Edita Baltrėnaitė · Pranas Baltrėnas
Arvydas Lietuvninkas

The Sustainable Role of the Tree in Environmental Protection Technologies

Springer

The Sustainable Role of the Tree in Environmental Protection Technologies

Edita Baltrėnaitė • Pranas Baltrėnas
Arvydas Lietuvninkas

The Sustainable Role of the Tree in Environmental Protection Technologies

Springer

Edita Baltrėnaitė
Department of Environmental Protect
Vilnius Gediminas Technical University
Vilnius, Lithuania

Pranas Baltrėnas
Vilnius Gediminas Technical University
Vilnius, Lithuania

Arvydas Lietuvninkas
Vilnius Gediminas Technical University
Vilnius, Lithuania

ISBN 978-3-319-25475-3 ISBN 978-3-319-25477-7 (eBook)
DOI 10.1007/978-3-319-25477-7

Library of Congress Control Number: 2015956777

Springer Cham Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media (www.springer.com)

For Lithuania and its people

Preface

Changes in Earth's biosphere as civilization has developed, its increased technogenic load, and reduced overall resources of resistant stability spur the natural and technological sciences to properly concentrate on the possibilