comprising 50–98% of their wet weight. Water has unique thermodynamic properties: high specific heat, high thermal conductivity, it expands when freezing. It is characterized by significantly greater thermal stability than that of the soil and air, which creates very favourable conditions for life. For example, in winter under ice, its temperature is never below freezing point (0°C for fresh water).

The following types of moisture are present in forest:

– precipitation;

– moisture in the atmosphere as water vapour;

– moisture in the soil.

Precipitation can be in the form of:

– rain;

– snow;

– hail;

– dew;

– frost (hoarfrost, crystalline ice, formed on branches and trunks of trees during the frost fog);

– glaciation (black ice, continuous glaze on the branches and trunks of trees; thickness being up to 3–5 cm).

The most significant impact on forest ecosystems is by precipitation in the form of rain and snow in some areas. A certain role is played by dew. The amount of rain is usually expressed by a layer thickness in mm: 1 mm of precipitation corresponds to 1 l of water per 1 m^2.

In Europe the best development of forests is observed in areas with annual precipitation of 600–700 mm. This corresponds to the conditions of sufficient or excessive moisture (see unit 2.1).

For forest ecosystems the most important factors are:

a) precipitation in the period of its greatest need by woody plants;

b) intensity of precipitation. Precipitation in the form of a few showers may have very adverse consequences. Precipitation takes from the atmosphere and gets to soil nitrogen, phosphorus, potassium, calcium, magnesium, and carbon. Passing through the canopy of trees, it washes away the dust, washes out a part of the organic matter, formed by plants during photosynthesis. The impact of snow as precipitation for the forest can be both positive and negative. Positive impacts are:

1) the soil is protected from freezing;

2) seedlings, sowing and low undergrowth are protected from winter kill and damage during timber harvesting in the winter;

3) seeds spread further on the snow crust.

Negative impacts are:

1) snowbreakage. Under the weight of wet, stuck to the crown snow trees fall out with roots. Snowbreakage is more typical for young pine stands with close crowns, their branches are angled upwards and the root system is not developed;

2) snow break. Under the weight of the snow the stems and branches get broken. Conifers, especially pine most often suffer from snow breaks. Aspen is most often damaged from deciduous species; it is characterized by the formation heartwood rot. The primary means of preventing snow breaks is formation of tree stands of optimal density, of a mixed composition, with vertical density;

3) snow storms cause soil erosion, and there are snow avalanches in the mountains;

4) hail damage flowers, fruits, buds, branches and even the trunks;

5) frost, black ice cause breakage of branches.

Humidity, which is characterized by the presence of water vapour, has also great value for plants. When long-term, low relative humidity is below 30–35%:

a) it reduces growth;

b) there is a danger of forest fires.

The main source of soil moisture is precipitation. The other sources are ground water, condensation of water vapour, irrigation. There are the following categories and forms of water in the soil (I. V. Sokolovsky, 2005):

1. Chemically related water is a constituent part of the minerals composing the soil, it is unavailable to plants.

2. Related (sorption) water is the result of sorption on the surface of the solid soil particles:

1) tightly bound (hygroscopic), unavailable to plants;

2) pellicular (film), partially available.

3. Free water fills capillaries and large non-capillary pores:

is capable of vertical (gravity) and horizontal displacement, available to plants:

1) capillary water fills the capillary pores, it is retained and moves through the capillary

a) capillary-suspended water is water, filling the capillaries of the upper part of the profile, it is not connected to ground waters;

b) a capillary-locked water is rising through capillary pores onto ground water;

2) gravity water is located in major capillary pores of soil, it easily moves under the action of gravitational forces, when reaching the impermeable layer forms perched water.

Low soil temperatures, lack of oxygen, high acidity of soil solution, a significant amount of mineral salts reduce absorption of available moisture by plants. Vital moisture for plants and in general for forest biogeocenosis is multi-faced; the deficit of this environmental factor cannot be compensated by any other:

1. Photosynthesis needs moisture from 0.002% by volume of water, absorbed by plants up to 0.2–0.5%. Most species of trees most successfully undergo photosynthesis at a relative humidity of 70–80%.

2. Transpiration (physiological evaporation) contributes to thermoregulation and, thus, optimizes photosynthesis. Active processes of photosynthesis can occur only at a sufficiently high level of transpiration.

3. Breath allows plants to obtain oxygen, liberate carbon dioxide and store energy. It is only possible with the participation in the oxidation processes of water.

4. Water is a unique solvent capable to transfer nutritional compounds.

5. Water provides osmotic pressure (due to which the nutrients transfer from the soil solution) and turgor (stressed state of plant cells).

6. The flow of water distributes seeds (black alder).

7. The processes of growth and development of plants, flowering and friuting, seed germination, in general, the processes of renewal, including vegetation, all occur with an obligatory participation of water. Lack of moisture causes some undesirable phenomena, in particular drought. It is of two kinds:

a) summer drought. Spruce, lime, ash, hornbeam, young stands of pine and oak suffer most often. The trees are weakened, the pests colonize their stems, and eventually death comes;

b) winter drought occurs with frequent thaws, when transpiration increases, and the root system is in the frozen ground and it does not replenishes the lost moisture, which leads to dehydration of needles and shoots (see unit 4.4).

Lack of water leads to the weakening of all the physiological processes of plants, reducing their growth, flowering, fruiting, stability to the action of unfavourable factors, and thus, lack of water sometimes leads to the death of not only individual trees, but the whole tree stands, there are side effects on the life of forest ecosystem as a whole.

Adverse phenomena may be associated with excess of moisture. Among them:

1) lack of oxygen in the soil leads to emergence among many tree species initially anaerobic respiration, then toxicities and their death;

2) drowning of seeds. Spruce seeds drown after 40 days of in stagnant water, pine seeds drown after 20 days;

3) rotting of seedlings occurs when soil is fully covered by water;

4) flooding. It is an increase of groundwater level in the vegetation period for more than 80–140 cm; the aeration zone is 20–80 cm. It is observed in reservoirs, as a result of beaver activity.

Birch, linden, oak, aspen, and spruce are susceptible to flooding. Willow species which form numerous adventitious roots are not susceptible to flooding. Partial flooding favorably affects alder. When pine is periodically flooded, it begins to rebuild the root system from a core one to the surface one. Optimal is the amount of moisture that fully covers the needs of plants and does not create a lack of oxygen in the soil.

5.2. The relation of tree species to moisture

In forestry there distinguish requirements of tree species to moisture and the demand for it. Requirement is the ability of tree species to draw moisture during its deficit from soil. Demand is characterized by amount of transpired moisture to form a unit of dry organic matter. The demand for water in tree species varies depending on:

1) the age of the trees. The demand is higher in the period of the highest growth rates;

2) season of the year, demand is higher in summer;

3) period of vegetation. In the seasonal cycle of development during the active processes of growth, the demand for water is higher;

4) time of a day. In the afternoon the demand for water is higher;

5) weather conditions. In hot weather the demand for water is higher.

In relation to moisture woody plants are divided into three main groups:

1) xerophytes have the ability to stand permanent or seasonal moisture deficit;

2) mesophytes stand average hydration;

3) hygrophytes live in conditions of excessive moisture.

There is also an intermediate group: xeromesophytes and hygromesophytes. There is a widely known scale by P. S. Pogrebnyak, according to the degree of hydrophily of tree species developed in conditions of forest-steppe:

1) ultraxerophytes are saxaul, junipers, pistachio, pubescent and cork oak;

2) xerophytes are Scots pine and Crimean pine, olive, buckthorn, elm (elm), bog willow;

3) xeromesophytes are oak, maple, apple;

4) mesophytes are linden, hornbeam, larch, beech, chestnut, drooping birch, aspen, Siberian cedar, fir, elm, elder;

5) mesohygrophyte are downy birch, grey alder, poplar, willow, goat, silver and brittle, cherry;

6) hygrophytes are black alder, grey willow, eared, and Lapland.

Positive point in the scale by P. S. Pogrebnyak is inclusion of tree species from different climatic regions, i.e. it is universal, common scale. The disadvantage is the lack of some important tree species and shrubs, such as spruce, mountain. Inclusion of junipers in the group ultraxerophytes is a very disputed item. Pine, indeed, very often is the only representative on dry sandy soils, where it acts as xerophyte. But it also forms monodominant sparse forest inoverwet sphagnum bogs. According to G. F. Morozov, pine is a double xerophyte and it is able to endure both physical and physiological action (in bogs) dryness of soil. The greatest productivity pine shows in average moisture conditions. Spruce is characterized by a narrower range of habitats in relation to moisture and, like its companion, mountain ash; it is, according to I. S. Melekhov, a typical mesophyte.

According to S. A. Sergeichik (2010), the main forest-forming tree species in Belarus are characterized by the following relationships to moisture:

1) xerophyte is Scots pine;
2) xeromesophyte is oak;
3) mesophytes are birch, aspen, maple, linden (*Tilia cordata*);
4) hygromesophytes are spruce, white birch, grey alder, ash;
5) hygrophytes are alder.

5.3. The influence of forests on surface and subsurface runoff, physical and physiological evaporation, humidity of soil and groundwater level, precipitation

The influence of forests on surface and subsurface runoff. Surface runoff may cause some unwanted effects: soil erosion, inundation. Forest transforms surface runoff into subsurface one due to:

– forest litter, absorbing moisture like a sponge;

– the distinction of the nano-relief and the live ground cover, presented by moss-lichen and grass-shrub vegetation;

– high overall porosity and permeability of soil, in particular, due to loosening action of the roots and animals (presence of molehills, worm holes, root channels and so on);

– the extended period of snowmelt, which reduces the probability of floods and inundations.

In order to detent and control the surface runoff in sparse forest areas, water regulation forest belts are created. Protective plantations near rivers and reservoirs strengthen the banks, protect floodplain lands from erosion, drifting sand, silt, and regulate runoff.

The influence of forests on physical and physiological evaporation. Physical evaporation in the forest is composed of:

a) physical evaporation, retained by canopy of trees during precipitation;

b) physical evaporation from the soil surface.

The proportion of precipitation retained by the canopy of trees depends to a considerable degree on the tree species. Deciduous retain up to 20% of precipitation, pine does up to 30%, spruce does up to 50%, up to 10% of the precipitation flows down the trunks of trees.

Moisture, retained by the canopy evaporates very quickly (so-called interception losses), which contributes to increased air turbulence, due to:

1) elevated location of crowns;

2) a good wind sweep through the canopy;

3) its roughness.

According to I. S. Melekhov, the amount ratio of moisture spent on transpiration is close to the value of physical evaporation from the crowns of trees. In coniferous forests, there is usually more physical evaporation from the crowns, and in deciduous trees, in contrast, there is an increased transpiration. Evaporation from the soil surface is difficult in the forest because of:

1) impact of canopy of the stand;

2) influence of the lower layers;

3) weakening of the wind.

According to N. S. Nesterov, in summer soil surface in the forest evaporates moisture 8 time less than in the open space. However, the canopy of the stand evaporates more moisture than open surface. It does not mean that forest uses water inefficiently.

The influence of forests on soil moisture and groundwater. According to I. S. Melekhov, when the groundwater is deep (not available for tree roots), it is more likely to increase their level under forests with powerful, vertically directed "lifting" impact (desucktion), emerging in the area of rhizosphere influenced by the roots of the layer, and also due to good filtration properties of the soil. The potential for an increase in groundwater level increases in soils with a limited capacity of the root zone layer (Northern latitude) compared to soils where root systems of woody plants have deeper distribution (South latitude). With the availability of groundwater for root systems of trees, due to physiological evaporation the level decreases. G. N. Vysotsky made the conclusion: "Forest dry plains and moisturizes the mountains".

The influence of forests on precipitation. Over forests, the amount of vertical precipitation increases by 10% due to air turbulence, increased output of water vapor in the atmosphere, decreasing temperature. It is established that due to the horizontal precipitation (so-called hidden precipitation, representing the products of condensation of water: black ice, hoar frost, dew) due to the greater surface forest additionally gets 15–30% of moisture. In forest air humidity is higher than in the field, winter precipitation is more.

Forest influences precipitation in cross-border regions, due to the saturation of the atmosphere with moisture as a result of evapotranspiration (physical (soil and plants) and physiological (transpiration) evaporations) and transfers it together with air flows. In this regard G. N. Vysotsky put forward the hypothesis concerning the transgressive role of forests, the essence of which is that the forests of the North and Northwest have a significant hydroclimatic impact on the remote southern areas due to the transfer to them large quantities of transpirated and evaporated moisture. It is still, as noted by I. S. Melekhov, relatively convincing and it is neither confirmed, nor refuted.

6 FOREST AND COMPOSITION OF AIR. FOREST AND WIND

6.1. Components of atmospheric air and their importance in the life of forest

Atmosphere is a gaseous shell of the Earth. The largest share (78%) of its composition belongs to nitrogen (N_2). However, for the forest nitrogen does not matter, because plants do not absorb it. The nitrogen concentration is fairly stable and is maintained at the same level.

The second place is occupied by oxygen (O_2), it is about 21%. It is essential for the respiration of plants, animals, microorganisms. A decrease or increase in oxygen concentration from the norm impairs photosynthesis. Oxygen is widely used by forests and other vegetation types, and for various industrial needs, its contents in the atmosphere vary according to geographical regions, local areas, directly in the forest. Usually for the life of the forest there's enough oxygen. However, it sometimes lacks in the soil that negatively influences the activity of root systems. In the absence of oxygen respiration of plants is terminated.

The most important for the forest vital activity is a component of the atmosphere carbon dioxide (CO_2). Its concentration because of the reducing number of forests consequently, reduces the amount of photosynthesis has increased since the late 18th century. Then increasing role in the accumulation of atmospheric CO_2 began to play the burning of organic fossil fuels like coal, gas, oil and peat. In 1860 the Earth's atmosphere contained 0.0295% CO_2, in 1974 its concentration increased up to 0.033%. By 2025 it is expected to reach 0.053–0.074%. The presence of CO_2 in the atmosphere causes the greenhouse effect, i.e. the increase in temperature surface of the Earth. Naturally, the increased concentration of CO_2 will increase the "greenhouse" effect. Note that the heat shield that creates this effect is formed also with the participation of methane, nitrous oxide and nitrogen monoxide, other gases, which are formed mainly due to the activity of bacteria in anaerobic conditions.

Green plants use CO_2 for photosynthesis. Concentration of it in the atmosphere is highly variable. In particular, it is higher in winter; it is below in summer, and at night it is higher than during the day. Increase of CO_2 concentrations up to some limit intensifies the photosynthesis of plants, and then photosynthesis decreases. This regularity was the base for plants nutrition in greenhouses and warm houses by increasing concentration (up to 6–8%) of CO_2.

About 1% in the atmosphere is taken by inert gases (argon, xenon, krypton, helium and others). It is believed that in the life of forest they do not participate. You can, however, suppose that their role in forest biogeocenosis is largely uncovered.

In the atmosphere there is some amount of ozone (O_3), which is a highly active oxidizing agent, accelerating decay and decomposition of organic matter. In the atmosphere there is always water vapor, playing a prominent role in the forest (see unit 5.1). Their concentration depends on many factors and varies considerably.

A distinctive feature of the modern period is the increased atmospheric concentration of dust. From the beginning of the 20th century its amount has increased by 20% and in large cities by dozens of times. Dust form both inorganic and organic components. The predominant inorganic part is 2/3–3/4 of the total quantity. The origin of dust is cosmic, volcanic, marine, plant, it occurs as a result of forest fires, soil inflation, emissions of industrial enterprises, from roads, etc. Dust reduces the influx of light and heat to the surface of the Earth and affects the vital activity of the forest. In large concentrations, it is damaging to plants, settling on needles and leaves and clogging stomata, thereby reducing the efficiency of photosynthesis. Accumulated in soil, dust affects its fertility. There are always pollutants in the atmosphere (aerosols, gases) emitted in large quantities by industry. Most of them are highly toxic and have harmful impact on forest.

As a result of metabolic processes in plants, mainly trees and shrubs, they emit into the atmosphere volatile organic substances, which are constantly acting environmental factor that has a positive effect on people's health.

6.2. The influence of forests on composition of air

The forest has an impact on all components of the atmosphere. The emission of CO_2 is mainly due to the decomposition of forest litter, respiration of plants and living organisms. According to the American scientists, in plantations of poplar black (*Populus nigra* L.) CO_2 is emitted due to the respiration of roots 35%, decomposition of roots 42%, and decomposition of forest litter 21%. And only 2% of the volume of CO_2 is released from other sources (the breath of the living organisms, for example). Because CO_2 is heavier than air, it is concentrated at the soil surface (mainly at 0.1–0.2 m), create new favourable conditions for the lower layers of vegetation. Here excess of CO_2 compensates the lack of light.

Using the turbulent fluxes, CO_2 rises into crowns of trees. Due to absorption during the photosynthesis by the plants of lower layers there is not always a sufficient amount of CO_2 reaches the crowns. For this reason, the concentration of carbon dioxide in the upper part of the wood is lower than at the soil surface. Sometimes there is even the lack of it.

The concentration of CO_2 in forest air during the day depends on the activity of photosynthesis. At night the CO_2 concentration is higher (up to 2 or more times), since there is no photosynthesis, and decomposition of organic environmental chemicals continues; in the daytime it decreases. Plants of identical composition, age, weight, characterized by similar ground conditions, have similar indicators of CO_2 in soil and in crowns. Plantations which differ by ground and soil conditions or at least one taxation characteristics have different carbon dioxide regime. For example, even a small admixture of birch to pine or spruce stands leads to increased soil biota that contributes to the decomposition of organic matter and increase the concentration of CO_2 in the air. In the stands of high density the concentration of CO_2 is higher than in the stands with low density. In high-bonitat plantings it is almost twice higher than in low-bonitat planting.

There are fewer changes in the concentration of O_2 in the forest than CO_2. Above-ground organs of plants do not have a shortage of O_2, its amount is enough. The root systems do with a less amount of O_2. However, in soil there is almost always not enough amount of O_2, which leads to a drop in productivity of forest stands. This is due to the active consumption of O_2 in the root layer of soil biota and difficulties arising when it penetrates deep into the soil because of high density or humidity. Because O_2 is formed by photosynthesis in the forest, especially in the tree canopy, its concentration increases if compared to a general level, although fluctuations of concentration in general are small. Impact on forest nitrogen renders as by absorbing it from the atmosphere by rhizobia, azotobacters, blue-green algae and reverse return due to the decomposition of organic substances, mainly forest litter. When oil, gas, coal, and peat are used in industry, nitrogen is emitted into the atmosphere. The higher the productivity of the forest and the more difficult goes the process of decomposition of forest litter, the greater its influence on the dynamics of nitrogen. This element enters the atmosphere also as a result of the combustion of organic matter in forest fires.

The influence of forests on dust is manifested in the fact that it is adsorbed by above-ground organs of plants of all layers and under the influence of wind and precipitation, together with forest litter, is then brought into the soil. Large concentrations decline soil fertility. In the wood dust concentration in the air is much less than that in the open place. As already noted, forest plantations absorb from 20 to 70 tons of dust per year per 1 ha. It was also indicated that in the living process, plants emit into the atmosphere phytoncides. They have a number of useful properties, in particular anti-mutagenic and anti-microbial ones. Various organic substances (amino acids, organic acids, coal, water, and others) are distributed in the root systems, creating some "phytoncides fields" in the soil.

6.3. The influence of wind on forest

Wind is the movement of air masses in the horizontal direction. But they also move in the vertical direction. When they are increased there is cooling and condensation, when they are decreased there is heating.The reason of wind is differences in heating the earth's surface and water surface, causing different air pressure. Pressure in the heated air is reduced; in the cooled air it is increased.

Two main characteristics of the wind are direction and speed. Wind is always directed in the direction of less pressure. The greater the wind speed is, the greater is the difference in temperature, and therefore its pressure. The wind speed can reach a great speed up to 40–60 m/s, and in the tropics up to 110 m/s. Professor G. Mayer, teacher of G. F. Morozov, wrote in 1909 about the wind: "Wind is the creator of the forest, the wind is destroyer of the forest, wind is the boundary controller of the forest". The influence of wind on the forest is characterized by the following aspects.

1. Morphological aspect. Long-term winds blow in one direction; affect the shape of the trunk and crown, height of trees, root system.

In the long-term impact of wind on trees increases taperingness or otherwise, buttress (the conical shape of the trunk), which has a negative effect on the economic quality of the wood. Taperingness is due to the accumulation of increment in the lower part of the trunk. Due to this, the center of gravity moves to the bottom and reaches a greater wind resistance.

Under the influence of long-term wind in one direction the shape of crowns has some deformations and deteriorations (they are better developed at the leeward protected from the wind side, and therefore, they gain a one-sided, flag-shaped form), the crowns of trees are tenar, their trunks often saber curved and eccentric (one-sided).

The growth and height of trees are decreased, and this reduces the productivity of forest stands. The biological nature of the reduction in the height under the influence of wind is the following. Plants under the withering influence of a constant wind force develop in the conditions of deficiency of moisture in the leaves and needles. In this regard, they physiologically, morphologically and anatomically differ in worse from trees grown in a protected location. According to the American tropical stations in the US, in Puerto Rico on the Western leeward slope trees grow two times faster than on the Eastern windward one. In Belarus the height of the trees under wind influence is particularly noticeable at the forest edges.

Thus, the overall pattern is that stronger the winds are, the productivity and quality of forests are lower. As previously noted, a strong wind is the cause of intercrowned and innercrowned whipping of trees, breaking branches, plucking fruits and leaves. In the areas of mechanical damage there is likely emergence of pathogens. Constant swaying of trees under the influence of wind causes fractures, breaks and wind rock of roots, which, in turn, contributes to the spread of tree-destructive fungi. Under the influence of wind erosion roots trees are exposed, as a result, the resistance of the plants is reduced. The above examples show the bounding role of wind in the spread of forest. However, under the influence of the physical impacts of wind more powerful, well-buried root systems are formed. Winter wind promotes the release of tree crowns from snow and reduces the possibility of snow fall and snow breaks.

2. Physiological aspect. The wind effects on transpiration, photosynthesis of trees. The intensity of transpiration of leaves and pine needles increases under the influence of blowing more powerful wind.

It takes away from the forest the air masses, saturated with water vapor, and brings new ones, not saturated. This may cause drying of assimilation. However, the wind contributes to the cooling of the leaves. At wind speed 2–3 m/s the efficiency of photosynthesis increases and with an abundant supply of moisture assimilation of carbon is 4–5 times increased. This is due to the improvement of gas exchange of leaves. Moving air causes the flow of carbon dioxide to the leaf surface, making possible a more effective photosynthesis.

3. Biological aspect. The wind carries the pollen, spreads fruits and seeds. Most coniferous and deciduous species are pollinated by the wind. Seeds of pine, spruce, birch, aspen, maple, ash, and other species are carried by wind over long distances. It is especially well spread by the wind the pubescent seeds (poplar, willow) or supplied by the wings (elm, maple, ash, birch, spruce, pine and others). In this case the wind plays the role of a creator of forest.

4. Microclimatic aspect. It is redistribution of moisture, heat, change of the composition of air and carbon dioxide concentration, light situation. In the open areas of forests (deforestation, burnt areas, blanks) wind dries the litter and worsens the conditions of regeneration of the forest. Withered litter by the wind in the event of fire increases the intensity of fire and contributes to the transition of ground fires into upland fires. Thanks to the wind the chilled air masses are mixed with warmer ones, thus reducing the risk of formation of radiation frosts. The wind carries dust and pollutants, including those which are able to damage the forest. When moving, sun flecks improve the light situation of the stand. The most harmful consequences for forestry are caused by windthrow (dumping of trees with roots) and windbreak (trunks breakage at different heights). The windthrow and windbreak are factors of destruction of the forest. They increase fire danger, contribute to the emergence of focuses of pathogenic organisms, reduce the economic value of the wood, and significantly complicate harvesting and hauling. In this case, it is fair to say that the wind is the destroyer of forests.

The following factors effect on the resistance of trees to windthrow and windbreak.

1. Biological and ecological features of species. They are the formation of certain root system, the quality of the wood of the trunk, etc. Windthrow species are species with surface root system; they are spruce, birch. Windthrow property of spruce is also promoted by thick, dense crown, increasing the overturning moment. Aspen, basswood,

poplar, and alder are exposed to windbreak; they are species with soft wood, often damaged by stem rot.

2. Soil and hydrological conditions. Development of root systems of trees depends on the soil fertility. On the well-developed, powerful loam even spruce successfully resists wind. In waterlogged soils pine is exposed to windfall. The increase in soil moisture weakens the resistance of trees to windfall.

3. The season of the year. Seasonal winds have different strength and direction, often windfalls occur in the autumn. On a frozen soil windfall is virtually impossible.

4. Age and phytopathological condition of the trees. Young trees are more resistant to wind than the old ones, which have more large sizes and are sometimes affected by root rot.

5. The density of forest stands. Trees growing in the open space or sparsestand, as well as on the edges, have a greater wind resistance.

Trees grown in dense stands have a weak wind resistance and are particularly susceptible to windthrow when placed in the open space, for example, during clearcutting or crown fires. The remaining wall of the forest can be completely thrown out by the wind.

6. The composition of forest stands. Mixed stands are more resistant to wind than pure stands.

Increasing the wind resistance of stands is achieved by:

1) their gradual cutting since youth that provides the development of root systems of trees. Thus, the multi-component, mixed with vertical closeness stands are formed;

2) formation of wind resistance edges. Wind resistance edge is a forest strip, designed to mitigate the harmful effects of wind and protect forest from wind throw. The borders with non-forested areas, mainly of deciduous tree species with deep root system, capable of developing a powerful crown are laid along;

3) the creation of wind resistance bands;

4) compliance with all regulations when cuttings are carried out.

6.4. The influence of forest on wind

The general scheme of the influence of forests on wind is the following. When the air masses approach the forest at a distance of 60–100 m and sometimes up to 10–12 heights of stands, they are split in two parts. A part of the air flow, accelerating, rushes up to the height of 1 km and higher; the other part, continuing movement, enters the forest, where the wind speed is already at a distance 120–150 m does not exceed 6–7% of the original speed in open space. However, the absolute calm in the forest does not exist. In the result of diversion of the air flow wind speed weakens by about 20–60% at a distance of about 60 m from the edge. The depth of penetration of the wind flow in the forest is largely dependent on the availability and conditions at the wind-resistance edge that increases wind-resistance of even such windfall species as spruce.

Bursting into the stand, the wind gradually loses its power, spending it on friction on the trunks, branches, leaves, as well as on their vibration. The attenuation of wind speed in the forest depends on tree species, weight, height and shape of the stand, foliation degree of trees. The tree stands formed by shade-tolerant species with well-developed crowns, reduce the wind speed to a greater extent, than do the stands of light-demanding species with highly raised open foliage. The layers of undergrowth, understory, and live ground cover impede the movement of the wind in the forest. In deciduous forests the speed of the wind depends on the phenological properties of the trees. When there is a full foliation inside the forest the wind speed is reduced more than in the absence of foliation.

The wind speed in the forest is:

– maximum above the canopy;
– decreases closer to the canopy;
– fades out inside the crowns;
– approaches zero at the soil surface.

Uneven, rough surface of the tree canopy edge contribute to the turbulent nature of the air flow over it.

The leeward side of the forest an air fall is formed at the distance of 10 heights of the forest. The overall impact on wind flow affects the distance up to 15–20 heights, i.e. “wind shadow” behind the forest can be up to 500 m and more.

Windproof action of forest is used in the forestry. The greatest efficiency in the range of protective actions is provided by bands with flush out and open structure. Windproof strip suppresses wind speed on the leeward-side of they are only in the immediate closeness that is used to be under protection of transport routes from the snow drifts. Affecting the wind, forest belts have to affect the whole climate inter-belt space.

7 FOREST AND SOIL

7.1. The relations of forest and soil

Soil is a surface layer of soil formed under effects of climate, vegetation and animals. The peculiarity of the soil as natural item is that it is characterized by fertility. At a certain stage of development of human civilization, the soil became the object of labour and means of production.

The soil consists of two parts, mineral and organic ones. Mineral part is formed by weathering rocks under the influence of climatic factors. Granulometric composition of the mineral part (the ratio of large and small particles of soil) is divided into sand, sandy loam, loamy (most siutable for farming), clay (very fine) ones.

The organic portion is formed by decomposition of residue of plants and animals. In the composition of the organic part there is humus, which determines the structure, water-holding capacity, acidity and nutrient value of the soil. The soil consists of three phases: solid, liquid, gaseous. The amount of soil consists of 50% of the solid phase, with the rest accounts for pores filled with water or air. Role of soil is very versatile:

1) the substrate for activity, it contains moisture and nutrition substances, it is mechanical support for all plants;

2) the habitat of animals, microorganisms, microfauna, and microflora;

3) the stabilizer of heat, air and moisture regimes;

4) the isolated storage of spores and seeds;

5) the key point of the circulation of substances.

Speaking about the relationship of forest and soil, it should be borne in mind that on the one hand the soil is the most important environmental factor, the role of which would be involved in each specific region; it is decisive for the forest. On the other hand, the eudaphotop is an integral component of the forest as an ecosystem. The relationship in the system "soil – forest – soil" most fully characterizes the forest.

In contrast to other forest ecosystems it is connected with the upper soil horizons, and through the forest with mother pore-water (subsoil). Bedrock participates in soil formation and lies under any soil. It does not only determine the forming of the upper horizon of the soil, its fertility, and hence the productivity and the structure of the forest, but also directly affect its state. I. S. Melekhov gives an example, when lime deposits occur very close; they form highly productive larch forest with a stock 600–700 m^3/ha, while on the sands of glacial origin, the productivity of pine stands is 2–3 times less. The relationship of forest and soil at different depths varies. It is quite natural that with increasing depth, it becomes weaker. But on the whole rooting depth, i.e. even at a depth of 20–30 m, the soil is influenced by forest vegetation.

The relationship of forest and soil manifests itself in a profound change in the upper horizons occurring in the accumulation of organic substances of forest litter in the litter and its gradual decay. And yet the soil is a habitat for various organisms, characterized by complex biotic relations, and also relations of air, thermal regime and, ultimately, the level of fertility, initially contributing to the growth and development of a certain limited stand and other, appropriate environment components of the forest. Soil is one of the important classification criteria of the forest. When distinguishing and characterizing the forest type, in forestry of Belarus the type of forest conditions must be specified (eudaphotop). But still, G. F. Morozov defining the forest type meant "homogeneity of plantings, combined into one large group according to the conditions of vegetation or soil and groundwater conditions". According to P. S. Pogrebnyak, soil fertility is characterized by poor (A, pine forest), relatively poor (B, subor), relative rich (C, complex subor), rich (D, oak forest) (see unit 8.6).

According to V. N. Sukachev, one of the components of the ecosystem, as has been noted above (see units 1.1, 2.2, 3.3), is eudaphotop. Thus, the relationship of forests and soil is manifested in the fact that certain soil types correspond to certain forest types and, in general, certain forest type formations. On sod-podzolic sandy soils pure pine stands are usually formed. On sod-podzolic sandy and loamy soils usually complex mixed stands with pine, spruce, oak, birch, and aspen predominate. On peat soils of oligotrophic bogs low productive marshy pine stands are formed. Spruce forests are common on sod pod sandy, loamy, and clay soils. They reach the greatest productivity in the presence of sufficient moisture in the upper layers, which is provided by their layers of thick heavy loams and clays. Oak stands are also mostly represented on sod pod, sandy, loamy, and clay soils. High productivity of oak stands is marked on soils with carbonate species. When there is a running hydration and an impermeable layer, oak stands grow on consolidated sands (Belarusian Polesie).

The relationship of forest and soil is reflected by successional changes. If on poor sandy soil pine is naturally replaced by European birch, the richer sandy loam or loamy soil is more likely to change it by another small-leaved pioneer species, aspen. The relationship of forest and soil is manifested in the confineness of those or other forest formations to soils with a certain acidity of the soil solution. The soil in spruce forest is more acidic than that in pine forest. Soil in deciduous forest is less acidic than in conifers forests. The most common soils in the forests of Belarus are sod pod soils. The structure of their profile is as follows (figure).

A_0	Forest litter
A_1	Humus horizon
A_2	Podzol (eluvial) horizon, nutrients and humus depleted as a result of washing out
B	Illuvial horizon, where accumulation occurs as a result of silt inwash
C	Soil-forming material

Structure of the sod-podzolic soil profile (according to I. V. Sokolovsky, 2005)

Soil as an ecological factor is amenable to change (drainage, irrigation, fertilization), which may increase its fertility and, consequently, increase the productivity of forest plantations.

7.2. The relations of forest plants and soil

Due to the fact that some tree species have a greater need for nutrients and at the same time can grow on poor soils, it is distinguished between “need” and “demand” of the plants in relations to nutrients.

Need is the necessary amount of nitrogen and ash elements for the normal functioning of plants, i.e. the real amount consumed by them.

Demand characterizes the ability of one or another species to meet the nutrition need in specific soil conditions.

Black locust, or Robinia (*Robinia pseudacacia* L.), for example, is characterized by high demand and low need (ability to extract the necessary elements from poor soils).

Pine is characterized by low demand, low need. At low need, trees form a well-developed root system. Ash is characterized by high need, high demand. It grows only on rich soil. According to fertility tree species, as well as representatives of the live ground cover (see unit 2.3), are divided into three groups:

– oligotrophic plants (low demand to soil fertility);

– mezotrophic plants (moderate demand to soil fertility);

– eutrophic plants (megatrophic plants) (high demand to soil fertility).

Scale of P. S. Pogrebnyak characterizing the demand of tree species to soil fertility:

1) oligotrophs are juniper, Scotch pine and mountain pine, drooping birch, black locust, Pinus nigra;

2) mezotrophs are downy birch, aspen, spruce, pine, Eastern white pine, Siberian larch, mountain ash, birch bark, goat willow, red oak, English oak, black alder;

3) megatrophs are Norway maple, sycamore maple, hornbeam, beech, fir, field maple, Amur velvet, willow, brittle willow, elm, ash.

Intake amount of nutrients depends, in particular, on species type and their age. Conifers consume less nutritional substances than deciduous do. The nutrients consumption by woody plants is higher at young age, and it is less at old age. According to the acidity of soil solution, it is classified acidophiles, these are tree species that are resistant to acidic soil (spruce, pine, birch, aspen). There is a group of halophytes tree species that contain a sufficiently high concentration of salts (Saxaul species (*Haloxylon*), elm, oleaster (*Elaeagnus angustifolia*)). Calciphiles (Calcivorous plants) prefer soil with lime (Siberian larch, ash). Calciphobous plants are forest species that, in contrast, avoid lime (pine, sphagnum, Heather, bilberry, blueberry, cranberry, blueberry). Nitrophilous plants are species that respond positively to nitrate in soil (elm, poplar, cherry, European Euonymus).

7.3. Role of forests in soil formation

Multilateral role of forests in soil formation is manifested in the following.

1. The tree canopy and the lower layers of vegetation create a unique microclimate, change the quantity and quality of moisture entering the soil. The climate, in turn, largely determines the humidity, temperature and water regime of the soil, as well as biochemical processes that affect the activity of soil fauna.

2. The roots of trees and other forest plants have physical and chemical effects on the soil. Physical effect is manifested in loosening soil, allowing improved aeration. Chemical one is the following:

a) extraction of chemical elements, including the lowest soil horizons and even parent rock, and returning them in the form of litter;

b) enrichment of soil byatmospheric nitrogen;

c) dying out and decay of underground parts (see unit 2.2).

3. In the annual dying and dropping of large quantity of organic matter in the form of leaves, needles, branches, bark, seeds, cones, forest litter is formed, decomposition of which is the formation of humus and mineral compounds that play a huge role in soil formation (see unit 2.3).

4. Specific fauna soils of forest ecosystems is actively involved in the process of soil formation (see unit 2.2).

7.4. Biological cycle of substances in the woods

In the formulation given by I. S. Melekhov, biological cycle is a "comprehensive multi-stage process of transformations, migration, and metabolism in phytocynosis and soil". Biological cycle in forest consists of small and large cycles (see unit 2.2), by its nature, is a soil-biological one. It is part of a broader cycle of substances and energy in nature.

During the biological cycle of substances and energy in the forest the following processes occur:

1) plants extract nutrients from soil;

2) formation of new compounds, biosynthesis of organic substances takeplace;

3) organic matter returns to soil with litter;

4) decomposition of litter, the formation of humus, and mineralization of organic matter again turns into nutritious material which is used by the stands and other components of the forest.

Compared to other ecosystems (grassland, wetland, lake), biological cycle in the forest is the most intensive one. There are differences in the activity flow of biological cycle in the forest, depending on climatic and soil conditions: it increases from the Northern taiga forest to forest steppe, from the moderate extended zone to the tropics.

Removing cut timber from the exploitable forests from the biological cycle eliminates some portion of nitrogen and ash elements. Currently, there is a trend of increasing use of tree phytomass, therefore, there emerge a problem of biological losses compensation.

8 FOREST CLASSIFICATION. FOREST TYPOLOGY

8.1. Climate and distribution of forests. Diversity on the globe. The forest vegetation types of the world

Regularities in the distribution of vegetation depending on climate were set by A. Humboldt in the early 20th century. Distribution borders of forests, their composition and productivity are determined by dominant climatic factors such as heat and precipitation, their amount and ratio. The Northern border of forests distribution, as it was already noted, coincides with the July isotherm of +10°C, i.e. the main limiting factor in the distribution of forests to the North is the lack of heat, especially in the soil. It limits not only the growth of the vegetative bodies, but the seed bearing (on the Northern boundary seeds ripen rarely, sometimes, once in a century).

In addition to heat and precipitation the distribution of forests is affected by other climatic conditions, for example the absolute temperature amplitudes, dry air and winds, causing loss of moisture by plants. So, if in the North of European part of Russia on tundra border there is spruce and pine, in Siberia there is only larch. The southern boundary offorests distribution is also related to the climate and it coincides with the line connecting the geographical points at which the ratio of the amount of the evaporated moisture from the water areas to rainfall equals to 1 : 1. Further in the South there is not enough moisture for forest regeneration.

Due to large differentiation of climates on the Earth the world's forests are very heterogeneous. According to the decision of the VI World forestry Congress (Madrid, 1966), it is distinguished 6 types of forest vegetation on the globe: coniferous forests of the cold zone, mixed temperate forests, rainforests of warm temperate climate, tropical rain deciduous forests, Equatorial rain forest, and dry forest areas.

Coniferous forests of the cold zone. Confined to the northern hemisphere and follow it around the entire circumference, occupying the whole of the Russian Federation, the Scandinavian countries, Canada, USA. The climate is characterized by long harsh winter, powerful, stable snow cover, and relatively short, cool summer. Species composition is poor: pine, Siberian spruce, European spruce, Sukachev's larch, Siberian larch, Dahurian larch, cedar Siberian, cedar Korean, fir, birch, aspen, willow. On the North American continent spruce white, spruce black, balsam fir, and other species grow. Forest of cold zone influence global biosphere, they are valuable in the economic respect, because they are the main logging source of the most popular coniferous wood on the market.

Mixed temperate forests. They are located further south of the coniferous forests in the cold zone. They are almost the same as coniferous forests coldzone; they cover the northern hemisphere around the ring, passing through the entire European continent, the Caucasus, the Russian Federation from west to east, Japan, North America. Climatic conditions in this forest belt are more favourable than in coniferous forests. Winters are softer, summers are warmer, and the growing season is longer. This determines growing of a larger number of tree species. Oak, beech, hornbeam, linden, maple, walnut, and chestnut dominate. Conifers, including pine, spruce, larch and others significantly participate in the forest belt, and on the North American continent these are Douglas fir, arborvitae and others.

Wet forest of warm temperate climate. They are not largely spread, fragments are found in the South-West of the USA (Florida), a narrow strip extends in the North-West of South America, occupy small areas in the South-West and South-East of Australia and in South-East Asia. The climate in these regions is even milder if compared with the previous type of forest vegetation. The species composition of woody plants is quite diverse. In the United States there are species of short-leaf and long-leaf pine, swamp cypress; on the other continents there is a large variety of deciduous (oak, eucalyptus and others). Forest are dense, they have a mixed composition, and a complex form.

Equatorial rain forest. They grow on both sides of the equator and are concentrated in South America (the Amazon with the adjacent territories), Africa (along the Gulf of Guinea to the middle of the continent), Indonesia. The climate is characterized by abundant precipitation during the whole year, a lot of heat. The average annual temperature is at least 20°C. The growing season lasts the whole year. These evergreen forests have the most diverse species composition of the tree species with a complex structure. It can be found up to 100 or more tree species per 1 ha, they form 4–5 layers of tree canopy. A small number of tree species have industrial value; some of them are characterized by exceptional valuable wood.

Tropical rain deciduous forests. They are confined to regions with abundance of heat. Wet seasons periodically alternate with dry ones. The areas of these forests are small; they are represented on all continents. In North America they occupy a small area in the extreme South West, South America's tropical forests are located in the heart of the continent, in Africa they are located in central part to the south of the equator, and in Asia they are concentrated in the South East region. Due to the seasonality of precipitation, forests are mainly deciduous. It is drought that causes abscission of leaves. Species diversity of tree species is quite large. Teak wood is the most common in Asia; it has the main economic value, it grows rapidly and has solid wood. The symbol of the Africa is baobab; a significant area is taken by acacia.

Forest dry areas. They are common on all continents in the areas where there are well defined dry seasons. They are most significantly represented in the Central part of Africa. They stretch across the continent from West to East, on the periphery of Australia, in Central India, in the Mediterranean (Spain, Italy, Morocco, and Algeria). The most characteristic species are umbrella pine and pinaster, cedar Atlas and Himalayan, downy oak, holm oak, cork oak, evergreen Laurel.

8.2. Geobotanical zones, subzones and districts of Belarus

The difference of climatic conditions on the territory of Belarus determines zonation of vegetation, which is reflected in the fact that in the direction from North to South of the boreal forest taiga type are changed by formations of deciduous forests. Zonation of vegetation in Belarus is characterized by two geobotanical zones and three subzones. Zones are Eurasian taiga and European deciduous forests. Zones are defined along the southern border of the area of the total distribution of Norway spruce.

Geobotanical subzones cover a vast territory; they stretch in the East West direction, and are mainly determined by the composition of the forest vegetation formations.

Subzone oak-conifer forests. It occupies the northern part of Belarus and is bounded on the South by the northern limitation of the area of hornbeam. Spruce forests here look like Eastern European southern taiga forests with admixture of broad-leaved tree species. Subarea includes three geobotanical districts: Western Dvina, Oshmyany-Minsk, and Orsha-Mogilev.

The Western Dvina district is characterized by minor spread of oak forests, increased participation of indigenous wetlands deciduous forests (birch, black alder forests) and derivatives of grey alder.

Oshmyany-Minsk district is dominated by pine forests on poor sandy soils with insufficient moisture. These are mainly pine stands dominated by heather and mosses, with rare lichen-rich associations.

Orsha-Mogilev district is characterized by the greatest spread of spruce forests and broad representation of sorrel series of forest types.

Subzone of hornbeam-oak-conifer forest. It covers the central part of the territory of Belarus between the northern border of the area of common hornbeam and southern Norway spruce. In this subzone there is a transition from the southern taiga dark coniferous forests to west European deciduous forests. They are characterized by a decline of spruce forests. In oak forests in addition to the admixture of spruce hornbeam appears. They include two geobotanical districts: Neman-Predpolessky and Berezinsky-Predpolessky, which differ by the proportion of spruce and oak forests, and the typological structure of pine forests.

Subzones of oak-conifer and hornbeam-oak-conifer forests belong to the Eurasian taiga zone.

Subzone of broad-leaved pine forest. It lies to the South of the boundary of total spread of Norway spruce and it is divided into two districts: Bug-Polesie and Polesie-Dnieper. This subzone is actually the Belarusian Polesie. By geomorphology, climate, and soils it is most homogeneous. Spruce is found only in small areas; constant admixture in the oak forest is formed by hornbeam.

Bug-Polesie district is characterized by a wide distribution of deciduous forests, wetlands, and Polesie-Dnieper is characterized by maximum distribution of deciduous forests. There are 25 geobotanical districts in Belarus, representing soil and hill territorial formation. Zonation of vegetation Belarus is well correlated with climate, soil, and orographic features of its area (fig. 8.1).

Fig. 8.1. Geobotanical subzones, regions, and districts of Belarus:
1 – subzone oak-conifer forests; 2 – subzone hornbeam-oak-conifer forests;
3 – subzone broad-leaved pine forests

Distribution of forest areas in Belarus according to prevailing species in the context of geobotanical regions, districts and subzones are shown in table 8.1.

In Belarus the dominant species is pine; it constitutes 50.7% of the forested area. The area of pine plants in the context of geobotanical districts ranges from 20.3% in Surazh-Luchessa area to 71.2% in Braslav district. The share of spruce forests accounted for 9.8%. Among hardwoods mostly oak and ash stands prevail, 4.0 and 0.4%, respectively. Among softwood species birch stands dominate (21.8%). Their share varies from 12.8% in Volkovysk-Novogrudok district to 35.7% in

Surazh-Luchessa district. Grey and black alder forests occupy 2.0 and 8.5%, respectively. Aspen forests cover 2.0% area.

Table 8.1

The distribution of forests in Belarus according to the predominant species (K. V. Labokha, D. V. Shiman, 2013)

County, district, subzone	Pine	Spruce	Oak	Aspen	Birch	Asp	Alder grey	Alder black	Others
I. Western Dvina	29.4	15.9	0.4	0.7	31.9	3.8	10.6	7.0	0.3
1. Polotsk	36.9	15.3	0.4	0.3	29.5	1.6	9.4	6.5	0.2
2. Surazh-Luchossa	20.3	14.9	0.4	1.1	35.7	5.7	14.9	6.6	0.5
3. Braslav	71.2	7.6	–	–	15.3	–	1.7	4.2	–
4. Disnen	31.3	19.6	0.6	0.7	29.6	4.6	4.3	9.1	0.2
II. Oshmyany-Minsk	52.4	17.6	1.1	0.2	19.6	2.4	1.1	5.1	0.5
5. Naroch-Vileyka	61.2	12.4	0.6	0.2	18.1	1.7	1.5	4.1	0.3
6. Verhneberezinsky	53.0	13.5	0.4	0.2	16.3	1.5	1.2	12.8	1.0
7. Minsk-Borisov	47.1	21.6	1.6	0.1	21.1	2.9	0.9	4.1	0.6
III. Orsha-Mogilyov	47.2	18.6	3.2	0.2	21.5	3.3	0.6	5.0	0.5
8. Orsha-Pridnieper	30.3	36.9	4.0	0.2	18.2	5.3	1.9	2.4	0.8
9. Berezino-Drut	60.5	9.9	1.2	0.1	21.2	2.0	0.2	4.5	0.4
10. Sozh	61.6	8.8	1.8	0.1	20.5	0.7	–	6.6	–
11. Besedsky	32.8	15.5	7.6	0.3	28.8	5.1	–	9.5	0.4
Total in the subzone of oak-dark conifer forests	41.7	17.2	1.5	0.4	25.0	3.2	4.7	5.8	0.4
IV. Nieman-Pripolesie	60.9	9.2	3.3	0.3	14.7	1.4	–	9.5	0.7
12. Nieman	65.4	8.8	2.0	0.2	13.5	1.3	–	8.5	0.3
13. Naliboki	44.8	15.3	2.0	0.6	22.2	2.9	–	11.7	0.5
14. Volkovysk-Novogrudok	58.4	12.8	8.4	0.3	12.8	1.9	–	4.0	1.4
15. Belovezhsky	69.9	5.1	4.0	0.8	–	1.1	–	17.8	1.3
16.Westwern-Pripolesie	58.8	5.8	2.1	0.2	19.8	0.8	–	11.6	0.9
V. Berezinsko-Pripolesie	55.5	7.1	3.2	0.4	22.0	1.7	–	9.3	0.8
17. Central-Berezinsky	47.5	10.2	2.7	0.5	26.7	2.0	–	9.8	0.6
18. Central-Pripolesie	60.4	4.8	3.6	0.9	19.7	0.8	–	8.9	0.9
19. Chechersko-Pridnieprovsky	58.3	6.3	3.3	0.1	20.0	2.0	–	9.2	0.8
Total in the subzone of hornbeam-oak-dark conifer forests	58.5	8.2	3.3	0.4	17.9	1.6	–	9.4	0.7
VI. Bug-Polesie	52.6	1.6	4.7	0.6	22.8	0.5	–	15.7	1.5
20. Bug-Pripyatski	57.2	1.1	5.0	0.3	20.3	0.7	–	14.7	0.7
21. Pinsk-Pripyatski	49.0	2.0	4.5	0.8	24.7	0.4	–	16.5	2.1
VII. Polesie-Pridnieprovsky	57.6	0.7	9.8	0.5	19.6	1.0	–	9.4	1.4

The end of the table 8.1

County, district, subzone	Pine	Spruce	Oak	Aspen	Birch	Asp	Alder grey	Alder black	Others
22. Central-Polesie	62.9	1.4	5.4	0.3	18.7	0.8	–	9.9	0.6
23. Pripyatsky-Mozyrsky	59.0	0.5	9.9	0.4	19.0	0.7	–	7.9	2.6
24. Southern Polesie	56.4	0.1	12.2	0.4	19.6	0.5	–	9.2	1.6
25. Gomel-Pridnieprovsky	50.6	0.4	12.7	1.1	21.5	1.9	–	10.6	1.2
Total in the subzone of broad-leaved and pine forests	55.9	1.0	8.1	0.5	20.7	0.8	–	11.5	1.5
Total in Belarus	*50.7*	*9.8*	*4.0*	*0.4*	*21.8*	*2.0*	*2.0*	*8.5*	*0.8*

Note. All data on the characteristics and species composition are given according to 01/01/2009. The information is prepared on the basis of materials of the forestry inventory 2008 and the current changes are made in the database of the "Forest Fund of the Republic of Belarus", which occurred as a result of economic activity of state forestry in 2009.

8.3. Basic concepts of forest typology

Forests are combination of forest plants that differ significantly according to certain criteria, at the same time, some areas are very close to each other, and unite by common properties, thus distinguishing forest types.

Forest type (GOST 18486-87) is a silvicultural classification category, characterized by a certain type of forestry conditions, stands species, composition of trees, other vegetation, and fauna. When there are equal economic conditions, specific forest types correspond to the same system of forest management activities. The type of forest conditions (GOST 18486-87) is a forestry classification category, characterized by homogeneous environmental conditions of forested and/or non-forested lands.

Forest conditions are complex of climatic, hydrology and soil factors determining the conditions for forest growth and development. Forest typology is science of forest types and forest conditions. The object of study of forest typology is forest as a complex of multicomponent system. The main task of forest typology is a classification of forest geobiosenosis.

Forestry is not able to develop without forests classification into homogeneous forest management areas, which are forest types.

8.4. Forest typology concepts by G. F. Morozov

In the doctrine by G. F. Morozov about the types of plants, and then the forest types it was observed in two periods, early and late ones. In the early period the type of plants were identified by common soil conditions and natural forest regeneration. Forest stands composition and other vegetation layers were not considered.

According to G. F. Morozov, type plantations (forest) in this period were determined as “a set of stands united in one vast group according to common conditions of habitat, or soil conditions”.

In the later period, taking into account the current state of knowledge on the forest typology of the forest, and the criticisms of colleagues, G. F. Morozov made some significant adjustments in his doctrine.

According to them, the types of plantings should be divided into 5 groups according to the symptoms: 1) the natural environment, they are climate, topography, soil and groundwater conditions; 2) biological and ecological characteristics of tree species; 3) relations between plants at all layers of the stands between them and the environment, between them and fauna; 4) historical and geological factors; 5) human factor. This concept by G. F. Morozov reflects his views on the unity of living organisms and the environment.

“Type of planting is always biological, geographical, social, and historical phenomena”. This is the final opinion by G. F. Morozov on the question about the essence of the forest type. Apart from the concept “planting type” (in modern interpretation this is forest type), G. F. Morozov used the term “forest type” as classification unit of a higher order (corresponds to the concept of geographical landscape).

G. F. Morozov classified forest types into:

1) parent (basic) ones, including plantings which mostly correspond to specific forest conditions with long-term wood species (pine, spruce);

2) temporary ones, formed by tree species, replaced parent types. They are not so long-term and not as valuable (birch, aspen, and alder stands, appeared instead of basic types of forest).

Ideas of G. F. Morozov in his early period formed the basis of the classification of types of forest conditions (Ukrainian direction); the ideas of the later period were developed by V. N. Sukachev, and formed a scientific direction, called “biogeocenosis typology”.

8.5. Biogeocenosis typology by V. N. Sukachev

In the concept by V. N. Sukachev forest type corresponds to the type of forest biogeocenosis; hence there is the name of the direction. The name of forest type is binary: the first word defines the wood species edificator, which usually constitutes the largest share of stock (pine, spruce, aspen), the second part of the name indicates the plant, which dominates in live ground cover, other layers, or characterizes the conditions of the habitat (pine-sorrel, spruce near streams and so on).

Forest type by V. N. Sukachev is association of forest plots (i.e. separate forest ecosystems), with homogeneous composition of tree species, other layers of vegetation and fauna, microorganisms habitats, climatic, soil, groundwater, and hydrologic-economic conditions, the relationship between plants and environment, inner biogeocenosis and inter biogeocenosis exchange of matter and energy, regenerative processes and direction of shifts in them. This uniformity requires the same economic conditions and homogeneous forestry management activities.

According to V. N. Sukachev the type of forest can only be referred to the areas covered by forest. Non-forested areas are considered as self-autonomous categories of forest conditions. In this case there is no major component of the forest, i.e. trees, presented by a certain species. The diversity of forest types V. N. Sukachev placed in the system of ecological-phytocenotic series representing the grid in the form of a cross (fig. 8.2).

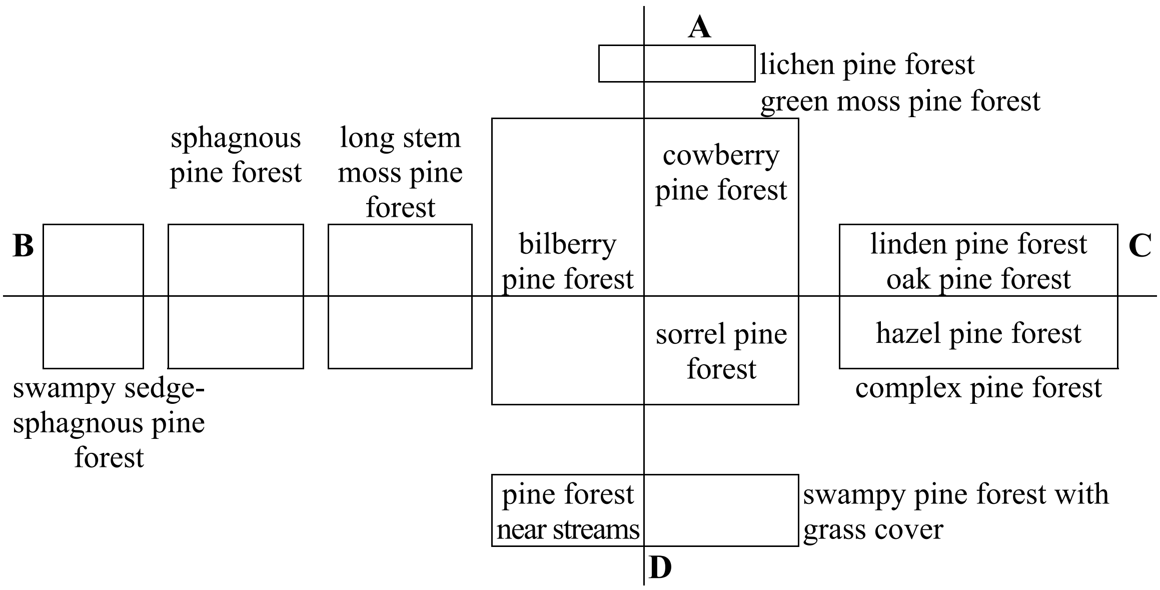


Fig. 8.2. The system of ecological-phytocenotic types of pine forests according to V. N. Sukachev

The central part is occupied by the forest type, satisfactory in all edaphic parameters, such as pine sorrel wood.

A row represents a decrease in humidity and eutrophication of soils.

B row represents an increase of stagnant moisture.

C row represents an increase of soil fertility.

D row represents an increase of moisture flow.

V. N. The Sukachev distinguished indigenous and derived forest types. Indigenous forests are the types of forests, which sustainably exist in these conditions. Derived forests are characterized by demutation (recovery) processes of indigenous edification; there can be irreversible development processes of ecosystems.

8.6. Classification of forest conditions types

Edaphic grid by P. S. Pogrebnyak based on the results of the early period of the forest types study types by G. F. Morozov, A. A. Kryudener developed a rather complicated and cumbersome classification scheme of forest types with regard to climate and soil conditions. According to the concept of this scientist, forest type is a specific plant community, formed by climatop under certain soil conditions; it has a more or less constant spatial character without human intervention.

E. V. Alekseev all the diversity of forest types according to soil and groundwater conditions combined into 6 groups: four of them were on dry land and two groups were in wet habitats, i.e. the scheme of forest types by A. A. Kryudener was greatly simplified, and based on their mechanical composition and soil moisture. E. V. Alekseev is considered to be the founder of the Ukrainian direction in the forest typology, called the eco-forestry. As his followers, he included non-forested areas in the forest typology.

The successor of the Ukrainian forest typology, P. S. Pogrebnyak perfected the classification of forest conditions and presented it in the form of the edaphic grid of forest types (table 8.2). The forest type is called tropho- and gygrotop (edaphotop): dry subor (B_1), fresh pinewood (A_2) and so on.

Under optimal moisture poor pine forests (trophotop A) are presented by oligotrophs, mainly pine, III, and lower classes of forest appraisal index. In the subors of pine stands of II and III classes of forest appraisal index there can be spruce and oak in the second layer. In relatively rich complex subors (C) pine-spruce and pine-oak forest grow with admixture of meso- and megatrophs: hornbeam, linden, maple, hazel. Rich oak stands (D) in the conditions of Belarus are presented actually by oak forests.

Table 8.2

Edaphic grid by P. S. Pogrebnyak

Gygrotops	Trophotops			
	A (poor)	B (relatively poor)	C (relatively rich)	D (rich)
0 – very dry	A_0	B_0	C_0	D_0
1 – dry	A_1	B_1	C_1	D_1
2 – fresh	A_2	B_2	C_2	D_2
3 – humid	A_3	B_3	C_3	D_3
4 – wet	A_4	B_4	C_4	D_4
5 – moist	A_5	B_5	C_5	D_5
–	Pine forests	Subors	Complex subors	Oak forests

Thus, according to the Ukrainian classification, the forest type presents a set of forest areas with similar soil, hydrological and climatic conditions, taking into consideration the historical factor. According to the concept by D. V. Vorobiev, (another representative of the Ukrainian direction), forest type must be determined within the type of forest conditions in homogeneous species composition in indigenous stands and their approximately equal productivity. In addition to the indigenous plants of the forest type, it comprises an indefinite number of derived plantings and non-forested areas. The forest types are considered, as it is generally accepted, within the boundaries of the zonal-geographical regions. Therefore, a distinctive feature of the Ukrainian forest-typological direction is to focus on the diversity of forest conditions. In this connection we should also note that some soil conditions are impossible to classify according to the developed edaphic grid (for example, types of oak forests in floodplains and on saline soils).

9 FOREST VEGETATION OF BELARUS

9.1. Features of the Belarusian forest typology direction

In the development of forest typology in Belarus N. F. Lovchii (1991) singles out four periods.

1. The emergence of ideas about the types of plantings and the first attempts to describe the types of forests under forest management (since the late 19th century to 1917).

2. The experimental period associated with the development of studies of forests on a scientific basis, implementation the ideas of G. F. Morozov (1917–1930) into the forest typology.

3. Phytocenological period associated with the wide deployment of forest typology studies, introduction phytocenological ideas of V. N. Sukachev (1930–1961) into forest typology.

4. Biogeocenology period, the characteristic feature is the application of the concept of ecosystem by V. N. Sukachev in the forest typology research (from 1961 to present time).

The beginning of modern biogeocenology in Belarus was the work of I. D. Yurkevich "some problems of forest typology", published in 1961, which distinguished the concepts of "forests" and "forest association".

The study of forest types Belarus was highlighted in the scientific papers by I. D. Yurkevich, V. S. Geltman, L. P. Smolyak, V. I. Parfenov, N. F. Lovchii, D. C. Holod, E. G. Petrov, and other scientists.

There are several features of the Belarusian forest typology direction.

1. It is based on the concept of ecosystem by V. N. Sukachev, based on the types of forest conditions, distinguished according to the two-dimensional edaphic grid by P. S. Pogrebnyak.

2. According to I. D. Yurkevich and V. S. Geltman, a basic typological unit is association, which is regarded as type of phytocenosis, i.e. forest association is the primary unit of vegetation classification, one particular form of the forest type existence, its variant, its subtype.

Forest type is a taxonomy unit of the next higher order, which is regarded as the type of forest biogeocenosis. One forest type may contain many associations. Therefore, forest type, or the type of forest biogeocenosis is a set of homogeneous forest associations, the components vary, but do not go out of the forest type.

3. Belarusian forest typology classification was improved:

a) basic associations were defined in each forest type;

b) a number of new types of forest like spruce glague, spruce nettle, oak fern, pine bracken, and others were introduced;

c) groups of forest types “pine complex” and “spruce complex” were broken up and transferred to the rank of forest associations corresponding to pine and spruce stands of bracken, sorrel, and blueberry.

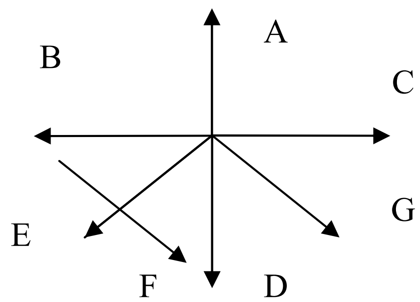
The diversity of forest types according to the Belarusian classification was arranged in the following system edapho-phytocoenotic series (figure):

A, B, C, D – as in V. N. Sukachev (see unit 8.5);

E – the increase of water content of peat-bog soils;

F – increase of flow moisture from oligotrophic (highmoor) to mesotrophic (transitional) and eutrophic (lowmoor) bogs;

G – increase of hydromorphicity (watering) of rich humic gley and peat-bog soils.



System of edapho-phytocoenotic series by V. S. Geltman (1982)

4. The forest type in turn is a classification unit of larger categories, such as forest formation, series of forest stands, and cycle of forest types. Forest formation unites forest types dominated by a certain relatively large area of a single dominant-edificator (edificators), for example the formation of pine forests. A series of forest types unites indigenous forest types of two and more forest formations, differing in composition of dominants-edificators of tree layer and similar in composition to other layers (sorrel series; these are spruce sorrel + oak sorrel, + pine sorrel).

The cycle of forest types in contrast to the series of forest types covers one type of vegetation conditions, it unites not only indigenous, but also derived forest types, reflecting different stages of decay and reforestation of the original indigenous forest types (mossy spruce → cutting (bare plot) → birch (aspen) mossy → mossy spruce forest).

5. It is distinguished indigenous and derived forest formations and forest types. As noted by V. S. Geltman (1982), "on the prevalence of indigenous forest types, the formations of pine, spruce, oak, ash, black alder, downy birch forests are indigenous ones, European birch, aspen, grey alder, hornbeam and some other broadleaf species are derived ones". Consequently, the tree stands formed by relevant species are indigenous and derived ones (see unit 2.3).

9.2. Classification of forest associations and definition criteria

Forest associations differ in origin. They can be grouped by causal entity, reflecting the processes of their formation, development and shifts. I. D. Yurkevich and V. S. Geltman distinguish the following associations of origin:

1) age associations reflect age, stage of development of phytocenosis and related changes in other components of biogeocenosis;

2) edaphic caused association sreflecting variations of edaphic conditions and the resulting variations of phytocenosis;

3) phytocenotic replaced associations reflecting variations of phytocenotic structure in one and the same or similar environmental conditions;

4) digressive-demutation associations reflecting changes in phytocenotic and ecotopic forest structure without changing the basic edificators due to anthropogenic and natural acidental influences;

5) radiation-ecological associations reflecting variations in conditions of heat and light and the resulting variations in plant communities.

Belarusian forest typology scientists (V. S. Geltman, 1982) developed the following criteria for definition of vegetation associations.

1. The admixture of deciduous tree species in the main layer of coniferous and deciduous trees in the amount of 25–30% or more of the total stand.

2. The mixture in the main layers of coniferous and deciduous species other coniferous and deciduous trees is in the amount of 15–20% or more of the total stand.

3. In indigenous coniferous and deciduous forests in the second layer of the stand the types that do not occur in the main layer, or grow it in a small admixture are presented. While quantities of trunks in the second layer is not less than 20% of the number of trunks in the first layer, and the reserve of species, which is in the second layer, is at least 40% of the stock of first layer.

4. The amount of young trees is not less than 5 thousand units per ha; average height is not less than 1.5 m.

5. The admixture in derived small-leaved forests of indigenous species is not less than 10% of the total stock.

6. The amount of understory with density not less than 0.3; the average height 1.5 m or more, and the total number of the basic form is not less than 5 thousand units per ha.

7. Association according to live ground cover is defined in case particular projective coverage is co-dominant (regarding the total projective coverage by herbaceous-shrub layer) not less than 20%. Here one should take into account the herbaceous-shrub layer, its total projective coverage is 10% or more, and in co-dominant one is more than 5%.

9.3. The modern structure of forests in Belarus

In the first world forest inventory, which took place in 1980, the forest-land percentage of the planet was 29%. Unfortunately, currently, there is a steady degradation of forests that is expressed in the reduction of forest cover occurring with a rate of 0.6% per year. A disappointing forecast reduction of the area of tropical forests will occur at a rate of approximately 5 million ha per year (L. N. Rozhkov, 2005).

In Belarus there is an opposite tendency. Over the past 60 years, the forest cover has increased 1.9 times. Today almost 39.1% of the territory of the country is forested; the total area of forest fund is 9,468 million ha. The stock of standing timber is estimated at 1,669 billion m^3. The balance of interests between environmental and economic constituents in forest relations in our country has developed in favour of the environment. As the results of the research scientists of the Institute of forest of NAS of Belarus, F. F. Burak and L. N. Tolkachev (2003), with an average annual growth of wood of about 28.6 million m^3, it is annually harvested 13–14 million m^3. On the whole, in Europe forestry constitutes 2.9 m^3 per 1 ha of forest lands, or 95.7% of the average growth; in Belarus is 1.36 m^3 per 1 ha or 38.7% of average growth.

According to a number of characteristics of forest resources, Belarus is in the top ten of forest states. Our country has 7.8 million ha of forest lands and exceeds approximately 2–3 times England and Austria by this index, all countries in the Baltic region together, it nearly equals in area to forests of Norway and Poland, and it is slightly inferior to Germany and Ukraine.

According to the amount of general stock of wood Belarus is considerably inferior in Europe only to Sweden, 1.4 billion m^3 vs. 2.83 billion m^3, it is close to such countries as Ukraine (1.59 billion m^3), Germany (1.63 billion m^3), Poland (1.53 billion m^3), Finland (1.88 billion m^3), France (1.8 billion m^3). With an average stock per 1 ha of forested land (174 m^3) Belarus occupies the 3rd place in the world, it is inferior only to Austria (211 m^3) and Switzerland (300 m^3).

The average increase per 1 ha of forested land in Belarus is only inferior to Germany, England, Austria, Ukraine and France, it is equal to the increase in Poland and Lithuania, it is significantly higher than the average growth of forests in Europe, Latin America, Asia, Baltic countries and multiple times forests of Russia. Belarusian forests are not only a source of renewable raw materials and energy resources. It is a treasure of biological and landscape diversity, an important habitat and environmental factor. On 01/01/2013, more than half of the forest fund, 51.7% is occupied by forests of the first group, performing mainly environmental role. The share of forests of the II group is 48.3%.

The species structure of the forests of Belarus comprises 60.6% of coniferous. The most common tree species pine is 51.1%, spruce is 9.5%. Deciduous species birch is 22.6%, and alder is 8.4%, and deciduous forests are mainly oak, 3.5%, about 4.0% of the forested area is occupied by aspen, grey alder, hornbeam.

Why pine dominates in the forests in Belarus? Primarily, it is due to the fact that it has a unique ability to grow in an extremely wide range of ecological-phytocenotic conditions. Secondly, of course, because edaphic and climatic conditions of our country meet the ecological and biological needs. And, in addition, one should take into account the regularity of development of agriculture in Belarus in the historic aspect, which is confined to more active development of fertile lands. That is why sandy and sandy clay soils with pine prevalence did not so much undergo anthropogenic impacts in the development of the agricultural sector. However, high quality of wood species, its wide distribution throughout the country and good accessibility for logging led to active exploitation of pine woods. Currently there is a negative dynamics of pine formation. From 1956 to 2001, the area of plantations has decreased by 8%. The strategic plan of development of forestry in Belarus, adopted in 1997, intended to increase the share of pine forests up to 60.6%.

The area occupied by the spruce formation, according to some researchers (L. N. Rozhkov, 2005), should be increased up to 13.2%. It is interesting to note that before 1988, the share of spruce ranged insignificantly and even tended to increase. Because of the droughts in 1992 and 1994, followed by other droughts, mass drying out, leading to the fact that the area declined by about 1% per year. There is a reduction of oak formations. If earlier the proportion of oak was 4.2%, now is 3.5%, i.e. decreased by 1.2 times.

The age structure of forests Belarus is the following. The young stands comprise 19.9%, including I class age, 8.7%, middle-aged stands, 46.8%, mature stands, 22.6%, ripe and overripe stands, 10.7%. The age structure of the forests of Belarus is not optimal. If young stands previously dominated (56.7%), now there is their noticeable reduction (19.9%), but the proportion of middle-aged forest properly increased today. That means, after 50–60 years again, there will be a problem of insufficient representation of mature trees, but their share will be too high if compared with other age groups of 40–50 years, at the age of clear cutting of the current middle-aged plantations, etc.

9.4. General characteristics of pine formations

The pine forests are the most widespread in Belarus. As noted above, historically, the fertile lands are most actively used for agricultural crops. The demand of sandy soils for agriculture was not significant. According to their ecological and biological features they are dominated by pine. Therefore, these soils are characterized by high forest land percentage, and the main forest-forming species is pine.

On 1 January 2013 it occupies more than half of the forested land, 51.1% or 3 million 554.9 thousand ha. According to some researchers

(I. D. Yurkevich, A. D. Yanushka, V. E. Ermakov, L. N. Rozhkov), the optimal share of Scots pine should be 60.6%.

The total stock of pine stands is 818 million m^3, while the sock of all species is 1 billion 450 million m^3. The stock of pine stands per1 ha is 228 m^3, the stock of mature and overmature pine stands per 1 ha is 259 m^3. The most common pine stands are mossy, bracken, blackberry, and heather ones, which account for over 82% of the area of pine formations. The area of each of the other types is less than 5%. Pine wood sorrels are more prevalent in Northern and Central subzones. Polesie woodlands are characterized by a marked decrease of pine sorrel woods and increase of the area of pine bilberry and long moss forests.

Pine is fairly evenly distributed throughout the territory of Belarus. Pine formation is represented by three subformations:

– monodominant pine forests (pine lichen, heather, cranberry, moss, blueberry);

– subor (pine bracken, wood sorrel, partially blueberry);

– pine bogs (pine herbal and stream stands, ledum, sedge, sedge-sphagnum, sphagnum).

Pine forests occupy poor sod podzol sandy soil. Subors are formed on richer and moist sandy soils, sometimes underlain by loam. Pine bogs grow mainly on peat-bog soils.

The average age of pine stands in Belarus on 1 January 2013 was 59 years. The age structure of pine formation is not the best one. The analyses of the lands distribution covered by pine forests regarding age groups show that in 2013, it was dominated by middle-aged stands, 44.9%, while in the young I class and mature and overmature stands there are respectively 6.4 and 5.7%. Young II class and premature pine forests occupy approximately the same area, 21.2 and 21.8%, respectively.

Mature and overmature forests are concentrated mainly in the forests of the first group;its clear cutting is limited. In particular, the National Park “Belovezhskaya Pushcha” is dominated by overmature pine phytocdenosis, which occupy about 40% of the area of the pine stands. It is interesting to note that there is a unique facility not only for Belarus, but also for Europe, considering its tourist and research value, these are old pine woods (160–190 years) area of over 100 ha, preserved in Negoreloe forest section of Negoreloe training and experimental forestry located in about an hour’s drive from Minsk.

The maximum productivity of pine forest is noted in complex mixed plantations on relatively fresh fertile soils (pine wood sorrel). For example, according to G. V. Merkul and his colleagues (2001), in Brytsalovski forest section of Osipovichi forestry, 120-year-old pine wood sorrel had a stock of more than 770 m^3/ha, average height of the stand 37 m.

In 2009 the share of pine forests on dry land of I and II classes accounted for 84.3%. For 31-year period their productivity increased, currently, the first class prevails. According to K. V. Labokha and D. V. Shiman (2013), this situation is explained by transfer of inefficient agricultural lands to forestry and cultivation here undemanding to fertility soils; and yet it is achieved a high productivity of Scots pine stands. 91.4% of pine bogs are presented by plantations of IV, V and V^a classes of forest index appraisal, of which the share of medium productive stands account for 30.3%, low ones account for 23.1%, and unproductive ones account for 46.6%. These data clearly show that wood harvesting in pine bog woods is in no case regarded to be a priority, it is reflected in the normative documents (Regulations of logging in the Republic of Belarus). There is a tendency of orientation on non-renewable resources such as berries, medicinal and technical raw materials; it is in these conditions much more prospective. Bog pinewood is an interesting object of the ecological tourism; its potential is up to the present time practically not implemented.

Within the boundaries of geobotanical subzone the middle class of forest index appraisal slightly decreases from North to South. So, in subzone of oak dark conifer forests it is about I,9; and in the subzone of broad-leaved-pine forests it is II,2.

In 1978, the average density of pine forests on dry land amounted to 0.72; in 2009 it was 0.71 (K. V. Labokha, D. V. Shiman, 2013). At first glance, for 20-year period, the value of this important forestry taxation index, one of probably the most significant in the economic relations subformations has not changed. However, a deeper analysis shows that during this time pine woods on dry land were marked by the trend of increasing medium dense (0.6–0.7) plantations (64.2%), while the share of low dense forest and high dense woods declined by 3.2 and 7.2%, respectively.

Analysis of the forest fund, represented by the pine of IV age class and older, grown on soils with deficient and moderate moisture, included by the Ministry of forestry of the Republic of Belarus into the main forestry use inventory, also indicates a decrease of the share of high dense plantations (K. V. Labokha, D. V. Shiman, 2013). Pure high dense pine forests of IV age class constitutes 12.7%, and of V, VI and older age classes constitute 4.4 and 2.5%, respectively. Among mixed pine woods of IV age class, high dense stands are 11.0%, and V, VI and older age classes are 4.2 and 3.8%, respectively. The low dense pine woods of IV, V, VI and older age classes can be mixed (9.0%), and pure (8.8%). They were mainly formed due to excessive thinning of the stands when conducting intermediate felling and partly as a result of their natural decay.

Wide prevalence, high exploitation properties of forest, a relatively good accessibility of pine forests expose them to strong anthropogenic influence. Unfortunately, there are digressive-demutation processes; and successions are sometimes undesirable. According to the ecological and forest pathology monitoring the conditions of the pine formation have deteriorated in recent years.

9.5. General characteristics of spruce formations

Norway spruce is one of the main tree species of Belarus and along with oak, hornbeam and grey alder characterizes the zonation of forest vegetation.

About 72% of all spruce forests of Belarus are the subzone of oak-dark conifer forests. Spruce is an edificator of forest ecosystems, characterized by wide edaphic amplitude of growth and it forms dark coniferous taiga forests.

In the northern part of Belarus spruce also occurs as the subdominant in the subor, oak forests, alder stand, it also dominates in the secondary small-leaved forest growth. Spruce forests are widely spread in the northeastern part of the country.

In the subzone of hornbeam-oak-dark coniferous forests, spruce also grows within its range and therefore it grows in the favorable soil-hydrological conditions.

In Polesye spruce reaches its natural boundary in the Boreal region. The share of spruce forests here is from 0.5 to 1.6% of all spruce forests. To the South of its natural boundaries spruce grows only in certain places, in the so-called “islands”. It is interesting to note that further to the South, in the Carpathian geobotanical region, spruce is commonly found. Boreal-Carpathian disjunction (gap) of its range covers the whole territory of the Belarusian Polesye. The narrowest corridor where spruce doesn't grow is 80–90 km and is situated on the territory of Belovezhskaya Pushcha (V. S. Geltman, 1982).

As at 1 January 2013, spruce formation covers 9.5% of forest lands, or 668,4 thousand ha.

The total stock of spruce stands is 166,5 million m^3, while the stock of all species is 1 billion 450 million m^3. The stock of spruce stands per 1 ha is 249 m^3, the stock of mature and over-mature spruce stands per 1 ha is 324 m^3. Stock of timber in spruce forests (1 ha, and in mature and over-mature stands) consists of softwood, hardwood and softwood species.

Thus, spruce is one of the most highly productive tree species, due to its biological properties and a favourable combination of climatic, soil and hydrological factors in Belarus. Spruce forests of I^a–I (about 50%) and II (45%) site classes prevail on the territory of Belarus. In our country, on the fertile and relatively moist soils, spruce forms a highly productive forests with wood stock at the age of 80 to 720 m^3.

Spruce forests occupy a fertile sod-podzolic fresh and moist sandy loam and clay loam underlain by moraine loams and clays.

The most common spruce forests are oxalidosum (38.7%), myrtillus (20.9%) and mossy spruce forests (25.5%), which accounted for about 85% of the total area formation.

As at 1 January 2013, the average age of spruce forests in the whole of Belarus is 55 years.

According to the environmental and forest pathology monitoring, spruce formation has been degrading throughout the country (starting with mass drying out period 1992–1998). According to the results of V. V. Carnacho (2009), from 1992 to 1998 there was a reduction in the area of spruce forests in different geobotanical districts by 2–15%, which is about 73 thousand ha. The largest area of dried and damaged stands observed in oxalidosum, myrtillus and mossy spruce forests.

Mass drying of spruce forests is caused by complex system. In all cases, the main predisposing factor of resistance lowering is extreme climatic conditions, especially drought in 1992–1994 and subsequent years.

Low resistance of spruce forests is the cause of mass reproduction of stem pests; primarily bark beetles, and diseases, such as root rot caused by honey mushroom.

In recent years there has been a certain decrease in the volume of dried spruce forests. However, hot and dry weather conditions of spring and summer may disrupt their relative stability and cause a mass outbreak of pests and diseases.

9.6. General characteristics of oak formations

The English oak is one of the main tree species in Belarus. Our country is famous for its oak forests, which are characterised by high productivity, it is up to 600 m^3 per 1 ha and more. Famous forester M. M. Orlov in 1900 spoke about the Belarusian oak: "Remarkable oak trees in the state Koshelevo of Mogilev province, which are two hundred years old, with straight, slender stems as columns raise their spreading branches... You can admire similar oak trees in the Belovezhskaya Pushcha...". In the early twentieth century not only Buda-Koshelevo but also Turovsky and Rechitsa oak forests were of great popularity.

Oak forests amount 86.0% of hardwood forests. On the territory of Belarus oak formation has the most pronounced zonal features.

1. Soil and climatic conditions of the country are generally favourable for the growth of highly productive oak forests, especially in the southern and central parts. Therefore, the area of oak forests increases dramatically to the south, in the northern part it is 1.6% of the total forested area, in the central part it is 3.4%, in the south is 9.9%. The ratio of the total area of oak formation, its distribution by geobotanical subzones from North to South is 14, 23 and 63%.

2. In the northern part of Belarus the oak is constantly mixed with spruce, in central part it is mixed with fir and hornbeam, in the south with hornbeam. This causes the division of the oak formation on climate sub-formation: spruce, spruce-hornbeam, hornbeam. The share of spruce oak forests is 13%, spruce-hornbeam is 19%, hornbeam is 51%.

There is also intrazonal floodplain oak forests, occupying 17% of the formation (1% – north, 4% – center, 12% – south).

According to V. S. Geltman (1982), the main reason for the reduction of oak-forest areas in the oak-conifer forest subzone is the temperature reduction to the north. Oak and spruce are soil demanding tree species and therefore the ratio of the distribution of spruce forests and oak forests within areas depends mainly on climatic conditions. In the northern part of Belarus the quantity of spruce forests increases.

To the south, especially in Polesye, due to the changes in climatic conditions phytocenotic sustainability of oak increases.

However, a more fertile and therefore more favorable for the growth of oak soils are more common in the north of Belarus than in the south.

During the middle Holocene, the climate was warmer and did not restrict the advancement of oak forests to the north of Belarus, where they were more common than in the south. Their distribution was consistent with the distribution of rich soil. This state is directly opposite to the present one.

In the northern areas oak forests concentrate mainly in the valleys and floodplains, and in the south they can be met on watersheds. On watersheds, the climate is more severe and therefore the successful growth of oak in the northern areas is possible mainly in the softer climate of river valleys (V. S. Geltman, 1982).

As of 1 January 2013 oak formation takes 3.5% of forested lands, or 244.0 thousand ha. Other hardwood species (ash, hornbeam, maple) account for only 0.5%.

According to the calculations by A. D. Yanushko with colleges, in Belarus oak and other hardwood stand should take more than 7% of the forested area or almost two times more than it takes now.

The total stock of oak stands is 41.9 million m^3, while the stock of all species is 1 billion 450 million m^3. On average the stock of oak per 1 ha is 172 m^3 and the stock of mature and over-mature forest stands is 242 m^3/ha.

Oak forests are characterized by many-storing, mixed composition, complex age-class composition. Not only spruce and hornbeam grow near oak but also ash, maple, linden and elm. Monodominant and even-aged stands make up about 10%. The average age of oak is 71 years. The age structure is as follows: young stock is 22.3%, middle-aged forest stands is 50.7%, ripening stand approaching maturity stand is 11.4%, mature and over-mature forest is 15.6%.

As a result of the integrated geobotanical analysis of oak forests of Belarus there have selected 7 types of dry-land (upland), 5 types of floodplain oak forests and more than 90 associations.

The state of oak forests in Belarus is now of great concern. In the early 1970s the drying-up was due to extremely cold with little snow cover combined with summer droughts. Low intensity of summer droughts and thicker snow cover in winter contribute to a better state of oak forests in the northern part comparing with the southern one. In the southern part of Belarus drying-up is observed mainly in stands with over-grazing and on recreational areas.

Sharp decline in the groundwater level, mass reproduction of leaf-eating insects and stem pests contribute to drying-up. Currently, the state of oak forests remains weak. The maximum number of deformed and dead trees is recorded in 1996–1997 and 2004–2005.

As a result of the overall impact of pests, diseases and adverse environmental factors there can be another period of oak forest degradation in large areas. The oak requires special attention from foresters. Improper and untimely silvicultural actions lead to the death of young seedlings of oak in 3–5 years. The result is a change of species with the formation of derivatives types of forests, such as aspen, birch and hornbeam.

Oak forests of Belarus belong to the I–III site classes. The average quality is high enough, it is II,2, however this is significantly less than the potential productivity of oak forests. 51.1% of the oak belongs to the II class, and 34.3% to III.

9.7. General characteristics of the soft-woody forests

Soft-woody forests of Belarus make up 35% of the forested area. They are represented by the following formations:

– birch (22.6%);
– black alder (8.4%);
– aspen (2.1%);
– grey alder (1.7%) (table).

Birch formation. It takes the second place after the pine formation and is represented by silver birch and downy birch (white). Varieties of silver birch can be met very rare in Belarus: karelian birch (*B. pendula* var. carelica Mork.) and black birch (*B. pendula* var. kotulae). Edaphic habitats of silver birch and downy birch are not the same but at a certain interval overlap, so there are mixed forests of these two species.

Formational structure of soft-wooded forests

Formation	Sub-formation	Geobotanical subzone
Native swamp forest		
Black alder	Black alder monodominant	I, II, III
	Spruce-broad-leaved black alder	I, II
	Broad-leaved black alder	II, III
	Downy birch-black alder	I, II, III
Downy birch	Downy birch monodominant	I, II, III
	Spruce-downy birch	I, II, III
Dry-land forests derived from formations		
Silver birch	pine	I, II, III
	spruce	I, II
	oak	I, II, III
Aspen	spruce	I, II
	oak	I, II, III
Grey alder	pine	I
	spruce	I

Notes: I – subzone of oak-conifer forests; II – subzone of hornbeam-oak-dark coniferous forests; III – subzone of broadleaf-pine forests.

The composition of birch forest can be both monodominant and contaminante (two or more dominants). The tree story of silver birch forests has pine, spruce, oak, alder.

Derivative silver birch forest formed on dry-lands, makes up 73% of all birch forests. They are distributed uniformly on the territory of Belarus. Higher concentration of silver birch forests is in the north and in the basin of the Western Dvina. Predpolesye and Polesye are dominated by native stands of white birch. The local name is Belle. Downy birch forests grow in fens and transitional mires.

Silver birch forests are characterized by higher quality class than downy birch forests.

Typologically silver birch forests are the most diverse because they can change, with rare exception almost all types of pine, spruce and oak forests (see table).

Lichen birch forests can rarely be found on the territory of Belarus. Apart from silver birch, downy birch can be found in birch Oxalis, myrtillus, prilocaine-herbal and dolgorocna along with the silver birch is also found birch. Birch Oxalis and myrtillus make up more than half

(55%) of birch forests on dry land. Over 40% of all birch forests grow in swamps and moist soils.

The average growth class of birch forests is I,8. It is higher in Belarusian Poozerye and in the uplands of the Belarusian Range than in Polesye.

Black alder formation. Radical formation takes rich soil with sufficient flow of surface and ground water in fens. The black alder forests are formed also on mineral soils with a humus horizon.

The degree of water content and water flow are the main factors that determine the formation of different types of black alder forests. The main massifs of black alder forests are located in Polesye especially in Pinsk Polesye.

The most common carniolans of all black alder forests is Tolgoy (41.9%). The forests sedge and marsh-fern-together takes about one-third of black alder forests (29.3%). The average growth class of alder stand is II,0.

Black alder forests play a major role in the use of fens to obtain valuable timber; also they have important water protection and water regulation value. Downy birch forests, pine forests on bog will be discussed in unit 15.1.

Aspen formation. Derivative usually is formed by the changing of native spruce and oak forests on the richest soils and very rarely when pine forests are changed. Aspen forests don't grow in dry forests, bogs and fens.

As under the canopy of the parent tree stand and after cuttings, aspen forests intensively are renewed by root suckers.

The main massifs of aspen forests concentrate in the north-east of Belarus, in the subzone of oak-conifer forests due to the most favourable soil and climatic conditions of this region of the country.

Mature aspen forest has less stock compared to the spruce once. Their marketability decreases dramatically with ages.

The vast majority of aspen stands have the highest growth class: I^a–I is 66%, II is 31.4%.

Grey alder formation. Grey alder is widely distributed in the northern part of Belarus. Its southern border runs almost parallel to the border of hornbeam. It is interesting to note that the configuration of the boundaries of the area of grey alder in Belarus corresponds to the uplands with a moderately cold climate, while the northern border of the area of hornbeam covers more warm plains (V. S. Geltman, 1982).

Formation of grey alder that is a derivative of pine and spruce forests concentrates mainly in the eastern part of the Belarusian Poozerye, in Surazhski and Luchesski forests. The absent of grey alder forests that is a derivative from oak stands is caused by slight distribution of the latter in the area of the grey alder. The phytocenosis of this type are formed during a much more compressed edaphic interval than aspen and especially silver birch.

The most common types of grey alder forests are oxalidosum, glague, gramineous and spiraea. The average growth class is II,1.

Due to the good seed and vegetative propagation alder grows quickly on open agricultural and forest lands. In the agricultural lands grey alder forests are primary forest phytocenoses of the gramineous type.

10 REFORESTATION (FOREST REGENERATION)

10.1. The concept of reforestation

Reforestation is one of the stages of forest forming process. Any deforestation includes forest renewal. According to the popular expression of G. F. Morozov, “deforestation is a synonym of reforestation”.

In silvicultural literature along with the term reforestation the term forest regeneration is also used. According to I. S. Melekhov, these notions are equivalent and can be considered as synonymous. However, reforestation has a special meaning as it is an active form of forest regeneration. First of all, this is artificial regeneration but it also includes activities aimed at the promotion of natural regeneration.

It is necessary to draw a line between reforestation (forest regeneration) and afforestation or forest cultivation, i.e. cultivation of forests was carried out in the territories where used to be the steppes, coal and peat quarries and other developments but not forest.

The concept of the reforestation includes several categories: natural, artificial and mixed.

Natural regeneration: the formation of new generation of forests in a natural way. Ecological and biological process occurs both under its canopy and clearings (burned areas, waste land, bare place, clearings).

Natural regeneration can be distinguished in two ways:

1) as a process occurring spontaneously without the forester, however, in accordance with certain natural laws;

2) as a process to be managed and directed by the forester. It can be the method of cutting, seed planting and conservation of the undergrowth in harvesting operations.

There are following types of natural regeneration:

– seed, when a new generation emerges from the forest seed;

– vegetative, when the renewal occurs by means of vegetative primordial;

– mixed, it includes seed and vegetative components.

Seed regeneration is the only way to renew conifers (except tissa). Natural vegetative regeneration process is carried on by means of coppice shoots, root suckers, cuttings and rhizomes. Natural regeneration in view of clear-cuttings is divided into following categories:

– preliminary regeneration, it is natural regeneration under the canopy of the forest (before clearing)

– accompanying regeneration, it is natural regeneration occurring during gradual or selective clearing

– subsequent regeneration, it is natural regeneration during clear-cuttings.

Artificial regeneration is an active form: seeds, plants or parts of plant get into the soil with the help of forester by means of seeding or planting. A mixed regeneration is a combination of natural and artificial regeneration.

Forest regeneration capacity includes formation of a sufficient number of undergrowth of economically valuable tree species, and it plays a great an important part not only in forestry but also in forest life.

In accordance with "Clear-cuttings rules in the Republic of Belarus", a sufficient number of viable undergrowth of economically valuable species is taken as the basis for choosing the method of felling, technology logging operations and measures to promote natural regeneration of the forest. Natural regeneration should be given preferences over artificial one in all cases.

10.2. Seed regeneration of the forest. The stages and factors of seed regeneration

The success of natural seed regeneration depends on:

1) the availability of fertile seeds due to the presence of seeding origin, and their quantitative and qualitative seed productivity

2) favourable conditions for seed germination

3) favourable conditions for seedling development, self-seeding, undergrowth.

For successful seed regeneration it is necessary to combine all these conditions. The process of seed renewal proceeds in several stages.

The first stage is the flowering and seed production of trees. Flowering, formation, maturation and seed shedding depend on the biology of species as well as climatic, orographic, edaphic, site conditions and the nature of the forest.

Significant changes in seed production may occur due to the weather conditions, insects, fungal diseases.

Typically, the amount of pollen in the pine stands of the highest bonitet, i.e. in more affluent conditions is more than in the lower ones. The ratio of seed crop on poor, medium and rich, fertile soil is 1 : 2 : 3. Research conducted at the beginning of the last century by A. N. Sobolev and A. V. Fomichev showed that in spruce forests only trees of I, II and partly III class by Craft produce seed (see more unit 11.4). According to G. M. Kozubova, the germinability of pine pollen in the northern regions (Murmansk region) is much lower than in the southern ones (South of Karelia) (I. S. Melekhov, 2007). The highest concentration of pollen on the female seed buds is observed on the windward side than on the downwind side.

The regular seed production depends on growing conditions. Seed production of the trees that grew in an open area is higher than the trees in the forest. For example, a pine tree in an open area begins to produce seed when it is 10–15 years, but in the plantation in 20–30 years, spruce, respectively, 15–20 and 25–40 years old, the oak is in the 20–30 and 30–40 years, birch is 8–15 and 20–25 years.

In the stands of vegetative origin the seed-bearing starts earlier than in seed regeneration, due to the well-formed root system. Seed quality in young and middle-aged stands is higher than in the mature stands.

Good seed production in a tree varies from year to year. Harvest years called seed intersperse with crop failures and low yield.

The frequency of seed years for pine is 3–5 years, for spruce is 3–7 years, for oak is 4–8 years, for black alder is 2–4 years. Birch and aspen produce seed every year.

Thinning, loosening and fertilizing help to overcome the periodicity of seed production and increase yields.

The second stage is the seed dispersal. The main methods of seed dispersal are the following.

1. Wind (most species).

Light seeds are spread by the wind to a distance from 20–30 m (linden, ash, maple) dozens of meters (pine, spruce, alder, larch) and up to hundreds of meters (birch, aspen, willow). Aspen seeds in dry weather can be carried away to several kilometers. Spruce and pine seeds are dispersed by the radius of 50–70 m.

2. Water (black alder).

The seeds of black alder can be transported by water for a distance of several kilometers.

3. Animals.

According to German researchers, throughout the season a jay disperses approximately 4,600 acorns at a distance of 4 km. V. N. Sukachev with colleagues found out that nutcracker (*Nucifraga caryocta-ctes* L.) saves on one hectare from 4,000 to 34,000 seeds of cedar and eats only half.

4. Snow crust (snow covered by icy crust).

Pine seeds can be transported on the crust at a distance of several kilometers.

The third stage is germination of seeds. For successful seed germination you need: heat, moisture, air.

The optimum temperature for pine and spruce seed germination is 20 to 30°C. The optimal soil moisture for germination of seeds of some tree species is in the range of 50–70%. Of particular importance is the moisture content of the litter. The moisture content for seed germination may exceed by weight in 2–3 times the weight of the litter in absolutely dry condition.

The fourth stage is the seedling establishment and growth. At this stage, in addition to these three factors (heat, moisture, air), there are two more factors: they are fertile substrate and the light. Regarding the latter, it is necessary to mention (see unit 3.4) that in the life of self-seeding and undergrowth the so-called "shadow period" is distinguished, during which plants adapt to environmental conditions.

Thus, for natural regeneration it requires a certain complex of abiotic and biotic factors that are changing during seedling germination, establishment and growth.

The micro environment and micro climate, micro topography, litter, ground cover also play a great role. In one case, the seed can be carried to the wet substrate with good access of oxygen in other cases it can occur on dry dense surface, where there is no moisture. The seed could also be, for example, on hollows and micro-depressions, under grass and moss cover or on the bare mineral soil that is loosened or pressed. The soil may have heavy or light granulometric composition. Litter has a variety of different conditions (see unit 2.3).

Negative role in the renewal of the forest play salernitani, such as gramineous plants (bush grass (*Calamagrostis epigeios* (L.) Roth), tussock grass (*Deshampsia cespitosa* (L.) Beauv.), the annual bluegrass (*Poa annua* L.)), etc. They form a dense turf that prevents the seed germination.

Germinating seeds are often "hang" in the moss cover of green mosses, especially hair moss and then die.

Heather, willow herb, Paris herb, Solomon's seal loosen the soil and improve its chemistry, contributing to the accumulation of nitrogen and phosphorus. Willow herb protects the seedlings and self-seeding from high temperatures.

The role of the undergrowth in the forest is ambiguous. Hazel has a beneficial effect on the regeneration of oak, ash and buckthorn on the regeneration of spruce. However, when regrowth occurs the undergrowth may cause harm to the regeneration of the main species, hence it needs clear-cutting.

The contradiction between the plant and the environment is most pronounced at the early stages of forest regeneration process. The good seed might get into a bad condition and, conversely, the seed with a bad heredity can get in good conditions.

The quantity and quality of undergrowth depends: under the canopy – on the age, origin, composition, shape, productivity and density of the forest stand, the nature of moss and grass-shrub and sub forest story, forest types and forest conditions. On cuttings, it depends on type of forest conditions, origin, composition and age of the parent stand, the distance of the walls of the forest cutting and placement in relation to the cardinal points.

10.3. Types of vegetative regeneration of the forest

As it was mentioned, natural vegetative regeneration can be obtained by coppice shoots, root suckers, cuttings, rhizomes.

Coppice shoots are young shoots that appear from dormant, i.e. not developing until the cutting of the stem (oak, ash, birch, linden, hornbeam, aspen), as well as adventitious or, otherwise, adventive (appearing in unusual places, such as roots) sprout (hornbeam, elm, black poplar, etc.).

Shade-bearing species have more ability to coppice reproduction than light-bearing species. Keeping in view vegetative regeneration by coppice shoots, cutting should be done when the growth of coppice begins to decline. Stumps are left low, otherwise their upper part dries quickly, and this has a negative impact on coppice. Cutting should be carried out in winter, thus, coppice will mature during the growing season.

Thus, for successful vegetative regeneration by coppice shoots the following factors are important:

– light, warmth, moisture are necessary for emergency of dormant buds;

– the thickness of shoots, there are more coppice on the subtle stumps;

– the age of the cutting trees. There are more coppices on the stumps of young trees. Birch and alder have high reproduction at the age of 15–20 years and end at 40–50 years, the oak, respectively, at the 60–80 and 100–120 years;

– living conditions, unmerchantable deciduous stands have a higher ability to form coppice;

– the season of cutting, stump height of top quality shoots will be in winter, stump height should be no more than 1/3 of its diameter.

Root suckers are shoots of tree species, formed from adventitious buds on the roots that are close to the soil surface. In silvicultural practices you have to deal with the creeping-rooted regeneration, especially well pronounced in aspen. This tree has root suckers at a distance of 40 m from the stump, so even a few aspen trees are able to form quickly a dense monodominant planting of vegetative origin on the cutting area. According to A. A. Molchanov (1968), aspen after felling can give more than 250,000 root suckers per 1 ha.

Layers are the woody and shrub plants growing from the ground shoots due to the formation of adventitious roots where the shoots contact with soil (bird cherry, linden, beech, hornbeam, etc.). Natural layering typically occurs when a branch touches the ground, whereupon it produces adventitious roots. Layer is used quite frequently in the reproduction of shade-bearing species, because they form low crown. This method of reproduction is quite rare and has value in mountains.

Rhizomes are underground shoots that serve as nutrients deposit, vegetative reproduction and propagation. This type of reproduction is typical for common hazel, cranberries, bilberry and many other living ground cover species (see unit 2.3, 3.4).

10.4. Assessment of regeneration and various aspects of its value

Assessment of natural regeneration is carried out when the method of reforestation is being chosen before the forest clear-cutting or when the amount of gradual felling techniques is determined.

Natural regeneration is estimated also for acceptance of the cutting area from loggers, also for inventory in forested land plots are left for natural regeneration.

Assessment of forest regeneration includes the following indicators.

1. The total number of plants (species). The ratio of undergrowth by species and the composition of the forest are written by formula (see unit 2.4).

2. Origin (seed, vegetative, mixed).

3. The time of clear-cutting (prior, concomitant, consequent).

4. Age structure of plants with their division into groups: self-seeding, 2–5, 6–10, 11–15 years, etc.

5. The structure of the undergrowth according to the plant height with the division into groups: light, medium, heavy undergrowth (see unit 2.3).

6. The condition of the plants. The undergrowth is divided into a revivable (healthy), failed, oppressed, dead.

7. The density of the undergrowth: rare, medium density, thick, very thick (see unit 2.3).

8. The distribution of plants area: uniform, uniform, group (see unit 2.3).

The size of the discount area that is located on the diagonal of the plot, as well as in rows or in a staggered manner: for very dense undergrowth 1–2 m^2, thick – 4–5 m^2, average thickness is 10 m^2, rare – 20 m^2.

The number of sites to estimate the undergrowth and natural regeneration in the plot area is up to 5 ha 10 pcs., from 5 to 10 ha – 20 pcs. and more than 10 ha – 30 pcs.

Renewal of the forest has a multifaceted meaning:

1) biological is the basis of formation of all components of the forest and the development of relations between them;

2) environmental, when multilateral environmental functions of forests are being restored and are formed;

3) forestry, when the forest stand is formed as the main component of the forest, which is the basic means and object of labour in the forest industry;

4) recreational, recreated forest landscapes (attractions) which have a positive psycho-emotional impact, contributing to the moral-spiritual and physical rehabilitation of people;

5) economic, continuity of the integrated forest productivity that is the base of all their economic functions;

6) social, when living and working conditions of people are saved.

10.5. The advantages and disadvantages of forest regeneration

Artificial reforestation. The advantages of artificial reforestation:

– the timing and simultaneity of afforestation of large areas, the formation of a planned composition of forest stands, corresponding to the site conditions, the prevention of uncontrolled species change;

– possibility of selection improvement of forest forming species;

– hypodispersion;

– improvement of forest conditions by agrotechnical actions.

Disadvantages of artificial reforestation:

– the depletion of the gene pool of tree species, ecosystem simplification and hence reduced resistance of the formed spaces to adverse factors;

– the cost and complexity of silvicultural works.

Seed natural regeneration. The advantages of seed natural regeneration to vegetative one:

– genetic prospects of forming populations by cross-pollination;

– greater durability, resistance to adverse environmental factors;

– the formation of forest crop with a complex species and spatial structure;

– high technical quality and greater yield of large-sized timber;

– financial and labor costs are low.

The disadvantages of seed natural regeneration to vegetative one:

– slow growth in first years of life, as a result fruiting and the lengthiness of seed regeneration lengthen the period of forest recovery;

– actions to promote natural regeneration increase the costs;

– clearing is required in mixed and complex young stands to control species composition.

Vegetative natural regeneration. The advantages to seedling:

– fast, cheap and simple method of regeneration of the parent species;

– lack of dependence on seed years and the rapid growth in the early years accelerate the formation of the forest environment after the cutting of the parent stand;

– preservation of positive hereditary traits and properties of the parent stand of future generations.

The disadvantages vegetative natural regeneration in relation to seedling:

– lower durability (almost two-fold) and the weak resistance of trees to root and stem rots, worsening from generation to generation;

– negative hereditary traits and properties of the parent stand;

– week regeneration ability of future generations.

11 FOREST FORMATION

11.1. Age-classes of forest stands

Speaking about the formation of the wood plantation we single out the following age classes of the stands (age group, see unit 2.4):

– young;
– middle-aged;
– maturing;
– mature;
– over-mature.

The period of young aged forest stand varies from its canopy closure to the end of II age class (GOST 18486-87).

The young forest including self-seeding, the undergrowth and the canopy closure forms thicket (I. S. Melekhov). Thicket is closed young forest of I age class (see unit 2.4).

The young forest also includes pole stand trees (II age class), characterized by intense growth in height, the largest mass of leaves and twigs and abrupt differentiation of trees in size of stem and crown and intense mortality of stunted and dying trees. Middle-aged forest stands age from the beginning of III age class to maturing one (GOST 18486-87). Middle-aged forest stand is characterized by the intensive growth of a tree diameter while the growth in height is decreasing. At this age a wood approaches maturity (it is characterized by seed-bearing).

Maturing forest stand precedes maturity (GOST 18486-87). Maturing stand continues to increase the growing stock per unit area. Technical and economic features are identified.

Mature forest stand is the age of maturity (GOST 18486-87). Mature forest stand is characterized by slow growth, especially in height, and high stock or yield of wood.

Over-mature forest stand exceeds the period of maturing in two or more age classes (GOST 18486-87). Over-mature forest stand is characterized by growth decreasing (in height and diameter), the large number of defects, the significant natural pruning (it falls more than grows).

11.2. The concept of growth and development of woody plants

Growth is the increase in the mass and volume (linear measures) of a plant or its organs (parts). It happens due to the increasing number and size of cells. It continues throughout the life, but usually declines with age. Growth has daily and seasonal rhythmicity.

Linear parts of plants can become bigger with the growth, while the gross weight doesn't change. Different parts at different age grow with different speed, as a result, the proportions of the plants change. Growth as a quantitative process is opposed to development as a qualitative phenomenon.

Development is irreversible, natural process of closely interrelated quantitative (increase in number of cells) and qualitative (differentiation, maturation, aging) changes in the plant from the appearance till its death.

We single out the following types of plant development:

– embryonic (or germinal) and postembryonic (after the deliverance from the embryonic membranes);

– progressive (with the development of new organs and systems) and regressive (with the disappearance of separate organs and systems).

If the concept of growth of woody plants is more closely associated with age periods, the notion of development is associated with age-stages in the formation of plantations.

I. S. Melekhov identifies the following age stages.

I stage is the emergence of seedlings and the formation of woody plants till their closure. This is the stage of regeneration or occurrence of a forest, characterized by multistage developments of woody plants: fertilization, seeding, germination of seeds and emergence of seedlings, the formation of self-seeding and undergrowth. Plants at the regeneration stage grow and develop mainly individually without affecting each other and the surrounding.

II stage is an interaction among trees, their further growth and development, the formation of plantations. Competition among trees becomes stronger, trees environment forming role grows. One of its main results is natural thinning (tree mortality).

III stage is the aging and death of trees. In contrast to the previous stages, mortality occurs mainly due to the age-related developments of individuals.

11.3. Pure and mixed, simple and complex forest stands formation conditions

The main condition for formation and existence of a stable pure forest stand is a correspondence of wood species. It is defined by the growth conditions which are unacceptable for other species. For example, pine forest stands are formed on the sands and the raised bogs while black alder forests are formed on fens with flowing moisture.

Pure stands are created with the help of manmade reforestation and formed by systematic thinning, when some species are cut down some and others are left.

The formation of pure stands is caused by ecological and biological characteristics of tree species: for example, shade-tolerant spruce displaces light-demanding birch. Fires also favour it, that means one type dies out and another type lives.

The main condition for the formation of steady mixed forest is biological compatibility of different tree species, their ecological and biological suitability of tree species to sites. Usually mixed forests are formed under optimal conditions in fertile soils.

In Belarusian forests we can see mixed combination of coniferous and deciduous species (pines, spruces, birches, aspens), mixed plantations composed of oaks and its associates (limes, hornbeams, maples, ashes, the elm family trees, etc) grow under good conditions.

The main conditions for simple one-storied and complex multi-storied plantation formation, as we marked earlier (see unit 2.4) are similar to the conditions of pure and mixed stands correspondingly. Complex forest stands are often mixed and pure forest stands, as a rule, are simple.

Environment conditions (which are characterized by the lack or excess of some ecological factors) favour the development of simple stands. When climatic and soil conditions improve, the stand form becomes more complex. Rich soils with optimal humidification usually have complex stand forms.

Their formation can also depend on ecological and biological characteristics of tree species: for example, light-tolerant species favour the appearance of complex plantations with shade-tolerant species in the lower stories.

11.4. Classification of trees: G. Craft's, B. D. Zhilkin classification, classification by economic-biological features

It is very important for foresters to define the future species of trees, to take care, to regulate and sometimes to substitute natural selection for the manmade selection correctly. In this regard, it is necessary to classify the trees in the forest.

G. Craft's classification. One of the first classifications in this sphere was a classification of a German forester. His name was G. Craft. He suggested this classification in 1884 with the aim to take care for the forest with clean even-aged stands. This classification is the successful as people use it nowadays. According to it, all trees are divided into two big groups: dominant trees and codominant trees (G. Craft's terminology).

The main criterion for choosing a correct group for a tree is the type and height of its crown. We can single out several classes in each group.

The classification of trees by classes is carried out within the boundaries of the small biological groups, where a competitive relationship of individual plants can be observed.

I class is dominant trees (subdominant) with developed crown, high and large in diameter stems. They take 10% of the total amount of trees in plantings, but they make up 20% of the stock.

II class is dominant trees with relatively well-developed canopy and almost the same height trees as the trees of I class. In planting they take 20–40% of the total number and about 40–60% on a stock.

III class is less dominant trees (codominant), they are smaller than the trees of I and II class, the crown is less developed and narrowed. In planting they take 20–30% of the total number and about 15–20% on a stock.

The trees of I, II and III classes form the main and dominating canopy of the forest.

IV class is oppressed trees. Crowns are compressed equally on all sides or on one side. The number of trees can be up to 30%, but they form no more than 10% of the stock.

We single out 2 subclasses in the IV^{th} class:

IV^{a} – trees with a narrow and equilateral crown;

IV^{b} – trees with a one-side flaglike crown;

V class: strongly intermediate dying or dead trees. They do not reach the top of the basic cover.

We single out 2 subclasses in the V^{th} class:

V^a – trees with a living crown;

V^b – dying or sphacelated trees but still standing with roots.

The advantages of Craft's classification:

1) reflects the nature of the tree classification by growth in pure even-aged stands;

2) relatively simple and easy to use;

3) helps to single out trees for cutting correctly (trees are mainly cut in the low subordinate cover).

The disadvantages of Craft's classification:

1) subjectivity and ambiguity of classes which are singled out for different biogroups of one stands;

2) limited use (only for pure, even-aged, mainly coniferous stands);

3) implementation difficulties in highly productive complex stands.

B. D. Zhilkin classification. In contrast to G. Craft's classification, Professor Zhilkin's classification by productivity isn't subjective.

Trees are singled out according to the average diameter of stands. Each class has correspondent interval of diameters:

I class – 1.46 and more;

II class – 1.45–1.16;

III class – 1.15–0.86;

IV class – 0.85–0.76;

V class – 0.75 and less;

To define the bounds of a class in any plantation an average diameter is multiplied by the relative diameter index.

Zhilkin's classification advantages:

1) This classification is the objective trees classification and is based on precise mathematical calculations;

2) corresponds to the natural distribution of trees in forest stands over the levels of thickness;

3) helps to designate the trees to be felled during thinning operations.

The disadvantages of the classification by B. D. Zhilkin:

1) classification of trees by classes of productivity must be preceded by a preliminary cameral data processing of the forest inventory;

2) the actual productivity of a tree is not always determined by its diameter;

3) complex calculation and analysis of the productive class dynamic for any change of average stand diameter.

In addition, the classification by B. D. Zhilkin also takes into account the quality of the trunk and the quality of the crown.

Trunks can be classified by their quality as:

– high;

– medium;

– low.

In terms of the manufacturing standard stems are divided into merchantable, semi-merchantable and unmerchantable (see unit 2.4).

Crowns can be classified by their quality as:

1) good quality crowns: narrow with thin boughs, evenly developed. These features characterize trees with quick and good apical growth;

2) middle quality crowns: wide with thick boughs. This type of crowns characterize trees with slow apical growth;

3) bad quality crown: unevenly developed, deformed crowns and crowns with others defects.

Classification by economic-biological features according to the currently in force "Cutting-practice rules of the Republic of Belarus". According to this classification during the cutting-practice time all trees on grounds of economic-biological features can be divided into three categories:

I category – the best;

II category – subsidiary (useful);

III category – undesirable (for cutting).

The best trees: healthy, with straight trunks, with well-formed crown, mainly seed-origin trees. They are chosen from the I, II and III class trees according to the Craft's classification by growth.

Subsidiary trees: help to clean the best trees from boughs, to form their trunks and crowns, fulfill soil-protective and soil-improving functions.

Undesirable trees (trees for cutting):

– different types of trees which prevent the best and subsidiary trees from forming good crowns;

– dead standing, snug, windfallen, defective and dying trees;

– curve, with forks and offshoots, multitops, strongly attenuate trees of the main race.

It is important to know, that trees that are subject to be cut, can be of different growth classes, it means they can grow in any part of stand.

12 SUCCESSION OF FOREST ECOSYSTEMS

12.1. The concept of succession. The causes of succession

Forest ecosystems are also in the position of permanent development. One of the most important displays of the development is successional changes of trees species.

Succession is a successive (naturally determined) change of the geobiocenoses (biocenoses, phytocenosis) by other ecosystems on the certain area in the process of its formation, renewal or destruction under the influence of natural factors, human activities, complex interaction of natural and anthropogenic conditions.

The main causes of successional changes in the species composition:

1) forest growth conditions changes (climatic, soil, hydrological such as drought, hurricanes, ground water lowering, strong frost, snowless winters);

2) ecological and biological characteristics of tree species (photophily, shade tolerance, longevity);

3) human economic activities (logging, reclamation);

4) forest fires;

5) the impact of forest fauna and other biotic factors (wood seed shift, damages, illnesses, influence on environment).

Species change can be provoked by one of the cause (cutting, fire) but, as a rule, it is defined by several factors in different combination.

The knowledge of the peculiarities of species change discloses interconnections among the components of forest ecosystem and makes it possible to foresee undesirable species changes. Taking it into account, people carry out certain practical steps for exclusion of this fact.

There exist general natural rules for species changes:

1) more shadow-tolerant species in favorable soil-climatical conditions force out light-requiring species;

2) under the sharp external influence on a forest, light-requiring species (which have annual abundant fruiting, quick growth and are tolerant to unfavorable abiotic factors) force out shadow-tolerant species.

12.2. Successions classification

By origin:

1) primary succession (synthesis) begins on almost inanimate area (sand dunes, burnings, etc.). The speed of change is not high, geobiocoenosis climax state can be reached in 100 years;

2) secondary succession takes place in geobiocoenosis where important parts of ex-geobiocoenosis were removed (for example, the primary stand is cut down). As a rule, relatively rich natural resources of former biocoenosis are being saved. Due to this fact, climax community formation forms considerably quicker than in the time of primary succession. In the time of primary succession, as in the time of secondary succession, the area is first assimilated by originals with light seeds, quick growth and shot period of individual development (a birch, aspen, willow, alder).

By the causes of origin:

1) naturally based;

a) endogenous successions are bound with inner causes and ecosystem processes. Endogenous successions which are directed at original community renewal are called demutative;

b) exogenous successions take place in the result of external influence (climate, animals, fires, etc.)

2) anthropogenic digressive successions take place in the result of cutting, trampling, anthropogenic pollution and other human activities. They can be also caused by planting and sowing of other species. For example, the change of fir groves by birches and aspens after cutting and father restoration of a fir is called digressive-demutative successions.

By the direction of successions:

1) destructive: this type is not completed by the final climax (relatively steady state of the ecosystem);

2) progressive: the change of the ecosystem in the direction of climax;

3) regressive: the changes take place in the opposite direction of climax, which can lead to the radical changes in the ecosystem or its destruction.

By the species:

1) century-long: a very slow accomplishment. It takes 100–1000s of years and occurs on huge areas connected with large-scale environment changes (f.e. ice age);

2) long-term: the changes take place within 10–100s of years, for example, the change of a pine by a shadow-tolerant fir occurs within 100–150 years;

3) short-term: these changes need relatively short period of time (within one forest generation) and are easy-to-see. For example, the change of pine forest by the birch forest takes place in the result of soil consolidation by the tourists; an anthropogenic pollution leads to the change of the conifers species by the deciduous ones and etc.

According to V. N. Sukachov, the species changes can be: phylogenetic, singenetic and ecogenetic.

Phylogenetic successions are bound with the vegetation dynamics from the historical-geological aspect. These changes take place within many thousands of years. They are conditioned by the large-scaled global factors, for example, coming or retreat of glaciers, historical settlements of wood species and etc.

Singenetic species changes take place on new areas, for example, when new alluviums appear and then are overgrown in flood plains.

Ecogenetic successions are widely-spread and take place when one species are changed by others due to the change in environment. Exactly these changes have decisive importance in the forestry.

12.3. The change of a pine by a birch and aspen

The change of a pine by a birch and aspen usually occurs on fresh, relatively fertile soils:

– after fires;

– after total cutting of pine and pine-deciduous stands.

The planted areas after cutting and sites of a fire by cereals (accompanying by their ramping) prevents the pine renewal.

Pine shoots, as well as birch and aspen shoots, are not afraid of the temperature oscillation and sun radiation excess (light frosts and the heat of the sun). But the seed productivity of a pine is rather lower than of a birch or an aspen (1 million and 300 millions of seeds for a ha correspondingly). We should also take into account, that the seed production of a pine is characterized, as it was already mentioned, by the expressed periodicity (a seed year can occur once in 3–5 years when birches and aspens produce abundant amount of seeds every year).

Abundant productivity, the capability to propagate vegetative and intensive growth promote fast replanting by birches and aspens. Their canopy is closing and the shoots and self-seed crops of the light-requiring pine are found there.

A pine can be grown over by birch (aspen) or a birch (aspen) forest can be formed with a little per cent of pine. As birch (aspen) is disappearing, pine is gradually increases its participation in the stand structure and can take a prevail part.

Pine is often replaced by birch, which is closer to its nature than aspen. As the importance of the pine timber is very high, the change of pine by birch is undesirable. However, the necessity for the birch and aspen timber exists and, in addition, this change increase soil productivity.

As a dry pine forest or a bog doesn't correspond to the ecobiological features of a drooping birch and aspen under these growth conditions these species do not change pine.

12.4. The change of pine by spruce and spruce by pine

Pine is replaced by spruce on fresh, fertile soils that are best suited for growing spruce.

The undergrowth of shade-tolerant spruce appears under a canopy of photophilous pines and develops well. Here it is protected from frost, sun and it has sufficient moisture and nutrition. Young spruce grows to the second story, goes into the first story, coexists with pine for a long time, provides the seed, and then displaces the pine. However, in dry, sandy soil shade tolerance spruce can't be replaced, because edaphic conditions do not correspond to ecological and biological needs of this species.

According to I. S. Melekhov, on the north of the country the change of pine by spruce also occurs as a result of fires that destroy pine on dry land and getting around wet depressions occupied by spruce forests. Subsequently, fire-damaged pine forests can be renewed by spruce as a result of seed dispersal from spruce forests saved in the lowlands areas. The question arises about the protective cover for the younger generation of spruce forests, suffering from sun and frost.

In this case, this function is performed by the remains of plants that remained after the fire.

The change of pine is a natural phenomenon, but it occurs only when the ranges of these species are similar.

Due to the ecological and biological characteristics the undergrowth of photophilous pines can't exist under a dense canopy of spruce.

Therefore, the change of spruce by pine is only possible in case of adverse influence of biotic and abiotic factors on spruce stand (ground water lowering caused by drought, the attack of the harmful insects, fire, windfall, clear felling), which may be completely destroyed. Features of the microclimate of open spaces are not typical for spruce forests and common for pine forests. The destruction by fire of the living ground cover (grasses and mosses) also favors the regeneration of pine.

12.5. Change of spruce by birch and aspen and the replanting by spruce

Change of spruce by birch and aspen occurs, as in the previous case, when a forest environment changes, which has become unfavorable for spruce regeneration under the influence of abiotic and biotic factors, i.e. when a spruce stand disappear and cutting occurs.

The younger generation of hardwood forms a closed canopy very quickly (7–10 years) where forest environment again begins to regenerate. Forest environment is favorable for the development of the young generation of spruce, emerging under the cover of aspen and birch trees as a result of plaque seed of forest border located near felling.

Shade-tolerant spruce undergrowth is protected by canopy of small-leaved species from the adverse effects of the environment.

At this stage of life spruce needs the protection of aspen and birch. There is a proverb: “Aspen is the babysitter of spruce”.

By the age of 40–50 years aspen and birch reach the height of 20–25 m and almost stop growing. There is natural thinning. Spruce by this time starts grow intensively and goes into the second story. To 80–100 years deciduous species, as less durable, dye, and spruce takes their place.

With timely intervention of foresters, this successional transformation process of deciduous forest to spruce-deciduous and spruce forest accelerates.

According to its ecological and biological properties, in particular the requirements to soil, aspen is closer to spruce than birch, that's why spruce stands are more sustainable.

Spruce is a more valuable species than birch and aspen, and so seeds with these small-leaved species are undesirable. However, they have a positive effect on the soil: reduces its acidity, improves chemical composition, changes the species composition of bacteria, litter becomes more friable.

12.6. Change of oak by other species and its regeneration

Natural regeneration under the canopy of oak plantations is insignificant, due to its light-demanding properties. Oak succession occurs as a result of clear cutting. The acorns seedling of felling is impossible, whereas plaque of seeds of other species occurs throughout its territory. Coppice sprouting oak may not happen because of old age, cut down trees.

Clear-cuts are often planted by birch, under the canopy of oak which grows slowly or doesn't grow of the difficulty in distributing acorns.

In a similar way oak is replaced by aspen. Moreover, it is actively renewed not only by seed, but root suckers and in the first year after felling it will spread almost over the entire area, which makes it impossible for oak to grow beneath its canopy. Pure aspen forest stand is formed.

The interrelationship of oak and lime is an important issue of silviculture. Being shade tolerance lime grows under the canopy of oak and plays the role of regrowth, helping to cleanse its trunks from twigs and accelerate growth. After the felling of mixed lime-oak forest, lime grows quickly, forming further a closed canopy. In such circumstances, the oak is not again renewed.

After felling not only oak but also hornbeam, maple, elm, and ash can't grow there. In all cases, the preferred tree planting should be given to the oak tree.

The general trend in the relationship between oak and spruce is characterized by a gradual change of oak by spruce. The position of the oak to spruce especially weakened to the North in harsher climate conditions (see unit 9.6).

The peculiarity of the relationship of oak and pine trees is as follows. Pine can't grow under the canopy of oak due to the existing dense litter from its leaves.

Oak grows under a pine canopy quite successfully. It may first reach the second and then first story. This process proceeds most actively on fertile soils.

The restoration of oak after changing by small-leaved species is possible, although it requires high costs of labor: the landing (planting) during reconstruction, with frequent thinning and other forest management activities (promotion of natural regeneration).

13 MIRE AS A NATURAL PHENOMENON AND OBJECT OF STUDY

13.1. Basic concepts of mire science

Strange as it may seem, there is currently no definition of a mire in national literature as the main concept of mireland science in eastern Europe, which would be widely recognized and accepted by the representatives of all the scientific fields involved in its study.

This paradoxical situation has several reasons. The main reason is the apparent complexity of mire ecosystems. It is quite clear that specialists of different scientific disciplines (see unit 1.2) while studying this unique biogeocenotic natural object focus only on some particular aspects that are of specific interest to a particular branch of science.

For example, botanists concentrate on flora and vegetation (V. B. Bogorad, 1963; N. F. Reimers, 1991). In botany every mire is characterized by certain flora and vegetation type. The total distinctive feature of the mire as the ecosystem is a dominance of plants that live in permanent or intermittent stagnant or relatively flowing overwatering. At the same time, some specialists overlook the most important component of wetlands, it is peat, and hydrology, geology and geomorphology are also not fully considered.

According to agrologists, "the mire is an area of land with periodic or constant excessive hydration where peat forms and accumulates" (I. V. Sokolovsky, 2005, p. 240). In this definition nothing is said about the vegetation.

Geologists also understand a swamp as "an excessively wet land area that often contains a peat story covered with specific wetland vegetation varying in different climatic zones" (Dictionary of geology, 1978, p. 83). It should be noted that various types of mires which are located in close proximity to each other and differ greatly in vegetation cover may be formed in a single climatic area.

Within the meaning of hydrologists, "a mire is an excessively wet land covered with a layer of peat" (Water Code of the Republic of Belarus, 1998, p. 1). As one can see, the emphasis is made on over wetting certain land areas when defining the term "mire" in hydrology. What is more, special attention is drawn to the moisture regime, as it is "abundant and low flow" (General hydrology, 1984, p. 344).

The analysis of modern scientific and educational literature indicates that the concept based on landscape and geographical position is prevailing in the definition of the mire nowadays (V. P. Denisenkov, 2000; V. M. Podolyako et al., 2003; T. I. Kukharchik, 1996).

In this case, the mire is described as an element of the landscape which is formed according to certain geographical principles, provided that its main features are abundant moisture, the absolute dominance of hydrophilic and hydrophytic vegetation, as well as a mire type of soil formation, the key point of which is the peat accumulation. The definition of the mire as a biogeocoenosis corresponds to the above approach. Consequently, in the same way as for the forest ecosystem, each of the mire components is closely related to all the other components; it has a particular impact on such components and on the environment, as well as suffers from responses.

For example, by definition of N. I. Pyavchenko (1985, p. 6), "a mire, or a mire land, is an ecological system which is originating and developing under conditions of both continuous or periodic abundance of moisture and oxygen deficiency characterized by a slow substance exchange and, as a rule, by accumulation of peat".

As compared to various approaches to the mire definition by representatives of different fields of science, its definition in accordance with GOST 179-73, p. 192 seems to be the most succinct, concise and corresponding to the conditions in the northern hemisphere, as will be shown below: "A mire is a natural formation taking up a part of the land surface, which is basically represented by peat deposits saturated with water and covered with specific vegetation".

There are a number of other important concepts of the mire Science. As noted above, a specific soil-forming process that results in formation of peat, i.e. "an organic rock formed in the result of dying-off and partial decay of mire plants under high moisture and lack of oxygen, as well as the content of no more than 50% of components on the dry matter basis" (GOST 21123-85) is typical for mires.

We emphasize that formation of peat is typical for temperate and cold climates where there is excess moisture and decomposition processes of the organic matter entering the soil surface in the form of plant litter are slowed down. However, there is often no peat in mires of steppe and desert zones, in tropical and coastal mires, where high temperatures, dry air or water salinity activate rapid decomposition of plant residues. Thus, the peat mires is only a special case of the mire as a phenomenon of nature, though it is rather a common element of the landscape, especially in the northern hemisphere.

Certain types of peat are formed depending on vegetation cover. If conditions of the environment change, a change of plant communities will take place which, in turn, will lead to a change in peat type sediments.

A peat type is "the lowest taxonomic unit of the peat type classification characterized by a certain, sensibly constant combination of prevailing residues of certain types of peat-forming plants. The type of peat reflects the initial phytocoenosis and formation conditions; it is also characterized by a more or less certain quality indicators" (S. N. Turemnov et al., 1977, p. 6).

In the process of peat accumulation a peat deposit is formed which is "natural bedding of certain types of peat from the surface to the mineral bed of the peat deposit or underlying lacustrine or organic-mineral deposits" (GOST 21123-85).

An industrially exploited peat deposit is called a peat field, i.e. "geological formation consisting of layers of one or more types of peat characterized in their natural limits by excessive moisture which may be subject to industrial or agricultural use by size and reserves" (GOST 21123-85).

The thickness of the peat deposits of 0.70 m in the undrained condition is the minimum value, which allows for industrial development (Geology dictionary, 1978; V. P. Denisenko, 2000).

The term peat bog is commonly used in everyday life and popular literature. According to N. I. Pyavchenko (1985, p. 9), it is "especially applicable to mires which have been drained naturally when they lose features such as excess moisture and specificity of the vegetation cover".

There are known cases, for example, when mires are drying up under the influence of natural draining, but more often under the influence of artificial reclamation. In such a case, the ability of transformed mire ecosystems to accumulate peat is lost along with the loss of their specific feature – excess moisture. The type of vegetation is radically changed. Hydrophilic plants eliminate, while forest, meadow and even ruderal (garbage) and segetal (weeds) plants not typical for mire appear, provided however that the power of previously accumulated layer of peat in the peat bog – and not in the mire any more (!) – though not increasing but also not significantly reducing during quite a long period of time.

There are three main types of mires depending on the nature of feeding and special features of vegetation, as well as spatial arrangement, namely:

– raised bog – ombrotrophic, oligo- or dystrophic;

– transitional mire or bog – mixotrophic;

– fen – minerotrophic, eutrophic.

Fens include mires feeding on ground water close to the soil surface that is rich in minerals. They are generally located in lower parts of the relief. As compared with the other types of mires, the ash content (the content of non-combustible part remaining after calcinations of organic materials at a temperature of 500–850°C) of the upper layer of peat is increased and usually equal to 9–12%; the degree of the peat decomposition varies within 30–50% (L. P. Smolyak, 1969). The most common swamps are forest, shrub and grass low-moor swamps characterized by the intense variety of eutrophic species. The distinctive feature of low-moor swamps is the absence of sphagnum or a minor presence of eutrophic representatives of Sphagnaceae Dum. only: Sphagnum riparium (*S. riparium* Aongstr.), Sphagnum squarrosum (*S. squarrosum* Crome), Sphagnum teres (*S. teres* (Schimp.) Aongstr. Ex Hartm), sphagnum obtusum (*S. obtusum* Warnst.), Sphagnum girgensohnii (*S. girgensohnii* Russ.), etc.

Unlike low-lying fens, raised bogs are mainly fed using precipitations extremely poor in mineral elements, and therefore the total mineralization of bog water is 10–30 times lower than the one of fens (N. I. Pyavchenko, 1985). The ash content of the upper layer of bog peat is 2–4%; the degree of decomposition is 5–20% (L. P. Smolyak, 1969). They are usually located at heighten areas of watersheds but initial phases of formation are generally related to lower relief elements. In the process of development, the surface of bogs is gradually becoming convex. Insufficient feeding conditions provide for a very poor species composition of vegetation. The main types of living ground cover are sphagnum mosses but of oligotrophic group only: Sphagnum magellanicum (*S. magellanicum* Brid.), Sphagnum angustifolia (*S. angustifolium* (C. Jens. Ex Russ.) C. Jens.), Sphagnum fuscum (*S. fuscum* (Schimp.) Klinggr.), Sphagnum rubellum (*S. rubellum* Wils.). The tree story is represented by a single species – a pine tree in a depressed state. Low shrub communities are not developed and can be presented by a fewspecies of dwarf birch (only in the northern part of the country) that is listed in the Red Book of the Republic of Belarus (Red Book of the Republic of Belarus, 2015)

For transitional mires, conditions of mineral feeding and vegetation cover have intermediate values between fens and raised bogs. For example, a tree species is usually represented by the pine which is an edificator of bogs, but there is also a quite significant admixture of white birch growing in fens. Another type of birch, artic dwarf birch (*B. schrank* Humulus) can be rarely found on transitional mires (more often in the Northern part of the country). This type of tree was included for the first time in the last (fourth) edition of the Red Book. Field layer is mostly represented by sedges (*Cyperaceae* Juss.) and is strongly reminiscent of fen swamp plant communities, although it is less abundant and developed. In transitional mires one may often see some shrub inclusions: blueberry, cranberry, Chamaedaphne calyculata (*Chamaedapne calyculata* (L.) Moench) or Andromeda polifolia (*Andromeda polifolia* L.) typical for bogs; both sphagnum mosses typical for fen mires and Bryales (*Bryidae*) typical for fens may be found under the sedge story and in communities of shrubs. The ash content of peat is 4–9%; the degree of decomposition is 15–35% (L. P. Smolyak, 1969).

It should be noted that the division of mires into three main types (fen, bog and transitional) is adopted by both researchers and practitioners of various fields of science and industry, however, by no means covers all their great variety. The list of swamp types is quite significant, for example, polygonal swamps, frost mound swamps, bogs, spring water bogs, slope swamps of "cloak" swamps, flooded areas, etc. (V. P. Denisenkov, 2000; N. I. Pyavchenko, 1985; J. Paal, E. Leibak, 2011).

13.2. Mire formation factors

Mire formation is a complex process involving different aspects, such as biological, physical, chemical, geographical, which is sometimes caused by human activities and occurs in warm and cold climates, in the plains and highlands, as well as in poor and rich soils.

The most important factors of the swamp formation are as follows:

1) climatic;
2) hydrological;
3) geomorphological;

4) soil and geological;
5) phytocenotic;
6) anthropogenic.

1. Climatic factor. The process of the swamp formation is more active in areas with wet and cool climate. Peat bogs are very rare in areas where dry and much less hot weather is prevailing.

The most important elements of the climate facilitating formation of swamps are precipitations and temperature which determines the intensity of evaporation and, ultimately, the excess or deficiency of moisture in the soil. The temperate climatic zone of the northern hemisphere is characterized by stable excess soil moisture, which is favourable to the development of the swamp formation process.

2. Hydrological factor. The hydrological factor is closely related to the climatic factor: in addition to the total excess moisture, the level of groundwater is usually located close to the soil surface, which activates the process of water logging.

3. Geomorphological factor. There is a clear dependence of the confinement of large areas of swamp systems to topographic lows, so-called depressions. Tectonic movements of the earth's crust contribute to the waterlogging process resulting in the lowering of the land surface. However, according to L. P. Smolyak (1969), nowadays there is an attenuation of swamp formation processes in Belarus, one of the reasons of which is the very tectonic uplift of the land surface.

Lowlands or slightly hilly terrain areas have a high degree of waterlogging. In contrast, hilled landscapes, as well as dissected relief landscapes and mountainous areas are characterized by the absence or very low representation of swamps.

4. Soil and geological factor. Geological origin of rocks affects the nature of the swamp formation process, which turns out to be in the role of underlying beds for swamps afterwards.

On poor sandy podzolic soils, the most common are raised bogs, the basic tree species on which is the Scots pine while the main peat-forming vegetation is sphagnum. At the same time, deposits of clays and clay loams cause generally predominant formation of fens and transitional mires, including a much more intense diversity of all plant species than those in the bogs.

5. Community factor. Occurence of various types of sphagnum mosses having minimum feeding requirements contributes to acceleration of the process of waterlogging of poor sandy podzolic soils. Green mosses (Hypnaceae family (*Hypnaceae* Schimp.) and Hylocomiaceae (*Hylocomiaceae* (Broth.) Fleisch.)) typical for forest communities are more demanding to the soil fertility and so eliminate, while sphagnums which are replacing them are accumulating moisture in very significant quantities and gradually becomes the main producers of organic matter that forms raised bogs.

The facts of fast waterlogging of cut-over and burnt-over areas are known from forest practices. It is connected to the lack of canopy of actively transpiring woody plants resulting in the significant decrease of the consumable item (physiological evaporation) in the water balance of specified areas.

Although forest vegetation especially woody one has a positive influence on water budget input (detention of snow and its equal distribution under the shadow of the dominant canopy; the lengthening of the period of snowmelt; smoothing of the amplitude of the temperature regime; reduction of surface runoff due to the nature of the microrelief, the presence of bedding and lower layers, as well as less soil freezing; reduction of physical evaporation and others), in general, we can see its restraining influence on the process of bog formation.

6. Anthropogenic factor. Sometimes the formation of wetlands results from human activities, leading to the modification of the hydrological regime, such as creating artificial reservoirs, dams that cause an increase of groundwater levels in adjacent areas. The above mentioned bogging of slashes and burnt areas are influenced by phytocenotic factor but human activity is often the reason of it. And even waterlogging caused by flooding as a result of beaver activity, also has indirect anthropogenic origin because the population of this species has exceeded the optimal parameters but is not artificially regulated.

The bog formation process cannot be caused by only one of the mentioned factors.

13.3. Methods of mire development

There are two ways of mire development:

1) in the process of peat formation in water reservoirs (terrestrialization);

2) in the process of mineral soil waterlogging (paludification).

1. Peat formation of water reservoirs occurs, as a rule, in the absence of water flow or if the flow is very weak. Approximately 8–10 thousand years ago, the glacier left a considerable number of lakes of different size and depth and other different water bodies (oxbows, backwaters), on the banks of which herbaceous vegetation appeared and began to grow. The formation and accumulation of peat occurs in the process of dying and incomplete decomposition of vegetation.

It should be noted that the process of peat formation occurred not only in the early post-glacial period, waterlogging of lakes occurs also at the present time. For example, during several decades as a result of eutrophication lowland bog may appear on the place of a shallow lake.

Waterlogging occurs in two ways depending on the bottom topography:

a) overgrowing from the bank;

b) floating overgrowing from the bank.

The overgrowing from the bank is typical for shallow pools with flat bottom. Any water reservoir has two main components of wildlife: phytocenosis and zoocenosis. In this regard, deposits, gradually filling the reservoir, consist both of higher plants residues, this is peat, and of microorganisms residues (phyto- and zooplankton), this is sapropel.

Thus, during waterlogging two new species of organic matter are formed in the result of dying microorganisms of sapropel, which is usually in direct contact with the swamp and dying of aquatic vegetation typical to different depths, accompanied by the formation of peat deposits (fig. 13.1).

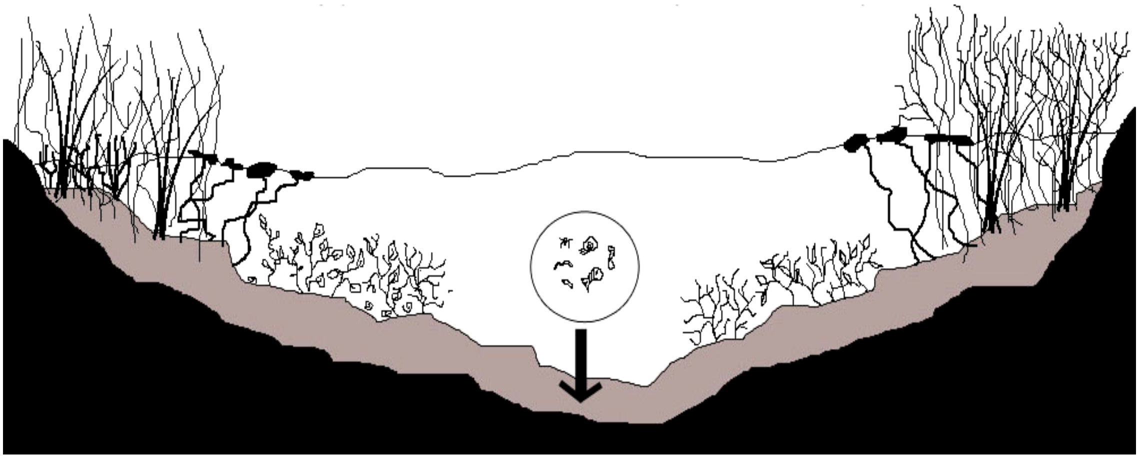


Fig. 13.1. The process of waterlogging (terrestrialization)
(figure by S. A. Evseenko)

The accumulation of plant and animal residues leads to a decrease of the depth of the shallow lake and the gradual displacement of vegetation zones from its periphery to the center. As it can be seen, two processes related to vegetation and wildlife run simultaneously: overgrowing of the reservoir and its peat formation. There comes a time when a lake disappears and becomes replaced by fen mire. It has a saucer-like surface: edges have the form of the coastline of the former lake, elevated above the central part, located in the lowlands. The surface topography of the bog which was formed as a result of overgrowing from the bank, follows the surface of the lake basin, but covered with a layer of peat formed during the time of turning the lake into a swamp.

Floating overgrowing from the bank is typical for ponds that are deep near the bank. As a result, typical plants of shallow waterlogging, such as sedges, wood bulrush (*Scirpus sylvaticus* L.), common reed (*Pragmites australis* (Cav.) Trin. Ex Steud.), broadleaf cattail (*Typha latifolia* L.) can't take root and begin the formation of a coastal community. The process of overgrowing is changing. From entwisted roots and new shoots (such as marsh cinquefoil, bean trefoil (*Menyanthes trifoliata* L.), marsh Calla (*Calla palustris* L.)) a kind of floating carpet, so called floating vegetation, begins to form. It is connected with the bank and gradually with the development of plant communities comes from the periphery to the center of the lake (fig. 13.2).

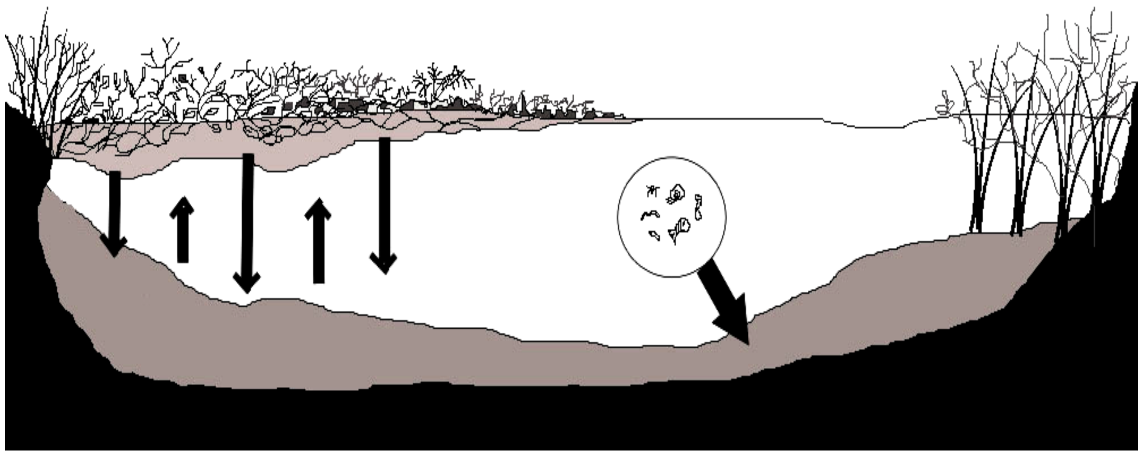


Fig. 13.2. The process of shallow lake terrestrialization (floating overgrowing from the bank) (figure by S. A. Evseenko)

There is an accumulation of the remains of dead plants (like in the previous case it was preceded by the accumulation of sapropel), as a result, floating vegetation mat grows not only in the horizontal direction, gradually reducing the water surface, but also vertically downwards. Thickness and induration of the floating vegetation mat create the preconditions for the appearance of other plant species. The next wave of "settlers" is represented by sedges, horsetails (*Eguisetaceae*), bur beggared (Bidens tripartita L.), water plantain (*Alisma plantago-aguatica* L.), cowberry, almond trifoliate, Calla marsh. Subsequently, depending on the water hardness, sphagnum or hypnum mosses (*Hypnales*), pod grass (*Scheuchzeria palustris* L.), typical wetland shrubs and even stunted willows such as a roundear willow appear. As a result of further vertical growing, floating vegetation that consists of brown silt (mutta) descend to the bottom of the reservoir. It gradually shallows and the water layer between the lower part of the floating vegetation and a layer of silt reduces until its complete disappearance (see fig. 13.2). In the place where the lake was, like in the case of overgrowing from the bank, lowland fen forms, and it has a similar form of a concave meniscus.

2. The main reason of waterlogging of mineral soils, represented by soils of dry land (the so-called upland habitats) is the change in water-air regime of the upper horizons that causes waterlogging.

The incursion of swamp on the land can be caused by different types of water:

a) alluvial (flood);

b) ground;

d) atmospheric.

The process of waterlogging by alluvial waters is more active in floodplains. However, phytocoenotic structure of wetland communities varies significantly depending on the temporal regime of excessive moisture, both due to the characteristics of the flood, and the presence and depth of the location of impermeable horizons. So, in the short-term flooding forested wetland communities (the black alder, downy birch) are the most common. In case of prolonged inundation of the floodplain and pre-terrace space there is domination of phytocoenoses formed by herbaceous vegetation, mainly sedge, common reed, broadleaf cattail, horsetail and other, along with willow, which are significantly more resistant to prolonged flooding than alder.

As it was mentioned, alluvial waterlogging is typical for floodplains and connected with flood water, and groundwater waterlogging occurs in low places on adjacent terraces, and low places near lakes, ravines and hollows. In all cases the excessive moisture of the upper soil horizons is caused mainly by groundwater which may significantly differ in chemical composition.

With the increased content of mineral nutrients (hard water waterlogging), there appear lowland forest swamps with the transition to the wetland forests. In different proportions there grow black alder, birch, spruce and a small number of pine, which need good mineral nutrition. The possibility of the formation of pure stand and downy birch stands is not excluded.

When groundwater is characterized by rather low concentration of mineral elements (soft water waterlogging), ecosystem succession is directed to the occurrence of transitional sedge-sphagnum bogs. Downy birch may appear at their edges, but most often unproductive pine-birch or pure pine mixed forests are formed.

Waterlogging of upland habitats by atmospheric waters occurs as a result of overwatering of the upper horizons by rainfall.

The following main factors providing this type of waterlogging are distinguished:

1) low topography elements;

2) impermeable horizon that consists of clay and loam, located at a relatively shallow depth;

3) low nutrient status of the soil.

The first two factors of the swamp formation process are quite clear and need no explanation.

In regard to edaphic (nutrient status) factor, it should be noted that in areas characterized by the predominance of precipitation over evaporation (humid climate), sandy soils and sandy-loam soils during leaching (leaching of various soluble substances by downward or lateral current soil solution) become less fertile and more acidic. In these conditions those plants have the advantage that can obtain nutrients from the precipitation, especially in atmospheric dust. These species are oligotrophic, acidophilus, i.e. able to grow in conditions of high acidity of the soil solution, and hygrophilous sphagnum mosses.

At the same time more demanding to edaphic conditions species of forest and meadow communities eliminate gradually. Sphagnum cover that replaces them, due to the peculiarities of morphology and nutrition component types, absorbs the amount of atmospheric water that is ten times greater than the amount of dry mass of plants. As a result of increased accumulation of moisture swamp begins to form which leads first to dramatic changes in the ecosystem, and subsequently, with the development of the swamp ecosystem, to the change of microlandscape and, consequently, environmental conditions not only directly in the area occupied by marshy tracts but also in surrounding areas.

13.4. Stages of mire development

As it was mentioned above, during waterlogging of lakes there appears low-lying fen with concave surface, predominantly covered with herbaceous vegetation. During its further development there occur peat accumulation and condensation, the surface becomes flat.

The shape of the low-lying mire surface that has upland origin undergoes the similar changes. In the beginning it has concave surface, but with the development of vegetation and the peat accumulation it gradually gets a flat shape.

If watering is temperate, there are good conditions for forest vegetation to appear in the mire. If watering is heavy, there appear grass, moss or grass-moss communities.

Thereafter, during lake waterlogging or upland waterlogging, in connection with the ongoing flattening of mire surface, the conditions of nutrition change and cause conversion of vegetation, which leads to appearance of transitional mire. The roots of plants, especially in the central part (where the thickness of peat is the most considerable), can't contact with the mineral bed close enough to get more abundant nutrition. Enriched with mineral elements deluvial (flowing down from the slopes of the surrounding upland) waters usually don't reach the central part of mire, and that's why nutrition here is provided only due to precipitation.

As a result, there is a gradual change of plants demanding mineral nutrition such as sedges, reeds, and other herbaceous plants by sphagnum mosses. Lowland fen is changed by transitional.

The first vegetation that appears in the central part of the bog is sphagnum mosses. Here they begin to transform the environment, creating conditions for increasing peat reserves. In particular, under the conditions of a gradual increase of acidity, plant residues decompose slowly due to the peculiarities of the chemical composition. As a result, due to accumulation of peat a bulge appears in the center of the bog, it results in further isolation of the root systems of plants from the mineral soil.

At the same time, more favorable conditions for the activity of the microorganisms which decompose plant residues are created on the periphery of the mire, where the surface runoff waters enriched with nutrients and oxygen come from the surrounding uplands. Peat formation slows down here.

Due to the ongoing accumulation of peat in the center of bog, there is further change in topography and vegetation, it becomes more oligotrophic. Raising relief (the excess over the periphery part can be up to 6 m (V. S. Geltman, 1982)) affects the hydrological regime: the flow is increasingly directed from the center to the swamp edges. The topography with time transfers from low to high, gently and plane convex forms of the raised bog (fig. 13.3). Most significantly, there is an increase of its area, along with the mire ecosystem, evolving from lowland in transitional and raised, grow and become more autonomous and less dependent on conditions existing on the adjacent territories, such as forest or grassland ecosystems. Adjacent to the marsh ecosystem areas have its positive effect, as will be discussed later in this chapter.

Thus, mire undergoes the following stages:

1) waterlogging of reservoirs, resulting from the overgrowth of vegetation from the bank; the waterlogging of mineral soils;
2) stage of fen;
3) stage of transitional mires;
4) stage of low raised bog;
5) stage of high raised bog;
6) stage of gently convex bog;
7) stage of plane convex bog.

The surface of the central parts of arrays of raised bogs and the upper parts of their slopes is often divided into uplands: ridges, hillocks, mounds, and lowlands: hollows, fens, small lakes, and lakes. The range between uplands and lowlands makes up to half a meter.

On the uplands hydration is reduced, and there are plant communities, represented by pine, shrubs, *E. vaginatum* L., and less hygrophilous sphagnum: magellanicum, brown, angustifoliate.

Flat lowlands are occupied by sphagnum: Baltic, angustifoliate, bog rosemary, moorberry, *E. vaginatum* L.

In the hollows, fens more hygrophilous sphagnum are widespread: cuspidate, Baltic, magnus, together with pod grass, mud sedge, *E. vaginatum* L.

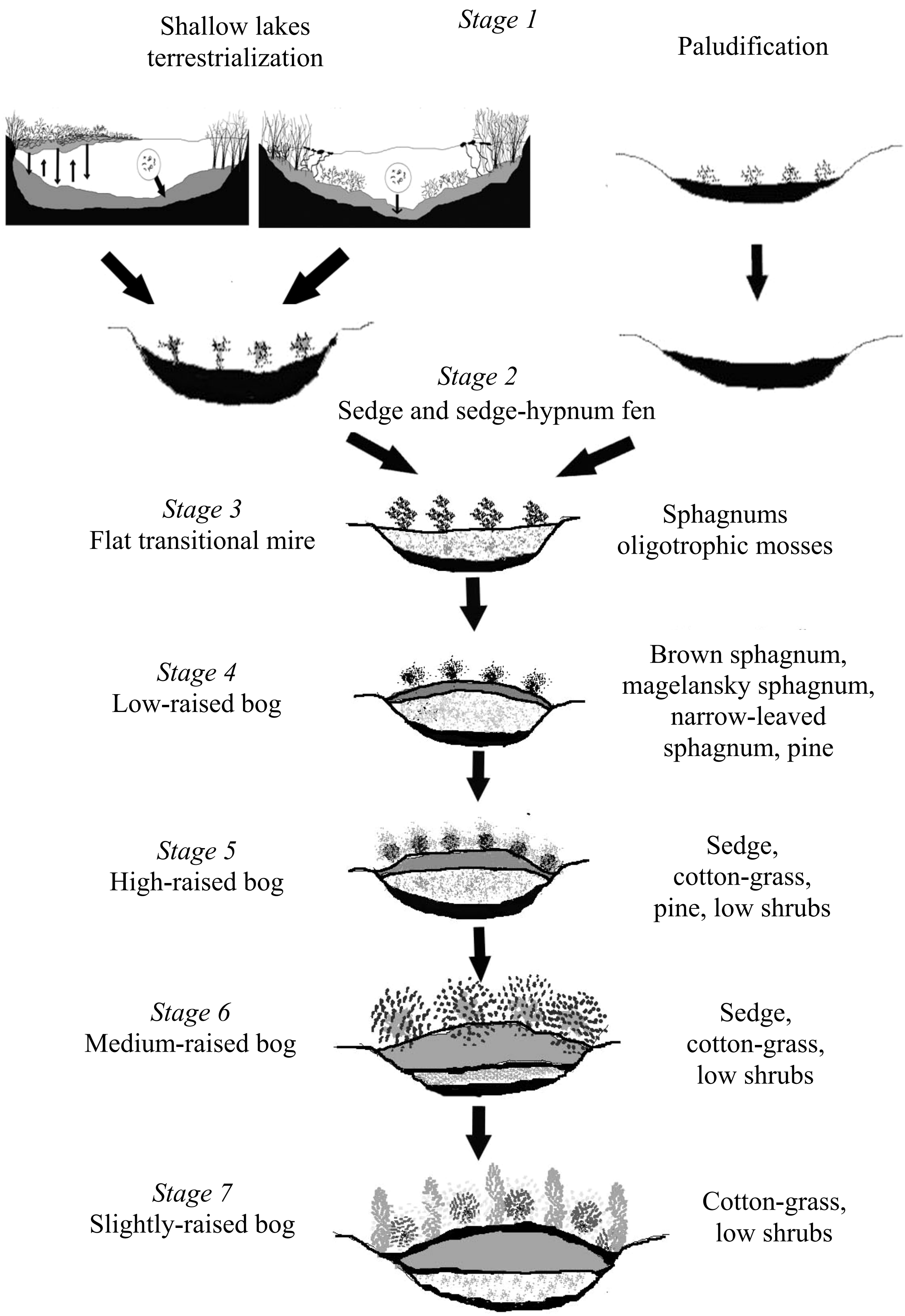


Fig. 13.3. Stages of swamp development (V. P. Denisenkov, 2000)
(figure by S. A. Evseenko)

In the result of stable combination of certain types of the above mentioned relief microforms, there are following types of wetland complexes: ridge-hollow, ridge-pool let and ridge-lake. Ridge-hollow type is typical for gently convex stage and noted for parallel strands, elongated perpendicular to the slope. For ridge-lake let and ridge-lake types, specific to plane convex stage, this feature is not typical.

The reasons of the formation of hollows and ridges are not fully determined, but it is believed that their appearance precedes the climax stage of development of oligotrophic bogs. Gradually hollows join and turn into lake lets and lakes. Their drainage capacity increases, which negatively affects the condition of the main peat former – sphagnum mosses, notable for their hydrophilicity. They are replaced by lichens, forming a relatively minor phytomass. Peat accumulation stops, swamp regresses.

13.5. Environment forming role of mires

Environment forming role of mires appears in a number of interrelated functions some of which are typical only for this type of ecosystem. The functions are the following:

1) accumulative;
2) intercirculative;
3) biological;
4) landscape;
5) gas regulating;
6) geochemical;
7) hydrological;
8) climate-regulating.

1. Accumulative function involves formation and accumulation of peat, which is a product of incomplete decomposition of the remains of dead mire plants. At the same time, there is an accumulation of solar energy enclosed in peat. Although peat refers to renewable natural resources, the rate of accumulation by wetland ecosystems is very low and makes up only about one millimeter per year. In one thousand years there can be peat accumulation capacity of about one meter. Before large-scale industrial operation of peat was launched (1960), our country's peat reserves were estimated at 5.7 billion tons.

2. Accumulative function is closely related to intercirculative one, the essence of which is the transfer of carbon, nitrogen, and other elements of the biological cycle of substances in geological one.

Decomposing in the active peat-forming layer (most favorable to the living microorganisms), dead marsh plants deposit as peat partially. Every year similar deposits occur. This leads to the situation when during thousands of years more and more layers of peat move to the lowest part of the peat deposits, where the degradation processes stop due to the anaerobic conditions. This is a kind of conservation of elements of organic origin, which from biogenic cycle turn into geological one. Further transformation of the formed organic matter in brown and hard coal occurs in accordance with the laws of Geochemistry.

3. Due to extreme environment conditions, bogs are characterized by relatively poor species range. That's why mires are unique deposits of genetic pool of specific representatives of flora and fauna. They include sphagnum species which are the main peat-forming species and play the main part in habitat forming role of wetlands.

4. The essence of a landscape function is the formation of unique wetland landscapes, sometimes formed by all three types of mires. Combined with the landscapes of adjacent areas, they form several types of complexes: lake-mire, floodplain mire, forest-mire, meadow-mire and complex. The latter are represented by at least two of the above types of systems and are the most important for tourism.

Another type of complex is wetland landscapes which are subjects to active anthropogenic impact in the process of economic development, accompanied by reclamation and further exploitation of peat deposits. These complexes are used for growing agricultural crops or forest regeneration, which is not always successful.

The first four functions are essential and can be realized only under conditions of the existence of wetlands.

5. It has already become a popular expression that "mires are the lungs of the planet". In the process of photosynthesis and production of organic matter by wetland plants, enormous amounts of carbon dioxide are taken from the atmosphere, and also an equivalent amount of oxygen is liberated. The carbon is deposited and stored for thousands of years in the form of peat and coal. By some estimates, its amount in the mires of the world is equal to the amount of carbon contained in the surface air. By the mechanism of action a gas regulating function is similar to the accumulative and intercirculation function.

6. Peat is an excellent adsorbent. When peat accumulates chemical elements coming from alluvial, diluvial and ground water, precipitation, atmospheric dust and air pollutants, it prevents their further spread. Geochemical function can be regarded as a kind of accumulative.

7. The global problem of deficit of fresh water determines enduring importance of wetlands that contain 10% of global reserves.

Rivers originating in the mires don't have a catastrophic spring floods after snowy winters. This is because their flow is mainly controlled by peat and sphagnum deposits, like a sponge accumulates and retains moisture and gives it up gradually. This provides a natural regulation of the outflow of surface and ground water on area not only occupied by marshes, but also in adjacent ecosystems, including agricultural landscapes.

Hydrologic function is directly related to geochemical and accumulative. Peat deposit, moss mat ("sphagnum sod", according to the expression of L. P. Smolyak (1969)) and the actual cover, especially well-developed on raised bogs, adsorb dissolved chemical elements, compounds, solid particles and contribute, thus, to its quality biochemical and mechanical cleaning.

8. Climate-regulating function is derived from the above functions. It implicates the deposition of carbon which reduces the emission of carbon dioxide (CO_2), which is a greenhouse gas. In addition, mires which are huge reservoirs of moisture, like seas and oceans decrease the amplitude of temperature and humidity on occupied and adjacent areas. As a result, there is less extreme drought, spring and autumn frosts, floods, and other undesirable climatic phenomena.

14 CHARACTERISTICS OF MIRE VEGETATION

14.1. Environment conditions of mire plants

There are some distinguishing features of mires as habitats that highlight conditions of growth of marsh plants from different ecosystems:

1) excess of stagnant or low flow moisture;
2) lack of oxygen;
3) good insulation properties of peat and its high heat capacity;
4) lack of nutrient elements;
5) permanent growth of the peat deposits and cover of mosses.

1. High groundwater level caused by the exceeding of the annual amount of precipitation over evaporation, their weak infiltration (flow of rain, melt water from the surface of the soil into its thickness) due to moisture content and water-holding capacity of mosses and peat deposits and its poor water permeability both in horizontal and vertical directions, and some other reasons determine the excess of moisture in the mires.

However, in extremely dry years that are frequent recently, the groundwater level drops sometimes below 1 m, in this case hollows and even swamplands dry up. In high moisture years, the water covers the surface of the mire, especially its edge area bordering with valleys.

Due to the high groundwater level, humidity of the surface layer of peat is usually over 90%, but depending on season conditions it may be reduced to 40–45%.

Large water capacity, poor water transmissibility, and small slope of the swamp surface cause stagnation or weak water flow or the rate of flow (L. P. Smolyak, 1969).

Due to the high water-holding capacity of peat defined by the presence of a great number of hydrophilic colloids even when there is enough water, the roots of the plant can't get it (physiological dryness). In this regard, some researchers consider that bog plants acquire xeromorphic features: leaf blades pubescence, their stiffness, reduction of their size.

2. Stagnant or low flow moisture regime is the reason for the lack of oxygen in the mires. With increasing of the water content of peat, air is displaced from the pores of peat which is accompanied by increasing deficit of oxygen.

The surface (active) layer of peat is the most aerated layer; the thickness of it in the raised bogs, as a rule, does not exceed 0.5–0.7 m, and in the low-lying fen reaches 1.0 m. In the active layer aeration is increased during temporary drying out of peat which leads to the activation of the decomposers and increases the decomposition of plant residues.

The roots of plants, live microorganisms and invertebrate animals are found in a narrow active layer of mires. Here, water from atmospheric precipitation is absorbed, stored, filtered; then it is absorbed by plant roots, and the process of peat formation occurs.

In the raised bogs, characterized by a lack of oxygen, the plant roots can't penetrate deeper than 30 cm. The degree of aeration of fens and transitional mires is higher; the lower limit of the rhizosphere corresponds to the depth of the middle summer groundwater level (V. P. Denisenkov, 2000).

Due to anaerobic conditions and low mineral nutrition, the root system of forest marsh plants has a developed surface structure. They are located mainly in the active layer sometimes in mat and even in a live cover of sphagnum mosses. Pine, for example, has thin ends of the roots that spread over some meters from the trunk and rise up in the search of oxygen; they are located in the moss cover (negative geotropism). According to L. P. Smolyak (1969), pine morphosis in the raised bogs that lies in forming extremely shallow root system increases intraspecific competition, resulting in the occurrence of the understocked tree stands.

Grass marsh plants are adapted to the growth of oxygen deficiency due to certain anatomical changes: a system of air passages and cavities forms in their vegetative body; they are supplied with oxygen diffused from the aerial organs, (wild calla, marsh trefoil, marsh marigolds, marsh cinquefoil, golden saxifrage (*Chrysosplenium alternifolium* L.), etc.).

With increased flow rate, i.e. with increase of the content of oxygen in water (fens, edges of raised bogs), the proportion and growth of woody vegetation increase although the saturation of the substrate with water remains high. It suggests that lack of oxygen in the peat has a greater influence on plants than the excess of moisture in the peat.

3. Among all the kinds of soil-forming rocks in terms of thermal conductivity, peat takes the last place (V. I. Belkovsky, 1982). Thermal

conductivity of peat in bogs and transitional mires is very low if they are characterized by low degree of decomposition (E. M. Volkova, 2009). The specific thermal conditions in mires are created by powerful thermal insulation of moss cover and also by a high heat capacity which is twice greater than that of sand and clay.

Its main feature is that the underlying layers of peat are poorly heated by the solar radiation, as a result the rhizosphere temperature can be 5°C below than it can be at the similar depth in the mineral soil. Therefore, peat soils especially in the bogs are considered to be cold. At the same time, in the period of the great solar activity in the middle of the growing season the mire surface may be heated to 35–45°C that is higher than the air temperature in the atmospheric surface layer.

As a result, the aerial and underground organs are under the influence of significantly different temperature regimes which leads to unequal activity of the processes of transpiration and water absorption. Thus, the increase of the aboveground organs heating causes an increase of the intensity of transpiration, while the absorption of water by roots and rhizomes which are located in the layer of low temperature does not correspond to the physiological level of evaporation. It negatively affects conditions of the plants.

Night frost is a common phenomenon for mires that is also explained by low thermal conductivity. The temperature of low overcooled and upper heated layers does not equalize at night. Therefore, night-time heat loss determined by radiation from the upper layers isn't compensated by heat inflows from the depth of peat deposits.

In spring due to low thermal conductivity of peat, it melts slowly and for a long time roots remain cold unable to function properly. For this reason, spring frosts last for a long time in the mires. In autumn, on the contrary, frosts come early because more dense cooling air masses flow to the depressions occupied by mires. In this regard, they are represented mainly by species able to grow in the conditions of short vegetation period.

4. As bogs receive nutrients mainly from atmospheric precipitation, dust and only partly (on the periphery) from deluvial waters, they are poor in mineral elements. The nutrition of transition and fens is richer. Except the precipitation, they get nutrients from the groundwater, alluvial and diluvial waters. In this regard, raised bog peat contains very little phosphorus and potassium, while the number of these elements is growing up in the fens.

Peat is rich in nitrogen, but its content in an accessible form for plants ranges from 1–2% of the total amount. The lack of available nitrogen is the cause of presence of insectivorous plants in the bogs (sundews species (*Droseraceae* Salisb.)). Other mire types, such as all berry bushes improve nutrition, being engaged in a symbiotic relationship with mycorhizal fungi. As a result, they get essential for life elements in a mycotrophic way.

Thus, in conditions of deficiency of mineral nutrients only the most undemanding to edaphic factor types can grow in the swamps.

All the plants of raised bogs and transitional mires with considerable peat acidity are typical acidophilous plants.

5. A permanent increase of peat deposits is the most active in the raised bogs. During the increase of peat thickness, the mire surface especially in its central part rises, and as a result the roots of plants (woody least) at a certain stage of development of mire ecosystems lose contact with the mineral bed and the surface of groundwater. As a result, the plant nutrition worsens; the mineral elements contained in very small amounts in precipitation begin to dominate in nutrition.

Besides, roots and bottom parts of perennial plants are gradually getting buried under peat layer, moss mat and canopy, which leads to their suppression. Only development of special accommodations allows them to adapt to the factor of continuous peat increment, for example:

1) additional roots are developed from buried parts (subshrubs);

2) tillering nodes are formed on the underground stems that grow vertically, their deposition on a surface (sundews species), further partiation.

For all those reasons, the conditions for the growth and development of mire plants are very specific and to some extent extreme, which, on one hand, narrows the species of floral representation. On the other hand, the diversity of wetland ecosystems due to the different ways of occurrence, temporal dynamics of stage formation and a wide geography allows representatives of different species and life forms to settle in and grow there.

14.2. Main peat forming plants

Peat forming plants are the representatives of species that dominate or dominated in the past in mire plant communities, thus their remains form certain types of peat and predominate in the composition of the peat deposits.

Mire flora includes mosses, herbaceous plants, low shrubs, shrubs, trees, algae and fungi. Sphagnum mosses and sedges are distinguished by phytocenotic abundance and number of species in mire ecosystems.

Sphagnum mosses of white color (sometimes they are called white moss) have a wide range of shades from green to yellow, red, pink or purple and brown.

Closely set sphagnum shoots stick together with twigs collected in bundles, thus, they form a complete carpet sometimes very thick that can support a man. Sphagnum shoots like all the bryophytes don't have roots but due to a large number (up to 75%) of the dead hyaline (aquifer) cells on the surface of the leaves and stems they have a good water capacity. The amount of moisture that is accumulated in cells exceeds the absolute dry weight in 30 times, and about half of it is a weight of water vapor contained in the air.

Sphagnum mosses appearing first on the poor leached mineral soils initiate peat forming process. Sphagnum dies annually in the lower part, forming the mat in the conditions of lack of oxygen and high humidity, and then forming peat, and at the same time grows in the terminate part. During the year, a single plant can grow up to 10 cm more than a half of the phytomass of oligotrophic bogs falls to the share of sphagnum.

Thus, sphagnum mosses are pioneer plants in the peat formation process, they are characterized by exceptionally high moisture content, low demands for water-mineral nutrition, pronounced acidophilism. Mosses play a significant role in the composition of the live-ground cover in the bogs and in the formation and accumulation of peat.

Brown sphagnum, narrow leaved sphagnum, Magellanic sphagnum, reddish sphagnum are widely spread in Belarus.

There are a lot of representatives of the Bryidae mosses subclass, they prefer rich mineral nutrition and therefore they are most lush in fens. They form a cover of green color, although there may be other variations of colors.

Among Bryidae mosses Hypnosia mosses (*Hypnales*) stand out, they are confined to over-moisturized habitats. The most common species are Amblystegiaceae family (*Amblystegiaceae*), in particular calliergon sensivitity (*Calliergon cordifolium* (Hedw.) Kindb.), Collierville pointed (*Calliergonella cuspidata* (Hedw.) Loeske), drepanocladus curved (*Drepanocladus aduncus* (Hedw.) Warnst.), different types of Brachythecium are included in the Brachythecium family, etc.

The subclass of Bryidae mosses includes common forest mosses: representative of Polytrichaceae family (*Polytrichaceae*) – politrix common, species of Hylocomiaceae family – pleurisy of Shreber, Hylocomium brilliant, etc. They grow in swamps, usually along the edges of bogs and on the phytogenic hummocks, in the base of trunks. These types (politrix compressed (*P. strictum* Brid.) should be added) are common at post-fire successions of mire ecosystems.

Species of Hepatic mosses classes are found in the form of small admixture to other mosses, marchantia polymorphic is the most common representative.

Marsh herbaceous plants are presented by typical perennial hygrophytes, which, as noted above, have a well-developed air cell system and long horizontal branching rhizomes. For individual species (sedges, cotton-grass, grasses etc.) xeromorphic characteristics are common, the causes of which are still a subject of scientific debates.

The abundance of herbaceous plants, their species richness naturally decrease from fen to transitional and especially to bog swamps.

Various kinds of sedges that are a part of the Cyperaceae family require good mineral nutrition and have a most phytocoenotic significance in fens. Common cotton grass (*E. polystachyon* (L.) is common in transitional mires, while E. vaginatum L. (*E. vaginatum* L.) is the indicator and the dominant speices for bogs. Both of these species are characterized by a very showy flowering, so called white powder puff that consists of numerous setae that gives a unique flavor to a marsh landscape. One more representative of the Cyperaceae family is woodland bulrush.

The representative of the Poaceae (Grasses) family also grows in the mires, where common reed plays a significant role in formation of peat bogs. Its inflorescence in the form of panicles rises to a height of 3 m or more. There is also another mire plant, the representative of the Cattail (*Typhaceae*) family, a common cattail with beautiful black spadices of right cylindrical shape placed at the crowns of stems. Unlike common reed, this specie does not form communities on large areas.

The Bog bean (*Menyanthaceae*) family is presented by marsh trefoil. It plays a crucial role in the peat forming process and grows mainly in fens, rarely in the transition mires. It has a well-developed air cell system in all organs. Swamp Calla the representative of Areunique (*Araceae*) family has similar anatomical structure and environment.

The Rosaceae family in fens and transitional bogs includes marsh cinquefoil, meadowsweet and water avens (*Geum rivale* L.).

In fens, spore herbaceous plants complex is formed by horsetails and ferns: marsh horsetail (*Equisetum palustre*), water horsetail (*E. fluviatile* L.), rarely forest horsetails (*E. sylvaticum* L.), meadow horsetails (*E. pratense* Ehrh.) and field horsetails (*E. arvense* L.); marsh buckler fern (*Thelipteris palustris* Schott), sometimes lady-fern (*Athyrium filix-femina* (L.) Roth) and male shield fern (*Dryopteris filix-mas* (L.) Schott). Horsetails (except marsh horsetails) and ferns usually grow in woody vegetation areas. There is a high degree of mineralization of bog waters if the vegetation community includes horsetails.

The most important herbaceous peat-forming plant in raised bogs and transitional mires is pod grass, a representative of the Scheuchzeria family. It is found in hollows and/or on the margins of bog pools.

Typical bogs herbaceous plants, members of the Sundew family, the most common of which is round-leaved sundew (*D. rotundifolia* L.) do not play a significant role in the peat forming process. However, since the times of Charles Darwin who first discovered and described them, they are of continuing interest because of carnivorousness that is caused by severe oligotrophic characteristics of bogs. Another noteworthy feature of the sundews, which was mentioned above, is the ability to make permanent new rosettes of leaves on the surface avoiding, thus, the dipping of small plants in the thickness of the peat.

Growing in raised bogs and transitional mires dwarf shrubs of the Erica family (*Ericaceae*) together with sphagnum mosses determine their phytocenotic image. Xeromorphy appears in the following characteristics of leaves: rigidity, pubescence, leather-likeness, ericoidness, evergreening. Not all of mire shrubs are characterized by these features, however, all of them possess at least one of these features. The feature that is necessary for all low shrubs is the presence of ligneous shoots and particularly stem. In the mires they, as a rule, occupy raised landscape elements. They are mycotrophic, oligotrophic and acidophilous plants, valuable food and medicinal plants.

The most common representatives of mire shrubs are marsh tea, sweet gale, bog rosemary, common heather, bog blueberry, bog cranberry, European blueberry, cowberry.

Black crowberry (*Empetrum nigrum* L.) is the only species of the Crowberry (*Empetraceae*) family that grows on bogs and transitional mires of northern Belarus. Shrubs are common in fens, where they are represented by species of the Willow family (*Salicaceae*), such as bay willow, or bog willow, bay willow (*S. pentandra* L.), basket willow, or almond-leaved willow (*S. triandra* L.), grey willow, brittle willow (*S. fragilis* L.), roundear willow, goat willow, and downy willow (lappish) (*S. lapponum* L.) that was included for the first time in the last (fourth) edition of the Red Book, etc.

As noted above, species composition of shrubs on bogs is limited byextinction species such as the dwarf birch (category II of protection) (Red Book of the Republic of Belarus, 2015)

On the raised bogs the species composition of shrubs is limited. There are rare species of dwarf birch (*B. nana* L.) (II protection category), whortleberry willow (III protection category) also can be found (M. V. Yermokhin, 2011).

Peat-producing role of trees is high, especially on the bogs that have enough nutrition and oxygen. These conditions are provided in eutrophic fens with flowing water. The most phytocenotic significance belongs to the representatives of the Birch family (*Betulaceae*), such as alder and downy birch. The latter type is common also on transitional mires. The species of the Pine family (*Pinaceae*), such as Norway spruce, Scotch pine can be found less often in fens mires and the representative of the Olive family (*Oleaceae*), such as ash occurs along the edges of fens very rarely.

The following species can be found mostly along the edges of all types of mires: grey alder, the Birch family (only in the north of Belarus), representatives of the Rose family, bird cherry, field ash.

The only wood species on the bogs is Scotch pine, and rarely downy birch can be found along the edges of mires.

14.3. The role of mires in the biodiversity protection

Mires and landscape complexes that are formed on the basis of wetlands along with the climate forming role have high scientific, aesthetic, recreational and economic value. They represent the unique standards of biogeosystems having distinctive geographical features which are the habitats of certain species of plants and animals adapted to life only in the swamps, as a result they are considered to be rare and vulnerable.

The flora of the mires of Belarus is very diverse and represented by 267 species of flowering and higher spore plants, including 37 species of tree and shrub plants, 167 species of herbaceous, 31 species of sphagnum mosses and 32 species of green mosses.

Mires of Belarus are a real storage place of medicinal, food and industrial raw materials. There are more than 50 species of medicinal plants, including common valerian, rosemary marsh, bog rosemary, marsh trefoil, etc., berry plants are widely spread: cranberry, cowberry, bog blueberry, bilberry.

The mires are inhabited by rare species of birds: osprey (*Pandion haliaetus* L.), short-toed eagle (*Circaetus gallicus* Gmelin), Golden eagle (*Aquila chrysaetos* L.), pigeon-hawk (*Falco columbarius* L.), black grouse (*Lirurus tetrix* L.), white partridge (*Lagopus lagopus* L.), frost bird (*Pluvialis apricarius* L.), greenshank (*Tringa nebularia* Gunnerus), Curlew (*Numenius phaeopus* L.); reptiles: turtle; amphibian: newt (*Triturus cristatus* Laur.); insects: yellow butterfly (*Colias palaeno* L.), the bluish megapesca (*Lycaena helle* Den et. Schiff.), Satyr Jutta (*Oeneis jutta* Hb.).

The mires in Belarusian Polesye are of great importance for the conservation of bird species under threat of extinction, such as the aquatic Warbler (*Acrocephalus paludicola* Vieilot.); the great spotted eagle, great snipe (*Gallinago media* Latham.).

The global value of Belarus for preservation of fauna biodiversity is provided by three global intercontinental water fowl migratory routes in the spring time (Polessky, Dneprovsky, Poozersky), and a significant amount of wetlands in the country.

It is obvious that the main reason for the decrease of the biological diversity of mire ecosystems is drainage, followed by the industrial development of peat deposits.

The reduction of the mire area and their anthropogenic deformation inevitably lead to the elimination, and sometimes to the complete disappearance of swamp species and replacing them by representatives of neighboring ecosystems. This undesirable successional transformation is due to mesotrophication of environment conditions. Mire conservation should be considered as an essential component of nature protection in general. The most effective form of conservation is creation of national parks, reserves, preserves. Significant mires that are unique to the European continent are located in the national Park “Pripyatsky”, Berezinsky biosphere reserve, the Yelnya reserve. The area of some mire massifs is more than 100 km^2, which is unique for countries of Central and Western Europe.

15 TYPES OF MIRE VEGETATION

Depending on the life form of plants-edificators of mires, the following types of mire vegetation are identified: forest, shrub, low shrub, herb, moss. The most specific and common type for mires is a moss type.

When subedificators are represented by plants of different life forms, types of mire vegetation are described as intermediate. They include herb-moss type (sedge-sphagnum transitional mires); moss-forest type (bog sphagnum mires with rare stunted pines that don't form a layer); grass-forest type (low-lying mires with a well-developed ground cover, mire grasses like sedges, reeds and woodlands of black alder, downy birches).

The division between the main and intermediate mire vegetation types to a certain extent is conditional, sometimes it is quite difficult to identify the specific type of a mire community.

It should be noted that there are types of mire vegetation that can be found rarely and they occupy small areas (lichen, microphytous, hepatic, psychrophile mossy). In the given text-book they are not considered.

15.1. Forest type

The division between a forest and a swamp and what area should be considered as a paludified forest and what as a mire forest continues to be a contentious issue. F. Z. Glebov (1988) while assessing the type of ecosystem whether it is forest or mire provides an indicator such as the timber stock per 1 ha (D. G. Grummo et al., 2010). The ecosystem can be classified as a forest one if in terms of the density of 0.3 timber stand is more than 40–50 m^3/ha if it is less then it is classified as a mire. According to M. S. Boch and V. A. Smagina (1993), the height of the tree story and crown density are the most indicative factors.

However, it should be noted that such criteria of the division of mire forests and forest mires are to some extent hypothetical. For example, you can often find areas with well-formed tree story, where living ground cover is presented by typical marsh vegetation.

Other criteria are used by L. P. Smolyak (1969): mire forests grow on overflooded areas where peat layer thickness is less than 30 cm, i.e. roots can reach mineral rocks while on the mires they are mainly located in the peat. A similar approach is used by Finnish bog scientists: areas with peat cover less than 30 cm, even if they have mire vegetation, are referred to as mire forests (The global peat resources, 1988).

Forest type of wetland vegetation is characterized by a wide variety of species and complex space structure that is typical for forest biogeocenoses. There can be found numerous types of herbaceous vegetation, shrubs, layer age is well-distinctive.

This type is common for lowland swamps with a peat layer thickness not exceeding two meters (V. P. Denisenkov, 2000), whereby the roots of the trees reach their mineral deposits and get nutrition. Due to the significant degree of decomposition, peat is characterized by high ash content (up to 20%) and low humidity.

Black alder, downy birch, Scotch pine are the edificators of mire forests and allow us to distinguish three subtypes:

– hydrophilic – black alder forests (swamp forests sensu stricto);

– meso-hydrophilic – downy birch forests (common fen forests);

– psychrophile – pine forests (bog forests).

Hydrophilic subtype is connected to fens. The presence of black alder in the tree story is a distinctive feature of lowland swamp, because this type is an indicator of flowage of water.

The increased flow of the waters of the swamps determines the increase of the degree of decomposition and ash content of peat and causes a richer species composition of trees and their high productivity. Downy birch, common spruce, Scotch pine and common ash grow in alder forest. Their vegetation cover is mosaic due to microrelief, as there are hummocks and depressions between them. The black alder trunks grow on hummocks, which makes it possible to avoid flooding of the root collar. The higher and longer spring waters stand, the higher (up to 1 m and more) and larger hummocks are. A well-expressed nanorelief causes the diversity of the grass and shrub cover of olses, which is initially rich due to improved nutrient status of peat.

On the tops of hummocks typical forest plants grow: shamrock, bifoliate bead-ruby, European pyrola, ferns (except common bracken), forest moss and such shrubs as roundear willow, cranberry high, common honeysuckle (Northern Belarus), alder buckthorn, bird cherry, black currant, Daphne, European Euonymus.

Between hummocks grow sedges such as *Carex pseudocyperus* L., *C. riparia* Curt., bladder sedge (*C. vesicaria* L.), elongated sedge (*C. elongate* L.), remote sedge (*C. remota* L.) etc; club rush, bog bean, marsh marigold, marsh Calla, meadowsweet, water plantain, creeping Buttercup, ashweed, golden saxifrage, water violet (*Hottonia palustris* L.), *Naumburgia thyrsiflora* (L.) Reichenb., purple loosestrife (*Lythrum salicaria* L.), bitter nightshade (*Solanum dulcamara* L.), marsh hawksbeard (*Crepis paludosa* (L.) Moench), touch-me-not (*Impatiens noli-tangere* L.), marsh hoarhound (*Lycopus europaeus* L.), thistle (*Cirsium oleraceum* (L.) Scop), hedge nettle (*Stachys palustris* L.) and many other types. Moss cover is poorly developed (sometimes sphagnum squarrose can be found), and presented in the form of spots.

Downy birch is an edificator of mesohydrophilic subtype. It is less demanding to edaphic conditions than black alder, and therefore can grow not only on low land but also on transition swamps, where it together with pine forms mixed pine forest. On the fens, downy birch grows almost in the same type of forest growing conditions as black alder, but in phytocenotic relation it is inferior.

Definite water flow in transitional mires plays a vital role in the formation of the herbaceous story of sedges such as slender sedge (*C. lasiocarpa* Ehrh.), beaked sedge (*C. rostrata* Stokes), common reed. There is also marsh trefoil, hypnum bog mosses. Sphagnum mosses are quite common and grow both on uplands and on flat ground.

The presence in different ratio of white birch and Scots pine in the tree story, sedges and sphagnum in surface vegetation cover indicates that it is a transitional mire.

Forest mosses, common cranberries, bog blueberry usually grow on wellbore hillocks. Sweet gale and swamp ledum communities are well developed here.

Psychrophilic subtype, represented by pine forests, is typical for transitional mires, bogs that are close to raised ones and the raised bogs, relating to the ecotopes with cold soils, which was described above (see unit 14.1).

In transitional bogs among the most common vegetation it's possible to find sedge-sphagnum pine often mixed with white birch that is distinguished by unchanging forest stand and poor species composition of the grass-shrub story. Sedges dominate here, also there are plenty of swamp shrubs, such as bog rosemary, sweet gale, marsh tea, berry species. Sphagnum mosses are usual companions of sedges.

Low-dencity sphagnum pine forests are common in raised bogs. They occupy the margin of the mire and they are unproductive. In exceptional cases, planting of IV–V growth classes can be found here. An average height of pine stands on the raised bogs in the age of 80–120 years ranges from 2 to 8 m.

The absence of downy birch in the tree story and sedges in the ground cover is common for sphagnum pine forests. Plenty of sphagnum mosses, bog blueberry, marsh tea, bog cranberry, Chamaedaphne calyculata can be found here.

15.2. Shrub type

Shrub type of bog vegetation is dominated by willow communities that are typical for low-lying mires, where the most common type is willow sedge (I. D. Yurkevich, 1980). The species composition of life forms of edificatory is presented by a bag willow, gray willow, a lappish willow, etc.

Osiers spread over a large area in flood plains of the rivers. Almond-leaved willow, sharp-leaved willow (*S. acutifolia* Willd.) prevail here. Sharp-leaved willows grow together with white willow, or Vela (*S. alba* L.) and brittle willow.

Osier forest can often be met in mire depressions, near streams and small rivers. In these conditions they form osier that includes grey willow, almond-leaved willow and black willow.

Sedge sphagnum osiers forest are typical for transitional swamps, they include grey willow, Lappish willow and etc. Osier forest spread, as a rule, along the outer edge of the bogs where nutritional conditions are richer. Peat layer under osier mire is no more than 1 m. Osier forests often represent a temporary type of the vegetation formed as a result of anthropogenic succession on the place of cuttings of black alder forests and downy birch forests.

15.3. Dwarf shrub type

The dwarf shrub type of mire vegetation takes small areas in the form of small spots which are a part of other dominating vegetation types.

Sections of dwarf shrub type are typical for bogs in sphagnum pine forests. For example, according to I. D. Yurkevich (1980), a synonym of a sphagnum pine forest is a pine low shrub-sphagnum forest.

Dwarf shrub communities include a Labradors marsh tea, bog rosemary, sweet gale, bog blueberry, cranberry marsh and crowberry in the north of the country.

Dwarf shrub communities can be represented both in the form of pure monoprepotent thickets of one type, and in the form of mixed thickets of several types. Ledum-sphagnum, blueberry-sphagnum, cranberry-sphagnum, ledum and blueberry sphagnum, blueberry-myrtle associations are typical for sphagnum bogs.

Dwarf shrubcommunities are formed actively on the drained and developed peat bogs, especially on the place of burned-down riding bogs where common heather, sweet gale, red bilberry grow rapidly.

As a result of low humidity the process of peat formation on such areas is slowed down, there is a replacement of sphagnum mosses by bryidae psychrophile ones, in particular, Polytrichum strictum.

15.4. Grass type

The grass type of wetland vegetation develops in the conditions of excessive moistening. It is typical for low-lying mires.

Depending on the dominating types, it can be presented by various communities: sedge, reed, equisetaceous plants, cotton-grass.

Sedge communities are well identified due to the so-called sedge meadow that is connected to floodplain fens, and have the microrelief in the form of dense soil hillocks up to 20–30 cm high while slight flooding and up to one and a half meter while heavy one. Hygrophilous vegetation is the most common type between hillocks: marsh trefoil, marsh cinquefoil, yellow iris (*Iris pseudacorus* L.).

Large sedge meadows formed by bladder sedge, beaked sedge, bank sedge grow in fens. The story of this vegetation reaches one meter high. Small sedge meadows that are presented by common sedge are also common for low-lying mires. (*C. nigra* (L.) Reichard).

In Belarus reed phytocoenoses are formed along eutrophic banks of the shallow lakes, low banks of the rivers and streams sometimes along strips on the edges of the mires that have an insignificant power of peat and good drainage. Along with reed communities, there are also mixed reed and sedge communities with inclusions of marsh herbs and horsetail.

In particular, reed vegetation is widely spread in lower reaches of large rivers in the southern part of Russia (Volga, Kuban, Dnieper, Dniester) where it forms dense similar by species composition high (up to 5 m) thickets where there is no peat or its power is small (10–20 cm) (V. P. Denisenkov, 2000).

The horsetail vegetation includes marsh horsetail, water horsetail, more rarely woodland horsetail, meadow horsetail, it forms small spots mainly on the places of mineralized waters outflow. It can be found along banks of rivers, lakes and on the floating bog. The mixed thickets of horsetails with a marsh cinquefoil, marsh trefoil, common reed, sedge are most widespread.

Cotton grass phytocoenoses on transitional mires are formed by common cotton-grass and rarely by *E. vaginatum* L. and marsh herbs, and confined to areas with a shallow peat deposit.

Monodominant cotton grass communities on bogs are often formed by *E. vaginatum* L. forming hummocks up to 25 cm high. Because of the well-developed fibroid root systems of the cotton grass, the surface between them is extremely dense, so water stagnates for a long time here and therefore the vegetable cover presented by other species is developed poorly.

However, cotton-grass and sphagnum communities can be found more often on bogs and they have a well-developed sphagnum cover with the identical in size cotton grass hummocks, between which there are marsh low shrubs, lustwort, pod grass.

Scheuchzeria community occupy small area and confined to almost impassable places of mire massif such as quaking bogs, hollows. Scheuchzeria-sphagnum bogs with hydrophilic sphagnum mosses such as sphagnum spiniform (*S. cuspidatum* Ehrh. tx Hoffm.), sphagnum Baltic (*S. balticum* (Russ.) C. Jens.), large sphagnum (*S. majus* (Russ.) C. Jens.) are most common. One can often find here one of the rare species of the sedge growing on bogs – a mud sedge (*C. Limosa* L.).

15.5. Moss type

This is the most common type of vegetation on mires in the northern hemisphere. It is characterized by excessive and, as a rule, stagnant moistening and sour, poorly decayed peat. This type of peat is formed mainly on raised bogs by sphagnum mosses that are less demanding to nutrition and get it mainly from the precipitation. Moss type of vegetation is less presented in transitional mires and especially in fens swamps where nutrition is richer and is derived from ground and surface-run off waters that cause the appearance of other types of vegetation (forest, shrubby, grassy). Moss communities are also developed in the process of peat forming on quaking fens, preceding appearance of ordinary fens.

Sphagnum mosses, as the most typical representatives of moss type, form mixed communities which depending on the share of other vital forms refer to forest, dwarf shrub and grass associations (pine-sphagnum, marsh tea-sphagnum, cranberry-sphagnum, cotton grass-sphagnum, Scheuchzeria-sphagnum, etc.).

There is a clear confinement of the specified groups of associations, as well as of monodominant moss associations to certain areas of raised bogs. In the structure of their relief, following parts are distinguished: raised in different degree surface of the central part (see unit 13.4), a margin slope, an edge.

The central part is developed in the conditions of extremely poor nutrition, occurring due to the atmospheric precipitation and microscopic particles of dust, which are airborne and gradually settle on the surface of the bog. In this regard, the floristic structure is exclusively presented by sphagnum mosses which need little nutrition and form a uniform cover with the help of narrow-leaved sphagnum, brown sphagnum, Magellanium sphagnum, etc. There are practically no forest associations in the central part of mire forests, as there is not enough nutrition for the development of wood plants which have considerable size and therefore need more nutrition.

However, edaphic conditions in the specified part of the bog satisfy ecological and biological demands of low shrubs that are mycotrophic by type of nutrition and rather small by size. In this regard associations with the sphagnum mosses, bog rosemary, sweet gale, bog blueberry, marsh cranberry which grow on the raised microrelief elements (hummocks, hillocks, ridges) are represented here.

On the slopes of raised bogs where the flowing mode of moistening is dominating, the phytocoenosis with participation of a pine, the sphagnum mosses, drawf shrubs are common for the central part of massifs.

Edges of raised bogs are characterized by mineral nutrition which is derived from various sources: ground waters that are sometimes close to the surface, surface-runoff waters from waterless valleys, poorly mineralized waters which are flowing down on slopes from the dome-shaped center of bog massifs, and atmospheric precipitation. It causes richer conditions of nutrition and, respectively, richer floristic structure of raised bog edges than their central part and slopes.

Ground water is the main source of nutrition on the eutrophic fens where hypnum moss communities usually grow and herb story is formed: marsh cinquefoil, marsh trefoil, common reed, sedge, fern marsh, horsetails and other species.

Sedge-sphagnum communities develop in the places moisturized by less rich waters on the mesotrophic transitional bogs. The role of subedificators is played by sphagnum mosses (sphagnum fallax, sphagnum Magellanicum, sphagnum angustifolium, etc), sedges (slender sedge, bottle sedge, black sedge, etc), cotton grass (vaginal and common), and also pod grass.

16 TYPES OF PEAT

16.1. The essence of the peat formation process

As it was mentioned above, peat is formed after incomplete decomposition of plant matter. This is due to high humidity and lack of oxygen which retains the activity of organisms-decomposers of organic matter. Depending on the degree of decomposition all types of peat are divided into three groups (V. I. Belkovsky, 1982):

1) fibric peat/weakly decomposed (less than 20%);
2) hemic peat/moderately decomposed (20–30%);
3) sapric peat/strongly decomposed (more than 30%).

The degree of peat decomposition is characterized by the percentage of humus, which looks like a structureless mass including humic substances and small non-humous residues.

All the basic properties of peat are determined by the growing conditions and the kind of the vegetation, in its turn, every type of bog vegetation largely depends on peat substrate. There is interaction and interdependence of edaphotop and phytocenosis in different ecosystems (forest, meadow), however, this feature is more expressed only in wetland ecosystems. This is explained by the fact that marsh soil is almost entirely a product of the life activity of vegetation.

In their origin black and especially brown coal are close to peat they have been peat before, and later were exposed to complex geochemical transformation in the result of which the elements of organic origin, as it has already been noted above (see unit 13.5), transferred from the biogenic cycle in the geological one.

Present peat deposits originated in the postglacial period (the Holocene) more than 10 thousand years ago, the age of ancient peat is tens of thousands of years (N. F. Reimers, 1991).

Simultaneous physical, chemical and biological phenomena form the basis of the peat formation process.

The physical component of this process consists in the maximum possible mechanical destruction of plant residues and their subsequent contraction in the thickness of peat deposits.

Their chemical and biological transformations are much more complicated they lead to the appearance of peat itself. It is known that all living organisms consist of organic and mineral compounds. It is necessary to note that because of difference in nutrition the share of the mineral compounds in peat forming plants growing in fens is significantly more than that one in raised bogs.

The chemical composition of the mineral part is represented by the following elements: phosphorus, potassium, calcium, iron, magnesium, silicon (sometimes up to 50%), microelements. The organic part is dominated by carbon (48–50%), oxygen (38–42%), hydrogen (6.0–6.5%), nitrogen (0.5–2.3%) (V. P. Denisenkov, 2000).

In the process of photosynthesis, substances used for plant nutrition and plant organs development are formed: proteins, cellulose in its various forms, lignin, representing highly resistant to decomposition by microorganisms polymer. Cells contain starch, essential oils, tanning materials. Surface of stems and leaves of marsh plants have waxes (it's one of the features of their xeromorphy). During the peat formation process all these substances undergo chemical changes, and as a result the carbon content increases in the same time with oxygen and hydrogen decrease.

Simultaneously with the chemical transformation, the process of humification of plant residues takes place (it is a biochemical process of transformation of decomposed products of organic residues into humus by microorganisms, moisture and the atmospheric oxygen (N. F. Reimers, 1991)), with participation of actinomycetes, molds and yeast fungi, bacteria, and invertebrates. This leads to the increase of humus content which is the most important result of the biological component of the peat formation process.

Actinomycetes, mold-fungi, yeasts start the humification. Bacteria take part at a later stage using the products formed in the result of activity of microorganisms-precursors.

The total number of microorganisms can reach enormous values, such as 800–1200 million in 1 g of wet peat (V. P. Denisenkov, 2000). Most significantly they present in the surface layer of peat, their number decrease with depth, and their qualitative composition is changing, as a result anaerobic microorganisms dominate.

In surface, the most aerated layer the depth of which is about half a meter the decomposition of plant residues is influenced by aerobic microorganisms. Here peat gains its main properties. Here comes the name of this layer as “peat-forming layer”. The activity of microorganisms intensifies in summer time when there is improvement in air mode. Aquifer hyaline cells of sphagnum easily lose water; they form the cover which dries quickly in the sun (crushing underfoot). Conversely, an increase in the flooding of peat in spring and autumn leads to attenuation of the biological degradation processes.

Decomposition of plant residues buried for centuries in the underlying layers of peat slows down, but does not stop completely. The bubbles on the surface of bogs are the allocation of the so-called marsh gas (methane, CH_4), indicating anaerobic processes of organic matter decay in the depth of peat deposits. Methane is a greenhouse gas with a strong greenhouse effect: one molecule of CH_4 is equivalent in its impact to 34 molecules of CO_2.

Different intensity of microbiological processes is conditioned not only by season and location in the thickness of the deposits, but also by global cyclical climate reflected in the interchanging of wet or dry periods.

The latter is connected with the irregular distribution of peat formation, due to the weakening or the intensification of microbiological processes. The deposition of young or hard peat occurs. Spotty peat formation is typical for raised bogs, where the main nutrition is atmospheric precipitation. Stable nutrition of fens by groundwater determines less intensity of peat differences by the degree of decomposition.

Mires of various types differ in ability and acidity of the peat. Peat is extremely poor in the raised bogs and its acidity is increased, which limits the species composition and number of decomposers and as a result the decomposition process slows down.

In general, this process largely depends on climatic conditions of the area. Mild climate, moderate soil moisture and relatively low acidity of the soil solution promote faster decomposition of plant residues in the swamps.

It should be noted that not only environmental factors, but also internal features of plants caused, primarily, by their chemical composition determine the degree of humification of peat. In particular, the stability of residues against decay depends on the biochemical composition of peat forming plants.

For example, sphagnum mosses are insuperable natural antiseptics because they contain significant amounts of phenolic compounds that actively inhibit the activity of microorganisms, therefore, sphagnum species have the lowest peat decomposition degree. At the same time residues of dwarf shrubs, sedges and mire grasses characterized by high content of protein compounds, carbohydrates, calcium) get mineralized relatively well.

According to the exposure to decomposition, three groups of plants-peat formers can be distinguished (V. P. Denisenkov, 2000):

1. Easily decomposed peat-forming plants are rich in nitrogen (more than 2.0–2.5%) and calcium, contained in an easily hydrolyzable organic substances: meadowsweet, bean trefoil, swamp Calla, wild calla, marsh marigold, golden saxifrage, woodland bulrush, common reed (fens), shrubs (transitional and raised bogs) are decomposed in two or three years.

2. Middling peat-forming plants have lower nitrogen content (1.5 to 2.0%) and easily mineralized organic substances with phenolic and terpenic compounds: slender sedge, beaked sedge, bladder sedge, black sedge, pod grass, sheathed cotton grass, cotton grass multispicate (mainly, vegetation of transitional mires).

3. Recalcitrant peat-forming plants are extremely poor in nitrogen, contain many phenolic compounds: sphagnum mosses (raised bogs).

16.2. Peat classification

The peat deposits are the result of the activity of mire communities. Each of them develops in certain environmental conditions and deposits only for this community type of peat.

“Classification of types of peat” by S. N. Turemnov (1977) is commonly accepted among former Soviet Union states.

All types of peat in this classification are classified according to vegetation and ash content:

– fen (ash content 6–18%);
– transitional (ash content 4–6%);
– bog (ash content is less than 4%).

Slightly different, but alike rates of ash content of peat types are given by L. P. Smolyak (1969).

Taking into account the ratio of woody, grass and moss residues, each type of peat is divided into subtypes and groups of peat (their names are the same for all three types):

1) woody subtype:
– woody group.

2) woody-swamp subtype:
– woody-grass group of species;
– woody-moss group of species.
3) fen subtype:
– grass group of species;
– grass-moss group of species;
– moss group of species.

Each group has different types of peat. There are 40 types of peat in S. N. Turemnov's classification.

Low moor type is formed in the conditions of rich diversity of vegetation, and as a result this type is represented by 20 types of peat.

Woody subtype, woody group includes 5 types of peat:
– alder;
– birch;
– spruce;
– pine;
– willow.

Peat-forming plant species composition, their growing conditions determine the characteristics of the basic properties of peat that correlate internally. Woody groups are formed on the basis of forest residues, mainly of wood, and are characterized by the highest degree of decomposition (60%), and hence by granular-crumbly structure.

A high degree of decomposition causes increase of ash content of peat, i.e. the presence of mineral particles. Mainly they have vegetable origin, i.e. in addition to the degree of decomposition of peat ash content also depends on its botanical composition. Groundwater and surface wastewater, atmospheric precipitations also have an impact on ash content of peat. The greater the degree of decomposition of peat the less it has cells and fragments of plant tissues that are able to absorb moisture. Peat of a wood group is characterized by a higher degree of decomposition, and therefore a low humidity.

In low moor type, woody-swamp subtype, woody-grass group includes three types of peat:
– woody-reed grass;
– woody-sedge;
– woody-equisetaceos.

Peat of woody-grass group is formed in worse conditions for woody vegetation and better for grass one, due to the increase of water flow. In this regard, the moisture content of the peat is high, thus the conditions for microorganisms are worse, and therefore, the degree of decomposition of peat, as well as its ash content, becomes smaller. In the peat of woody-grass group residues of sedges, reeds, horsetails are well distinguished.

Low moor type, woody-swamp subtype, woody-moss group includes two types of peat:

– woody-hypnoid;
– woody-sphagnum.

These types are formed in incomplete stands and sparse on the swamp with a well-developed moss cover. Water content in comparison with woody-grass group increases and, consequently, it affects the structure and moisture content of the peat. It becomes more coherent and wet. Along with woody debris fragments of hypnum and sphagnum moss are found. The latter grows in very weakly mineralized groundwater.

Fen type, swamp subtype, moss group includes 6 types of peat:

– horsetail;
– reed grass;
– sedge;
– reed-sedge;
– buckbean;
– scheuchzeria.

Woody vegetation cannot grow because of even more significant drowning of the territory, mainly due to groundwater and river water. This way woody vegetation is changed by different kinds of grass, the most common of which are sedges. Due to their morphology and deterioration of the conditions of plant residues decay, peat changes its structure. It gets fibrous, ribbon-layered or felted structure. The moisture content of the peat increases. The degree of decomposition and the ash content are less than that of peat of woody and woody-swamp subtypes.

Fen type, swamp subtype, moss group includes 2 types of peat:

– sedge-hypnoid;
– sedge-sphagnum low-moor.

Excessive moisture by the ground and surface wastewaters that are low in mineral nutrients, leads to a partial elimination of grass component from plant communities. Phytocoenotic role of mosses that are less demanding to the edaphic conditions especially sphagnum mosses increases. The moisture content of the peat increases, the degree of decomposition and ash content comparing with grass peat group is reduced.

Low moor type, swamp subtype, moss group includes 2 types of peat:

– hypnoid;

– sphagnum.

The conditions of plentiful but poor nutrition, mainly due to groundwater, promote formation of moss peat. Its moisture content is maximal for low moor type, decomposition is inconsiderable, ash content is decreased. Within the considered group, sphagnum peat formed in the floating fens and hollows to the fullest extent characterizes the above mentioned.

In the transition type, as well as in fen and bog types there are three subtypes (woody, woody-swamp, swamp), six groups (woody, woody-grass, woody-moss, grass, grass-moss, moss). They include eight types of peat: woody, woody-sedge, woody-sphagnum, scheuchzeria, sedge, sedge-sphagnum, hypnum, sphagnum, which fall in between peat of fen and bog types.

The greatest degree of decomposition in a transitional type belongs to woody peat (40–55%), which is a part of the forest subtype, woody group. Accordingly, this type of peat is characterized by low moisture content (87–89%) and increased ash content (4–10%).

The degree of peat decomposition of forest swamp subtype woody-sedge (woody-grass group) and wood-sphagnum (wood-moss group) has a lower value (30–50%), slightly increased humidity (88–91%) and lower ash content (4–8%).

Fen subtype is presented by scheuchzeria, sedge (grass group), sedge-sphagnum (grass-moss group), hypnum and sphagnum (moss group) types of peat, which are less decomposed (5–35%), therefore their moisture content increases (90–94%) and ash content decreases slightly (3–8%) (S. N. Turemnov with colleagues, 1977).

The transition type is represented by types of peat that consist of residues of oligotrophic (blunt sphagnum, sphagnum deceptive, sphagnum magellanicum, narrow leaved sphagnum, sheathed cotton grass, bog rosemary, bog Myrtle, bog blueberry), eutrophic (sedges) and mesotrophic (hypnum mosses, Labrador tea bog) plants.

All types of bog peat are formed under conditions of poor nutrition, as a result the ash content in comparison with the types of low moor peat decreases by 3–5 times, the acidity significantly increases, i.e. pH reaches 2.0. Harsh growing conditions reduce the species diversity of vegetation, which reduces the number of types of peat up to 12.

The main peat-forming plants are pine and sphagnum mosses, and shrubs, moss, pod grass.

Bog type, woody subtype, woody group only include a pine-shrub type of peat.

This type is characterized by a high degree of decomposition, comparable with the criteria of the peat of wood group of lowland type (up to 60%) and, accordingly, reduced humidity (86–89%). The ash content is higher than all other types of peat have, but within the limits typical for a given type (3–5%). The peat is dark brown, remnants of bark and pine wood can be observed, and roots of shrubs make up more than 50% (S. N. Turemnov with colleagues, 1977).

Bog type, woody-swamp type, woody-grass group only include pine cotton-grass type.

This type has similar to pine-shrub peat properties characteristic. Except the remnants of bark and pine, black roots and fibers of the stems of the cotton-grass can be clearly observed.

Bog type, woody-swamp type, woody-sphagnum group include pine sphagnum type.

From bogpeat of woody and woody-swamp subtype, this peat is deposited along the edges of bogs and it is the least decomposed one (up to 30%) due to increased hydration of pine-sphagnum communities and, as a result, the formation of a developed layer of hygrophilous sphagnum. The humidity of this type of peat is increased (up to 91%), ash content is at a level, typical for raised bog peats (2–5%). The colour is brown, besides remnants of pine, twigs and stems of sphagnum are easily determined (S. N. Turemnov with colleagues, 1977).

Bogtype, swamp subtype, grass group includes two types of peat:

– cotton-grass;

– scheuchzeria.

Cotton-grass peat is deposited in the marginal zones of swamps. The colour is brown. This peat is characterized by a high degree of decomposition (30–45%). Humidity reaches 90%; the ash content is 2.5–4.0%. The remains of cotton-grass make up 60% or more (S. N. Turemnov with colleagues, 1977).

Scheuchzeria peat is deposited under the mires and in hummock-hollow and hummock-lake complexes, which are common for regressing bogs (see section 13.4). The color is olive, in the air it darkens. It has high humidity (88–90%), degree of decomposition is 25–40%, ash content is 2–4%, it has mucous-fibrous structure. The share of the residues of scheuchzeria accounts for 60% or more (S. N. Turemnov with colleagues, 1977).

Bog type, swamp subtype, grass-shpagnum group includes two types of peat:

– cotton-grass-sphagnum;

– scheuchzeria-sphagnum.

Cotton grass-sphagnum peat is the most common in the bogs. The colour is light brown. The composition is dominated by the remains of the cotton-grass (50%) and Magellanic sphagnum and narrow-leaves sphagnum. Peat moisture is increased (91–93%), the degree of decomposition is 20–35%, ash content is 2.0–4.5% (S. N. Turemnov with colleagues, 1977).

Scheuchzeria-sphagnum peat, with colour from yellow to dark brown, has similar properties with Scheuchzeria peat, but has a greater number of residues of sphagnum moss and has a lower degree of decomposition (15–30%). Humidity is increased from 91 to 94%, ash content is 2–4% (S. N. Turemnov with colleagues, 1977).

Bog type, fen subtype, sphagnum group includes five types of peat:

– angustifolium peat;

– magellanicum-peat;

– fuscum peat;

– sphagnum hollow peat;

– integrated upland peat.

Raised bog peat of moss group is deposited in poor nutrition conditions and is common for the marshes of the Belarusian Poozerye. The composition is dominated by the residues of oligotrophic mosses. This type of peat is characterized by high humidity – up to 95%, a low degree of decomposition – 5–25% and ash content of 1.5 to 4.0%.

The angustifolium-peat is relatively rare; it has a shape of lenses in the layers of peat deposits up to 1.5 m. The color is light yellow. The residues of angustifolium make up up to 60%.

Magellanicum-peat is the most common type of peat in the raised bogs. The color of the peat is light brown. The remains of magellanicum make up 70%, not only stems but also twigs of mosses are well distinguished.

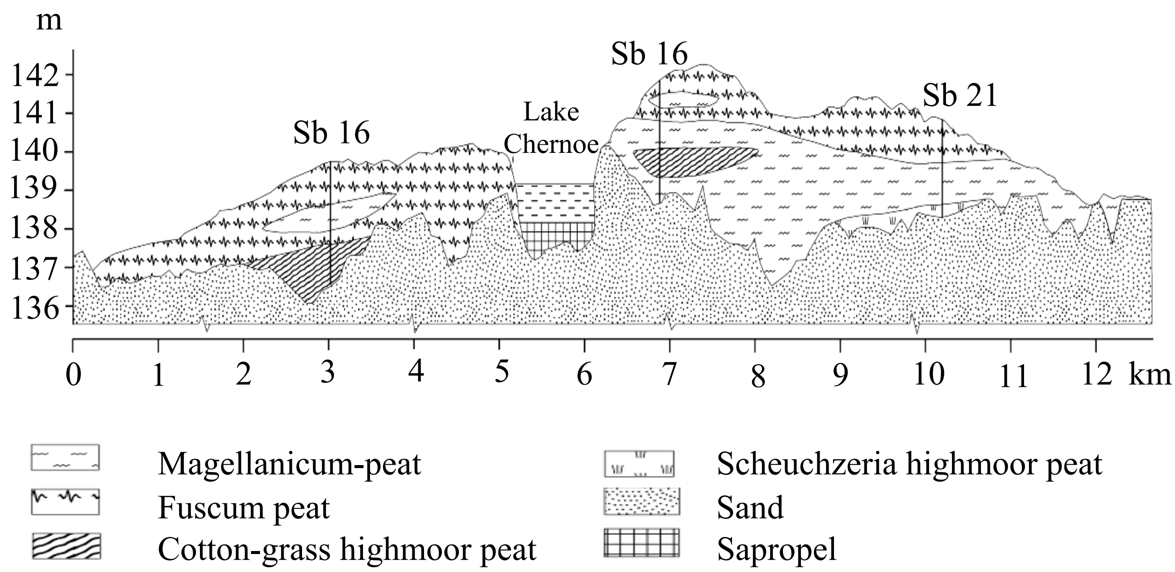
Fuscum-peat is also a very common species of peat. The color varies from light yellow to light brown. Well identified remains of fuscum make up 50%.

Sphagnum hummocks and hollows peat is formed on the hollows and lawns. The color is yellow or light yellow. The structure is fibrous and spongy. The stems of hydrophilic sphagnum are well identified including sphagnum cuspidatum, balticum, large.

A complex high moor peat is also formed in the hollows and lawns. It has characteristics similar to sphagnum hummocks and hollows peat, but the color is darker. The remains of sphagnum-forming plant differ in color: sphagnum cuspidatum is light yellow, sphagnum magellanicum is dark yellow, sphagnum brown is brown. The content of sphagnum residues on hollows (brown sphagnum and magellanicum sphagnum) is increased (S. N. Turemnov with colleagues, 1977).

16.3. Mire chronicles

The accumulation of peat is caused by the formation of peat deposits made up of successive layers of different types of peat (see unit 13.1). The thickness of the peat deposits can reach up to 10 m, but usually it varies in the range of 1.5–6.0 m. For example, the maximum thickness of peat deposits in the Yelnya national landscape reserve reaches 8.3 m, the average thickness is 3.8 m. The accumulation of peat deposits in this area took place during 8.200–9.000 years in various climatic and hydrological conditions (figure).



One of the profiles of peat deposits in the Yelnya reserve
(D. G. Grumo with colleagues, 2010)

The change of one type of peat by another in the vertical profile of the peat deposit results from time change of vegetation communities, which in its turn caused by variation of nutritional conditions in this region.

Constantly low temperatures, small quantities of oxygen in water and peat and sterilizing properties of sphagnum are the main factors contributing to the continued preservation of plant remains. Consequently, peat accumulation is a kind of chronicle of the mire, which covers the main phases of its formation connected with nature of flora of the past and with the conditions of its existence. And it is absolutely true, without any subjectivity as it is written by nature itself. You only need to learn how to read it.

Different mires and even different parts of the same mire, as a rule, are characterized by different structure of the peat deposits. The structure of the peat deposits of the central and marginal parts of the mires differ significantly, this characteristic is common for bog mires.

When conducting scientific research or peat extraction, it is important to know the structure of the mire deposits. Stratigraphy is the study of the succession of the layers of peat formed by the different types and their spatial interaction.

According to the structure of the peat deposits, i.e. by alternating layers of peat with a predominance of plant residues, spores and pollen of certain plant species it is possible to identify the features of successional changes in wetland communities, and thus to become aware of the hydrothermal regime and the dynamics of climate processes. Active formation of deposits on the territory of Belarus is connected with the warming and moistening of climate.

The surface layers of peat deposits are excellent indicators of air pollution with industrial emissions. Unfortunately, currently the surface layers near industrial centers have higher ash content than the layers on the remote areas of wetlands.

Value at a depth of over 40 cm on raised oligotrophic bogs corresponding approximately to the period before the beginning of 17th century was taken as a reference value of peat contamination, reflecting the beginning of active human impact.

Increased ash content of the upper layers of the peat deposits, despite a lower degree of peat decomposition, is determined by:

1) atmospheric dust deposits (gravity fallouts);

2) the concentration of minerals by plants and their return after the dying-off of the latter.

But there are exceptions: layers with increased ash content can be observed in the depths due to the gain of mineral elements, for example in floodplain fens.

The differences in the decomposition of peat at different depths of the deposit depend on its botanical composition and type of nutrition. In the fen deposits, the difference in the degree of decomposition of the peat profile is not so evident due to stable nutrition by groundwater. In the raised bogs more significant variations of peat decomposition degree are possible at different depth, because in this case the nutrition was provided mainly by means of precipitation that are quite irregular in long historical retrospective.

The degree of peat decomposition is connected with moisture distribution along the profile. The decomposition of peat increases when its moisture content decreases. Reduced moisture content in the base of the peat deposit is caused by the consolidation due to pressure of upper layers.

The chronicle of the mire is expressed in specific property of the peat deposit – its stumpiness, characterized by content of large woody inclusions, mainly in the form of stumps, rarely trunks. Resinous pine stumps are especially well preserved in the thickness of the peat. The residues of trunks of conifers are partially dilapidated and stumps of deciduous trees (birch, alder) are poorly preserved. In quantitative terms, stumpiness is determined by the ratio of the volume of wood in deposits to its total volume, expressed in percent.

These large inclusions form well distinguished in the peat thickness stump-containing horizon, called recurrence horizon. It proves that serious climate changes took place in previous times. For example, woody vegetation has appeared on the mire only due to significant warming and mire drying out. Reverse change of woody vegetation by grassy one was, evidently, connected with worsening of climate conditions which resulted in overmoisturizing.

17 THE TYPOLOGY OF MIRES

17.1. Mire as a phenomenon of geographic landscape

According to V. N. Sukachev (1926, p. 6, 7), the mire "is a specific geographical phenomenon…, a particular type of the earth's surface where the lithosphere, pedosphere, atmosphere, hydrosphere and biosphere factors form an integral unit and one particular landscape".

There are a number of definitions of the mire stating that it is a phenomenon of the geographical landscape. For example, a well-known bogologist N. I. Pyavchenko considers the mire to be "a certain element of the geographical landscape", which "appears and develops in a permanent or sustained excessive hydration of the surface layers of the earth's crust, resulting in the forming of vegetation specific for wetlands, and specific aspects of soil processes leading to the accumulation of peat" (N. I. Pyavchenko, 1985, p. 5).

As it was mentioned above, the predominance of organic matter accumulation on the earth surface over its decomposition can be attributed to the mire as a particular type accumulating landscapes (see unit 13.5). The ratio of the mass of peat and water (the dominant components of the swamp) are, accordingly, about 5 and 95%. The accumulation of peat leads to the formation of the convex surface. Consequently, the surface of the water contained in peat deposits, also has a convex spherical shape copying the mire relief. Figuratively speaking, it holds in equilibrium convex "underground reservoir", the volume of which is determined by the volume of the mire.

In the process of its development, the mire landscape is becoming less dependent on adjacent territories. There is a formation of autonomous hydrological network, the relief gets the characteristic features, the ground cover becomes more specific.

As it's known, phytocenosis is the visual edges of forest ecosystem, and all its components both biotic and abiotic are homogeneous to some extent. However, this cannot be entirely attributed to mire ecosystems.

One of their specific characteristics is certain heterogeneity. It is especially noticeable when comparing the central and marginal parts of the same mire and it becomes evident when comparing a number of characteristics, such as vegetation, hydrological regime, types of nutrition, the microrelief etc. A specific mire, thus, is not some sort of exactly identical spatial type of landscape, it represents a set of biogeocenoses that are joined and are in constant development and close cooperation, that differ to some extent and are part of one big bog ecosystem, the main components of which include water, vegetation, peat.

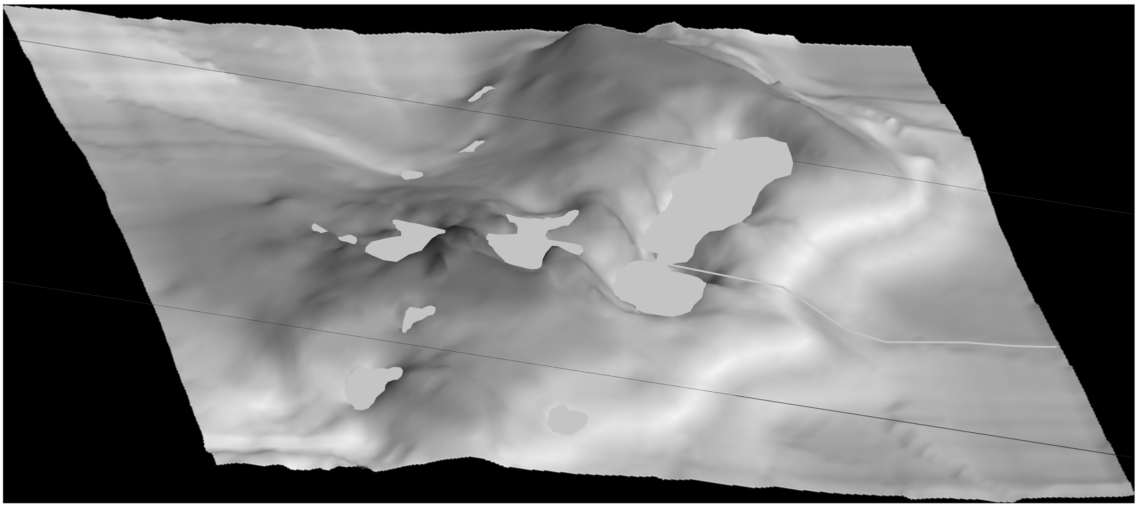
In this regard, low classification units, such as micro landscape or facies are distinguished in the mire landscape. They are characterized by specific spatial homogeneity of vegetation, microlandscape (microforms), and similar properties of water regime of peat horizon. According to GOST 19179-73, p. 194, swamp microlandscape is "part of the mire with a homogeneous vegetation cover, surface microrelief and water-physical properties of the active horizon. It is represented by one vegetative association, a group of close on floristic composition and structure plant associations or by the complex of different plant associations regularly interchanging".

Mesolands (tracks) is a larger unit of mire landscape classification, it is considered to be the main landscape unit. Mesaland is an isolated mire with boundaries as a separate outline appearing in one mire hollow and composed of interrelated and interdependent combinations of microlandscapes.

Natural dams (relief uplands, rivers, lakes) that exist between separate mesolandscape disappear in the process of development of mires. This leads to the formation of mires microlandscapes (swamp systems), which are a combination of wetland tracks merging into one mire in the process of mire formation and having several genetic centers.

Genetic center is a part of the mire with the earliest lowland change to a transitional stage, and then to a high stage. In the genetic center of the mire the spherical surface forms firstly, whereby the root systems of the plants lose contact with mineral bottom of the mire.

Let us illustrate it on the example of the bog Yelnya using 3D models (figure). As it shown in figure, the microlandscape of the reserve has a form of a hilly plain. The absolute level of the surface is changed from 138 to 145 m. The central part is high convex and has two ridges, i.e. two genetic centers. The top of the northern part of the massif is wide and rises up to 5–7 m. The excess above the dry land in the southwestern part is 3–4 m.



Model of the surface topography of Yelnya bog massif
(D. G. Grummo with colleagues, 2010)

Mire systems can be simple or complex. Simple mire system consists of two or more massifs that are at the same stage of development (for example, convex stage of bog mire). Complex mire system consists of two or more massifs that are at different stages of development (for example, gently convex and plane convex stages of the bog).

Spatial boundaries of any mire system are: the upper level of the vegetation, mineral soils underlying peat, the adjacent dry lands.

The biggest mire in the world is the Vasuganye, that is situated in the Western Siberia. Its area takes five million ha, which is approximately equal to the territory of nine Frances.

One of the most well-known on the European continent lowland wetland systems are the Pinsk mires. Actually they spread not only in Pinsk district, but also take a number of nearby areas: Rechitsa, Stolin, Mozyr, Zhitkovichi, Luninets. Among other major lowland wetland systems of Belarus located in the southern part are Olmanskiye swamps (95,000 ha), Vygonoshchanskiye (35,000 ha), Grishin (33,000 ha), Zvonets (16,000 ha), Dikoe (15,000 ha).

The largest mire system of Belarus and Europe is Yelnya (25,000 ha), which definitely should be considered as a national treasure of the country. It is located on the north of the country in Miory and Sharkovshchina districts of the Vitebsk region.

17.2. Principles of mires typology and their classification

Due to the variety of mires that differ in a number of important features and properties (vegetation, the structure of the peat deposits, conditions of nutrition and water availability, location in landscape, micro and macro relief, development stages, etc.), different types of mire classifications are created by researchers in many countries.

One of the best known classifications of wetlands was developed in the early 20th century in Germany by K. Weber. The classification is based on the landscape principle. Types of nutrition and vegetation are also taken into account. All mires are divided into two categories:

1) flat;

2) raised.

Flat bogs located in the lowlands are characterized by a relatively smooth surface. The main source of nutrition is groundwater rich in mineral elements. Flat mires are divided into:

a) fen mires that are rich in nutrition, sphagnum mosses are absent;

b) transitional mires that are less rich in nutrition, the proportion of sphagnum moss in addition to live ground cover is quite significant.

Raised bogs are characterized by a convex surface, poor nutrition (mainly consisting of precipitation), domination of sphagnum mosses in live ground cover.

Subsequently, the division of wetlands into fen, transitional mires and raised bogs was used commonly.

In Finland mires are classified on the basis of biological and geological principles, and biological classifications are presented in several interpretations. According to the classification based on vegetation, mires are divided into four types (Global peat resources, 1988):

1) grass raised moor;

2) grass low moor;

3) forest raised moor;

4) forest low moor.

The classification of mires by R. I. Abolin is based on water-mineral nutrition principle. The author distinguishes four groups of mires:

1) flooded, alluvial nutrition;

2) hard water, ground nutrition;

3) soft water, ground nutrition;

4) rainy, precipitation nutrition.

Referring to the material presented above (see unit 13.3), we see that the classification of R. I. Abolin conforms to the ways of waterlogging of mineral soils.

The classification of mires according to V. N. Sukachev (1926) is also based on the principle of water-mineral nutrition conditions. Phytocenological characteristics of mires (vegetation) are additional criteria.

V. N. Sukachev identified the following main groups of mires:

1) mires that are fed by ground water, represented by fens and transitional mires;

2) mires that are fed by precipitation (raised).

V. N. Sukachev divided fen mires into:

– grass;

– hypnum;

– forest.

Transitional mires include:

1) forest;

2) grass.

While developing the classification of mires, V. S. Dokturovsky took phytocenotic principle as a dominant one.

The author divided swamps into three groups:

1) hypnum-grass;

2) forest (transitional) with hypnum and sphagnum mosses;

3) sphagnum.

Thus, these classifications are based on the following principles: landscape, hydrological, water and mineral nutrition, phytocenotic. And nowadays they haven't lost their scientific and practical significance. They can be used in the economic development of wetlands, creation of specially protected natural areas, researches in various fields of science. However, these classifications characterize not only bog massifs, but separate parts corresponding to bog microlandscapes (facies).

The classification of mire massifs wasn't studied as well as mire microlandscapes, thus the authors also used different principles, in particular phytocenotic one.

For example, the classification of swamps after I. D. Bogdanovskaya-Gienef is based on the edifying role of sphagnum mosses.

The author divides bog mires into three categories:

1) typical;

2) south;

3) decomposed.

Typical bogs have the edifying role of sphagnum mosses. Sphagnum moss cover of southern swamps is not developed as well as the cover of the typical swamps, but phytocenotic significance of green moss increases, and woody vegetation is better formed. On decomposed northern swamps, the growth of sphagnum mosses is reduced, the role of lichens increases. This corresponds to the previously reviewed climax stage of oligotrophic bogs development (see unit 13.4).

The classification of wetlands by S. N. Turemnov and E. A. Vinogradov is based on geomorphological principle (the location on the relief, peculiarities of lowlands). The authors distinguish the following types:

1) floodplain fens;

2) terraced;

3) watershed mires in sewage and closed hollows.

A. A. Nitsenko identified five categories of mires according to the kinds of peat accumulation:

1) peatless, where there is no accumulation of peat due to climatic conditions (e.g. deltaic marshes in creeks in the southern hemisphere);

2) thin, shallow where peat accumulation is slow, hydrological system is absent (polygon mires in the area of tundra);

3) mosaic-focal, where peat deposits are located on uneven territory (hollow swamps in the north of Russia);

4) typical, mires of forest zone, including Belarus;

5) blancket bogs, where there is intense peat accumulation, not depending on relief conditions (coastal regions of Western Europe).

Widely known classification of mires developed by E. A. Galkina for the north-west European part of Russia shows peat-forming process in dynamics.

The classification is based on geomorphological principle, where the form and nature of mire depression is combined with a number of other significant factors, primarily hydrological and phytocenotic.

E. A. Galkina identifies three variants of mire massif development.

1. Central oligotrophic variant (the most common), less demanding to nutrition conditions plant formations appear in the center of the massif, at a distance from mineral dry land around the mire providing richer nutrition. This variant of wetlands development is typical for closed basins.

2. Periphery-oligotrophic variant, the least demanding to nutrition conditions plant formations appear on the periphery of the massif. This variant is typical for areas with rugged landscape. Basins are narrow

and have a flow along the longitudinal axis, which increases the availability of oxygen and causes the grow of eutrophic and mesotrophic vegetation.

3. Mixed variant, in the early period of swamp development mire communities appear on the periphery of the massif, and at later stages of development during formation of bulges they move to the center.

According to T. I. Kucharchik (1996), the typology of bogs of Belarus includes three main types of formation and the evolution of the mire massif.

1. Raised bogs of eluvial origin that are confined to eluvial landscapes (on the watersheds). Waterlogging of dry lands occurs on soils of different permeability due to the strong desalination of soils (see unit 13.3).

2. Raised bogs of superaquatic origin (above-water). Waterlogging occurs in the basins fed by the groundwater. Originally deposited lowland species of peat are changed by transitional and upland ones (see unit 13.3).

3. Raised bogs of subaquatic origin (underwater). Mire massifs are formed during waterlogging of water bodies and include lowland and transitional stages. In deep waters sapropels of 3–8 m deposit first. In shallow waters sapropelic layer is absent, lowland and transitional types of peat accumulate, then the development of the swamp according to oligotrophic type occurs (see unit 13.3).

18 THE GEOGRAPHY AND THE USE OF MIRES. ANTHROPOGENIC CHANGES IN MIRES VEGETATION AND THEIR CONSERVATION

18.1. Mire zoning of Belarus

Belarus is a relatively small country. However, different areas differ significantly in the peat-forming factors: climate, geology, hydrology, vegetation, etc. This is the reason of uneven distribution of mires and also of differences in their qualitative characteristics and quantitative parameters.

The lowest degree of waterlogging occurs at elevated and dissected uplands. They are Vitebsk, Orsha, Minsk, Novogrudok, Slonim, Volkovysk, Grodno uplands, Kopyl and Oshmiany ridges, which are a part of the Belarusian ridge, spread from West to East.

Low degree of waterlogging occurs on uplands of the Belarusian Poozerye that are part of the Baltic ridge: Sventyanska, Braslav, Osveya, Senno ridges, Nescherdovsky, Ushachski-Lepel, Gorodskaya and Lukomlsky hills.

The left side of the Dnieper basin has a low degree of waterlogging.

Polesskaya lowland, in particular, the Central part of the Pripyat Polesye is the most waterlogged area. But even on this territory, there are areas with low waterlogging: Yurovichi and Mozyr ridge, Khoiniki-Bragin upland. And other lowlands which take less area, such as Naroch-Vileiskaya, Verchne-Berezinsky, Chashnikskaya, Polotskaya, also have higher degree of waterlogging.

In general, we can say that the waterlogging of ridges and uplands is less than of the plains and the waterlogging of the plains is less than of the lowlands.

Mire zoning of Belarus is based primarily on geomorphological principle. An average thickness of peat bogs of the Belarusian Poozere is 2.5 m, the thickness of Belarusian Polesye marshes is only 1.4 m. This is explained by the peculiarities of geomorphology of the northern and southern parts of the country (V. M. Podolyako with colleagues, 2003). So, if in Belarusian Poozerye the beginning of the mire formation process was characterized by waterlogging of relatively deep lake basins which have appeared because of the activities of the glacier, in Belarusian Polesye the formation of wetlands occurred in the conditions of flat landscape. Therefore, the south of Belarus is dominated by horizontal formation of mire, which have, as was mentioned above, a small thickness of peat deposits in comparison with the northern part.

Intensive development of the mire formation processes on the territory of Belarus would be impossible without the supportive hydrogeological conditions promoting stable waterlogging of low relief. For example, a characteristic feature of the Poozerye and Predpolesye is shallow bedding of basal moraine deposits and glaciolacustrine clays. The deposits represent water-resistant horizons, which provide excess moistening by minimizing the subsurface flow.

This hydrogeological feature contributed to the eutrophication of large areas even at high river watersheds, such as Drut and Berezina, Neman and Ptich, Western Dvina and Disna, Western Dvina and Obol (V. M. Podolyako and colleagues, 2003). High groundwater level contributed to the waterlogging of Polesye lowland which is covered by sandy rocks with a good draining ability.

According to L. P. Smolyak (1969), the climatic factor also plays an important role in the spreading of mires of different genesis on the territory of Belarus. It is the excess of precipitation over evaporation that made up about 40–50 mm in the north, and in the central part of the country 21–41 mm, determined the appearance of raised bogs.

A. P. Pidoplichko (1961) determined that the development of mire in Belarus is determined by three main factors:

1) geomorphological conditions;

2) soil-geological structure of the territory;

3) peculiarities of water-mineral nutrition of wetlands.

According to A. P. Pidoplichko (1961), there are 5 peat regions and 20 peat districks, which are generally accepted in our country (table).

The highlighted areas differ in the ratio of fens and bogs. Raised bogs prevail in the northern part of Belarus and fens – in the southern part. In general, in our country the share of raised bogs accounts for 18.2%, transition mires make up 20.7% and fens make up 61.1% (D. S. Hunger, 1999).

Peat regions and districts in Belarus

Peat districts	Waterlogging, %	Types of peat deposits, %		
		lowland	raised	transitional and mixed
North region				
1. Braslavsko-Shumilinski	10.6	31.9	60.1	8
2. Gorodosko-Chashniski	8	59.1	36.7	4.2
3. Ostrovetsko-Lepelski	15	72.9	20.2	6.9
West region				
4. Grednensko-Novogrudski	5.7	93	7	–
5. Skidelsko-Ivevski	10	98.7	1.1	0.2
6. Oshmyansko-Slutski	8.8	95.7	2.3	–
7. Logoisko-Dzerzhinski	6.6	98	1.5	0.5
Central region				
8. Borisovsko-Glusski	20.6	75.1	17.7	7.2
9. Krupski-Klichevski	8.9	52	45	3
10. Buchovski-Svetlogorski	12.5	88.3	10.3	1.4
East region				
11. Orshanski-Mstislavski	3.1	87.7	10.3	2
12. Mogilevsko-Chotimski	4.2	75	–	25*
13. Kormyansko-Gomelski	6.3	95.4	–	4.6*
South region				
14. Kamenetsko-Maloritski	10.5	99.6	–	0.4
15. Kobrinsko-Pruzhansko-Gantsevichski	23	86	–	4*
16. Drogichinsko-Pinski	21	99.5	–	0.5*
17. Stolinsko-Lelchiski	24.7	56	25.3	18.7
18. Luninetsko-Lubanski	27	76	–	24*
19. Petrikovsko-Braginski	15	94.1	2.6	3.3
20. Kalonkovichsko-Elsko-Narovlyanski	3.7	99.2	–	0.8*

* Raised and transitional

According to V. M. Podolyako with colleagues (2003), the north peat region is represented by raised bogs which are formed in the hilly lake landscape. The west region is dominated by fens of western-moraine landscape. The central peat region is characterized by large raised bogs and fens of undulating ablative plains. This plain is formed from the accumulation activity of the glacier in the degradation stage; ablative moraine is usually represented by unconsolidated sediments, where there is an increase of sandy and coarse-grained material. In east peat region, where a lot of loess-like species are situated, raised bogs and fens are the most common type of mires. Large fens of Polesye landscape are a distinctive feature of the south peat region.

18.2. The distribution of mires in the world

Bogs are found everywhere in the world, except dry land countries like Arctic and Antarctic.

Their distribution has a distinct zoning. There are more mires in the northern hemisphere with temperate climates. Maximum concentration of mires can be found in West Siberia, in most cases they are raised bogs, and they spread to the coast of the Atlantic Ocean. Another region of the northern hemisphere where wetland ecosystems dominate is located in the northeastern part of North America. In the southern hemisphere the maximum number of mires is situated on the islands of Southeast Asia. In these three regions more than 80% of the world reserves of peat are concentrated. The approximate total area of mires in the world is about 500 million ha.

The total area of mires located on territory of the former USSR is approximately 245 million ha (3.8% of total area), and peat deposits are estimated at 200 billion tons, or 40% of the world reserves (Global peat resources, 1988).

In the 60-ies of the last century, before the wide-ranging land reclamation peat mires in Belarus covered 2,939,000 ha, or 14.2% of the territory of the country. 54% of wetlands were drained during 1960–1990. In the early 21th century (2002), the area of wetlands was 1,345,000 ha, or 6.2% of the country (V. M. Podolyako with colleagues, 2003).

The total area of mires in Europe is about 24% of the whole territory, and mires predominate in the North.

Finland has the largest mire areas in the world, they take 30.6% of the territory (10 million ha). The Finns call their country Suomi, the country of mires. There are many mires in Sweden, 14% of the territory (7 million ha) and Norway (9.2% of the territory (3 million ha)). The total area of wetlands in central Europe (Poland, Germany, and other countries) is small and is not more than 5%. The area of bogs in Ireland is significant (17.0% of the territory). There are practically no wetlands (0.4%) in southern Europe (Pyrenees, Balkans, Apennines).

In Asia mires occupy a small area (1.2 %). They can be found in three countries: Indonesia (13.6% of the territory (26 million ha)), Malaysia (7.0% (2.36 million ha)) and China (0.43% (4.16 million ha)).

The total area of mires in North America is 0.9% of the territory (23 million ha). Zoning is a common characteristic for wetlands of this continent. In the north it is mires of tundra. In the south it is sphagnum bogs, further to the south it's eutrophic mires. Sphagnum bogs are concentrated in the west and the east of the continent.

Mires in South America occupy 7% of the territory (127 million ha). The mainland stretches from the tropics to the subarctic zone and is therefore characterized by a pronounced natural diversity. Tropical grassy mires which cover a large territory are distributed in the river basins of the Amazon and Orinoco. Brackish mangrove mires are common on the cost. Olses resemble them due to significant nanorelief, presented by well-developed hillocks), especially those olses that are formed by creeks and streams coming out of their banks during the period of snowmelt. On the south of the continent waterlogging increases due to the formation of so-called "wetlands-cloaks" or "wetlands-blankets", they look like nature has thrown them on various landforms.

The area of peat deposits in Africa is 2.9 million ha. Distribution of mires in its territory is characterized by extrazoning, i.e. the lack of climatic conditions. They occur in delta (estuaries), floodplains, lowlands of drying lakes, sometimes in high mountain regions with relatively low temperature.

The total area of mires of Australia is 0.4% of the territory. They are located mainly in seabank strip bordering almost the whole continent. The width of this band is more significant in the north and west of the continent, with well-developed tropical mires (delta and mangrove ones).

18.3. Use of mires in the national economy of Belarus and in the world economy

Draining a mire is the main activity of using wetlands in forestry. It strives two main purposes:

1) to provide access to all places of forest-bog massif to carry out economic activities;

2) to form a water-air regime that causes the growth and development of woody plants.

According to RUE "Belgiproles", currently it has been drained about 250 thousand ha of mires in the forests of Belarus. A positive effect has been obtained in 43% of the area; the growth of timber is absent or not obvious in the rest of area (V. M. Podolyako with colleagues, 2003).

The low efficiency of land reclamation calls for three reasons:

1) fail in scientific research, for example, 9% of the drained land was raised bogs, which use from the beginning was doubtful.

2) fail in reclamation network servicing that leads to a new development of the swamp formation process;

3) fail in the water regime regulation of the dried objects, which increases fire hazard during periods of drought.

More than 3 million ha of mires have been drained for agricultural exploitation in Belarus, and among them more than 2 million ha were in Belarusian Polesye. There are no examples of such large-scale reclamation of the landscape in the world practice.

Properly conducted reclamation provides highly efficient agriculture. However, a number of negative phenomena have been revealed recently, on reclaimed lands as well as on adjacent territories. These circumstances caused the deterioration of environmental conditions and reduced the efficiency of agriculture.

River and stream straightening for fast disposal of water excesses has led to a substantial derangement of the water regime and the pauperization of biodiversity on the objects of reclamation, as well as on adjacent areas. As only less than half of the planned reservoirs and ponds have been built, the predominant part of the surface water and groundwater is discharged into the rivers and is irretrievable for Polesye region. As a result, atmospheric drought has become a common phenomenon in the south of Belarus. Taking into account the concerns of ecologists on conflicts between countries arising in the near future over water resources (which have happened already), the situation when the country voluntarily deprives itself of a significant part of water resources cannot be considered normal.

Cultivation of annual crops on reclaimed peat soils and the lack of erosion control measures have led to the development of deflation (wind erosion). As a result of peat shrinkage, its salinity and deflation organogenic layer of reclaimed peat soils decreases annually by 1–2 cm. Thus there is a decrease in the level of groundwater and eutrophication of species composition of the vegetation. The products of peat decomposition pollute rivers and streams, causing their eutrophication which is resulting in deficit of oxygen and disappearing of the animal world.

The peat extracted in our country is used mainly for making fuel (peat briquettes). For example, in 2002, 2.2 million tons of peat out of 2.7 million tons was used for briquetting (V. M. Podolyako with colleagues, 2003).

In agriculture extracted peat is used for the production of fertilizers, composts, in greenhouses, and also for the production of peat pots, growth stimulants. According to some experts, the peat-manure composts are not effective enough and very often the cost of their production and transportation are not money-worth. It would be better to use sapropel as fertilizers. It is assumed that production of this raw material will also help to improve the ecology of the lakes.

On the territory of Belarus 29 peat deposits have been identified, which are the sources of bituminous materials. They are grouped into 5 bases (Valerianovsk, Cherven, Klichev, Bobruisk, Starye Dorogi) (V. M. Podolyako with colleagues, 2003). It is quite promising to use 21 peat deposits for commercial production of sphagnum peat with low degree of decomposition that is used as the hydrolysis of the raw material. They are grouped into 4 bases, located in the northern part of Belarus. It is also promising to use 113 peat deposits as raw bases of therapeutic mud. The largest number of them (53) is concentrated in the Vitebsk region. Based on the identified deposits, bituminous, hydrolysis and mud reserves were created.

Unfortunately, the peat extraction is associated with a number of environmental and economic problems. The current practice of transferring peat-hag to other land users (farming and forestry) has been ineffective, because the cultivation on this land traditional agricultural and forest crops is not economically efficient.

The overwhelming number of peat hags currently is not being used. These peat hags are in a derelict state and represent fire hazard areas. Industrial peat fields often border with the protected wetland areas, which leads to disruption of the hydrological conditions of the reserves, their complete or partial degradation and the increase of fire danger.

On the moor peat is extracted for gardening as fertilizer and supplements to the substrates to improve their structure (Sweden, Finland, Germany, Poland, China, USA, Canada).

In some countries there are factories that produce peat-mineral fertilizers, peat pots for seedlings, greenhouse soil (pressed tiles enriched with mineral fertilizers) (Ireland, Norway, Denmark, Sweden, Germany, Poland, USA, etc.).

Peat is used as mulch in gardens, for growing vegetables, industrial crops, and berry beds.

Prehumic sphagnum peat is characterized by high moisture content and sorption, antiseptic properties, so it is widely used as bedding for pets.

Peat layers with grass cover are used in the slopes landscaping (England, Ireland and Finland).

Sometimes peat is used as insulating and building material (Poland, Sweden, Finland and Germany).

In limited quantity peat is used to produce coke, gas, briquettes, activated carbon, bitumen, wax and other products. It is also used to produce drugs, bioactive additives in products, ointments, creams, used in medicine, food and perfume industry (England, Germany, Denmark, Ireland, Poland, Sweden, Finland, USA). Feed additives for farm animals are developed on the basis of peat in some countries.

Peat hags are used in agriculture, gardening, forestry, pond fish culture. In the USA, Canada, a number of tropical countries peat deposits are used for growing vegetables, horticultural crops.

In mires with berry vegetation, fertilizers are applied to increase yields (Finland, Sweden).

Thus, from one side, mire ecosystems are of global significance for biodiversity conservation, accumulation and storage of huge quantities of carbon and fresh water. On the other side, their utilitarian use provides employment, financial resources for many people and contributes to the satisfaction of a number of important human needs, e.g. food, fuel, fertilizers, as raw material for various industries. Unfortunately, the second statement contradicts the first one. In this regard, it is necessary for public conscience to change its priorities in relation to mire ecosystems. Their rational balance is of high importance. It would be better to abandon the practice of unconditional support of departmental approach, instantaneous interest of various branches of the economy, and to draw attention to complex approach to the swamps. This would provide one of the prerequisites for stable life conditions for future generations.

18.4. Anthropogenic changes in mire vegetation

Anthropogenic vegetation changes occur under the direct influence of fires, drying, cutting, livestock grazing, lay of services, change of water regime during the construction of reservoirs and other structures, and indirect influence of air and soil pollution by industrial and agricultural waste.

While cutting down the pine trees on the raised bogs, Labrador tea, vaccinium uliginosum, myrtle marsh, bog rosemary start overgrowing. Litter fall of wetland shrubs has negative effects on sphagnum mosses. They are displaced by bryidae mosses.

Birch and black alder cuttings are overgrown by marsh grasses, willows (bay-leaf, gray, roundear, swamp, etc.).

In case of fire intermittent shallow margins of mires are affected strongly, peat can burn to mineral bed there. In the central parts of the mires sphagnum moss mat and the surface layer of peat burn out. Ponds and hollows burn out rarely.

On the burnt area, fertilized by the ash, thickets of willow-herb, heather occur. Later this area becomes covered with Labrador tea, bog rosemary, cotton-grass, blueberry, heather.

Sphagnum mosses are replaced with polytrichaceae mosses. Hypnum mosses may appear between hollows.

Along the burnt margins of mires communities of downy birch, willow appear, the life ground cover is dominated by meadowsweet, common reed grass, bush grass. Willows are more diverse in species composition of the life ground cover.

When reclamation of mire occurs, the growth of mire plants varies considerably, especially near drainage channels. Draining forested oligotrophic bogs improves the growth of pine trees and wetland shrubs conduces the appearance of birch and forest mosses. However, there is no more cranberry, cotton-grass, pod grass, sedge, sundew, sphagnum moss. In drained transitional mires, woody vegetation of which is represented by pine-birch communities, the role of downy birch increases, forest and meadow-marsh plants appear, such as ferns (female fern, male hield fern and chartres (*D. carthusiana* (vill.) H. P. Fuch), bush grass, tussock grass, ortilia secunda, stone bramble (*R. saxatillis* L.), blueberries and cranberries grow. Covered with litter (birch leaves) sphagnum mosses start to eliminate and get replaced by forest mosses.

General regularities of anthropogenic mire vegetation changes are the following:

1. Eutrophication of plant communities, it is the replacement of oligotrophic sphagnum mosses by mesophilic bryidae mosses and the appearance of weed (ruderal, segetal) plants.

2. Depletion of mire flora, elimination of its typical representatives, and development of communities including forest, meadow and wetland, riverside, anthropophytous (that have become a part of local flora due to human and growing on the manmade habitats) plants.

18.5. Mires protection activities

As a result of human activity, an area of mire in Belarus has decreased by more than 50% and in Western Europe by more than 80%. Further decline of the mire area is unacceptable, because it will inevitably lead to degradation of environment and irreversible changes in the biosphere.

Currently, the concept of scientific-based management of mires and peat deposits is considered to be a promising approach to the protection of wetlands of Belarus (V. M. Podolyako with colleagues, 2003). Its highest form is the biosphere-compatible nature management. The most important principle of this concept is the balance of ecology and economy. This requires the following measures for protection and rational use of mires.

1. Mires that are located on the way of the mass migration of birds and that are their habitats during nesting or resting, along with those ones which represent habitats of rare and endangered species or support hydrological regime on a large area should be excluded from industrial development or land reclamation, and should obtain an appropriate international status.

2. Economic development of peat deposits should be carried out only in case when technical, economic and environmental aspects of the project guarantee the absence of catastrophic consequences for ecosystems of adjacent territory.

3. After the development of peat deposit a set of activities defined at the design stage is taken to restore all its biosphere functions.

A necessary condition is to restore the hydrological regime, which contributes to the formation of the original type of the mire.

4. Complex inventory is carried out to create an information basis for the protection and sustainable use of natural mires.

5. Previously reclaimed and developed peat bogs that are unprofitable for economic use are derived from circulation and are subject to rebogging with simultaneous implementation of comprehensive scientific monitoring to adjust the ongoing activities and control their effectiveness

6. The network of specially protected natural areas is being improved (SPNA). In mires, which are the key habitats of rare and endangered species are created new SPNT.

More than twenty mire objects are identified on the territory of Belarus that can be included in the list of Ramsar wetlands. Among this list the most essential are the following Republican reserves: "Sporovsky", "Srednaya Pripyat", "Zvanets", "Osveiskoe", "Olmyanskiye swamps", "Yelnya", "Kotra". Each one is inimitable and unique. The "Sporovsky" reserve, for example, was the first classified as Ramsar sites, its area supports 57.4% of the European population of the endangered aquatic warbler.

An interesting fact should be noted: unusual competitions on hand hay-mowing take place on fens, which attracts tourists from various countries of Europe. Scientists from Germany and the UK, who have visited the "Middle Pripyat" reserve, called it as "European Amazon". This comparison is quite reasonable, as a significant site of floodplain of the central European river is preserved in its natural condition. The "Zvanets" reserve represents the largest fen mire in Europe. Its uniqueness is due to amazing beauty of the dry land, covered with mixed forests. The largest in Europe raised bog is the "Yelnya" reserve, which has been repeatedly mentioned in this text-book.

Specially protected natural areas make up a natural basis of our country, the main resources of biological and landscape diversity are concentrated here. Currently they occupy 7.8% of the territory of Belarus (data from 2014) and include: Berezinsky biosphere reserve, national parks "Belovezhskaya Pushcha", "Braslav lakes", "Pripyat", "Narochansky", and 85 reserves of national importance, 249 local reserves, 306 natural monuments of national importance and 568 local ones. Their further development is provided.

In the context of sustainable development on the basis of the conservation and rational use of natural diversity, the international community adopted a number of Conventions. Among them:

– Convention on biological diversity (1992);

– The United Nations framework Convention on climate change (1992);

– The United Nations Convention to combat desertification (degradation) land (1994);

– Ramsar Convention on wetlands (1971).

The Republic of Belarus, as a party of the mentioned Conventions, has undertaken a number of obligations, one of which is to preserve wetlands.

In our country February, 2 is the International Day of Wetlands, guided by the UN since 1971, when in the Iranian city of Ramsar the above-mentioned Convention on the conservation of wetlands and ponds that are critical to migratory birds was signed.

Currently, the International peat society (IPS) coordinates the protection of wetlands in the world. The form of wetlands protection is diverse: natural national parks and reserves, wildlife preservation areas, natural monuments.

REFERENCES

1. Белковский, В. И. Улучшение свойств торфяных почв / В. И. Белковский. – Минск: Ураджай, 1982. – 119 с.

2. Белов, С. В. Лесоводство / С. В. Белов. – М.: Лесная промышленность, 1983. – 352 с.

3. Биосферно-совместимое использование лесных и болотных экосистем (мировые тенденции и опыт Беларуси) / В. М. Подоляко [и др.]. – Минск: Поликрафт, 2003. – 190 с.

4. Богорад, В. Б. Краткий словарь биологических терминов / В. Б. Богорад, А. С. Нехлюдова. – М.: Учпедгиз, 1963. – 236 с.

5. Боч, М. С. Флора и растительность болот северо-запада России и принципы их охраны / М. С. Боч, В. А Смагин. – СПб: Гидрометеоиздат, 1993. – 223 с.

6. Бурак, Ф. Ф. Республика Беларусь как лесная держава / Ф. Ф. Бурак, Л. Н. Толкачев // Проблемы лесоведения и лесоводства. – Гомель, 2003. – Вып. 56. – С. 97–105.

7. Водный кодекс Республики Беларусь от 15 июля 1998 г. № 191-З (с изм. и доп.): принят Палатой представителей 18 июня 1998 г., одобрен Советом Республики 29 июня 1998 г. // Ведамасці Нац. сходу Рэсп. Беларусь. – 1998. – № 33. – С. 473.

8. Волкова, Е. М. Методы изучения болотных экосистем: учебное пособие по организации и проведению исследовательской работы / Е. М. Волкова. – Тула: Тульский государственный педагогический университет им. Л. Н. Толстого, 2009. – 94 с.

9. Гельтман, В. С. Географический и типологический анализ лесной растительности Белоруссии / В. С. Гельтман. – Минск: Наука и техника, 1982. – 326 с.

10. Геологический словарь: в 2 т. / Х. А. Арсланова [и др.]; под ред. К. Н. Паффенгольца [и др.]. – М.: Недра, 1978. – Т. 1: А–М. – 486 с.

11. Гидрология суши. Термины и определения: ГОСТ 19179–73. – Введ. 01.01.75. – М.: Изд-во стандартов, 1988. – 34 с.

12. Глебов, Ф. З. Взаимоотношения леса и болота в таежной зоне / Ф. З. Глебов. – Новосибирск: Наука, 1988. – 125 с.

13. Голод, Д. С. Растительные ресурсы Беларуси, их состояние и рациональное использование / Д. С. Голод // Природные ресурсы. – 1999. – № 1. – С. 88–101.

14. Дашкевич, Е. А. Болотные леса Беларуси, их природноресурсный потенциал и основы рационального использования / Е. А. Дашкевич. – Минск: БГТУ, 2004. – 188 с.

15. Денисенков, В. П. Основы болотоведения / В. П. Денисенков. – СПб.: Издательство Санкт-Петербургского университета, 2000. – 223 с.

16. Ермохин, М. В. Охраняемые лесные виды животных и растений Беларуси. Полевой атлас-определитель / М. В. Ермохин, В. Веннекенс. – Минск: В.И.З.А.ГРУПП, 2011. – 173 с.

17. Морозов, Г. Ф. Избранные труды: в 2 т. / Г. Ф. Морозов; редкол.: И. С. Мелехов (пред.) [и др.]. – М.: Лесная промышленность, 1970. – Т. 1: Учение о лесе. – 558 с.

18. Инструкция по проведению лесоустройства государственного лесного фонда: утв. постановлением Комитета лесного хозяйства при Совете министров Респ. Беларусь 23 сент. 2002 г. № 12. – Минск: Белгослес, 2002. – 94 с.

19. Казенс, Д. Введение в лесную экологию / Д. Казенс. – М.: Лесная промышленность, 1982. – 142 с.

20. Короткевич, В. С. Черный замок Ольшанский. Дикая охота короля Стаха / В. С. Короткевич. – Минск: Мастацкая літаратура, 1992. – 604 с.

21. Красная книга Республики Беларусь. Растения / гл. редкол.: И. М. Качановский (предс.), М. Е. Никифоров [и др.]. – 4-е изд. – Минск: Беларуская Энцыклапедыя імя Петруся Броўкі, 2015.– 448 с.

22. Кухарчик, Т. И. Верховые болота Беларуси: трансформация, проблемы использования / Т. И. Кухарчик. – Минск: Наука и техника, 1996. – 135 с.

23. Лабоха, К. В. Постепенные рубки в сосняках Беларуси / К. В. Лабоха, Д. В. Шиман. – Минск: БГТУ, 2013. – 284 с.

24. Лесаводства: вучэб. дапаможнік для студэнтаў спецыяльнасцей «Лясная гаспадарка» і «Садова-паркавае будаўніцтва» / Г. У. Меркуль [и др.]. – Мінск: БДТУ, 2001. – 434 с.

25. Лесоводство. Термины и определения: ГОСТ 18486–87. – Введ. 01.01.89. – М.: Изд-во стандартов, 1987. – 16 с.

26. Луганский, Н. А. Лесоведение / Н. А. Луганский, С. В. Залесов, В. А. Щавровский. – Екатеринбург: УГЛТА, 1996. – 373 с.

27. Мелехов, И. С. Лесоведение / И. С. Мелехов. – 4-е изд. – М.: Изд-во ГОУ ВПО МГУЛ, 2007. – 372 с.

28. Лесаводства / Г. У. Меркуль [і інш.]. – Мінск: БДТУ, 2001. – 434 с.

29. Молчанов, А. А. Лес и окружающая среда / А. А. Молчанов. – М.: Наука, 1968. – 246 с.

30. Нестеров, В. Г. Общее лесоводство / В. Г. Нестеров. – 2-е изд., испр. и доп. – М.; Л.: Гослесбумиздат, 1954. – 656 с.

31. Общая гидрология (гидрология суши) / Б. Б. Богословский [и др.]. – Л.: Гидрометеоиздат, 1984. – 419 с.

32. Основы лесной биогеоценологии / под ред. В. Н. Сукачева, Н. В. Дылиса. – М.: Наука, 1964. – 574 с.

33. Пидопличко, А. П. Торфяные месторождения Беларуси / А. П. Пидопличко. – Минск: АН БССР, 1961. – 193 с.

34. Правила рубок леса в Республике Беларусь. Технический кодекс установившейся практики: ТКП 143-2008 (02080). – Минск: Министерство лесного хозяйства Республики Беларусь, 2013. – 94 с.

35. Практикум по лесоводству / В. П. Григорьев [и др.]. – 2-е изд., перераб. и доп. – Минск: Вышэйшая школа, 1989. – 311 с.

36. Пьявченко, Н. И. Торфяные болота, их природное и хозяйственное значение / Н. И. Пьявченко. – М.: Наука, 1985. – 152 с.

37. Ражкоў, Л. М. Лесазнаўства і лесаводства. Практыкум: вучэб. дапаможнік для студэнтаў спецыяльнасцей «Лясная гаспадарка», «Садова-паркавае будаўніцтва», «Лесаінжынерная справа» / Л. М. Ражкоў, К. В. Лабоха. – Мінск: БДТУ, 2009. – 248 с.

38. Рожков, Л. Н. Экологически ориентированное лесоводство / Л. Н. Рожков. – Минск: БГТУ, 2005. – 181 с.

39. Реймерс, Н. Ф. Популярный биологический словарь / Н. Ф. Реймерс. – М.: Наука, 1991. – 537 с.

40. Сарнацкий, В. В. Ельники. Формирование, повышение продуктивности и устойчивости в условиях Беларуси / В. В. Сарнацкий. – Минск: Тэхналогія, 2009. – 333 с.

41. Сибирякова, М. Д. Типы леса лесорастительных районов Европейской части СССР с иллюстрацией подлесной флоры / М. Д. Сибирякова. – М.: Гослесбумиздат, 1962. – 208 с.

42. Смоляк, Л. П. Болотные леса и их мелиорация / Л. П. Смоляк. – Минск: Наука и техника, 1969. – 209 с.

43. Соколовский, И. В. Почвоведение / И. В. Соколовский. – Минск: БГТУ, 2005. – 329 с.

44. Справочник работника лесного хозяйства / под ред. И. Д. Юркевича, В. П. Романовского, Д. С. Голода. – Минск: Наука и техника, 1986. – 624 с.

45. Сукачев, В. Н. Болота, их образование, развитие, свойства / В. Н. Сукачев. – 3-е изд. – Л., 1926. – 162 с.

46. Тихонов, А. С. Лесоведение / А. С. Тихонов, Н. М. Набатов. – М.: Экология, 1995. – 320 с.

47. Тихонов, А. С. Лесоведение / А. С. Тихонов. – 2-е изд. – Калуга: ГП Облиздат, 2011. – 332 с.

48. Ткаченко, М. Е. Общее лесоводство / М. Е. Ткаченко. – 2-е изд. – М.: Гослесбумиздат, 1955. – 597 с.

49. Торф. Термины и определения: ГОСТ 21123–85. – Введ. 28.06.85. – М.: Изд-во стандартов, 1985. – 46 с.

50. Торфяные месторождения и их разведка / С. Н. Тюремнов [и др.]. – М.: Недра, 1977. – 263 с.

51. Торфяные ресурсы мира. Справочник / под ред. А. А. Оленина. – М.: Недра, 1988. – 383 с.

52. Трибис, В. П. Слово о болотах / В. П. Трибис. – Минск: Ураджай, 1989. – 231 с.

53. Флора и растительность республиканского ландшафтного заказника «Ельня» / Д. Г. Груммо [и др.].– Минск: Минсктиппроект, 2010. – 198 с.

54. Юркевич, И. Д. Выделение типов леса при лесоустроительных работах / И. Д. Юркевич. – Минск: Навука і тэхніка, 1980. – 120 с.

55. Юркевич, И. Д. Фенологические исследования древесных и травянистых растений: метод. пособие / И. Д. Юркевич, Д. С. Голод, Э. П. Ярошевич. – Минск: Наука и техника, 1980. – 88 с.

56. Юркевич, И. Д. География, типология и районирование лесной растительности // И. Д. Юркевич, В. С. Гельтман. – Минск: Наука и техника, 1965. – 288 с.

57. Paal, J. Estonian mires: inventory of habitas / J. Paal, E. Leibak. – Tartu, 2011 – 221 p.

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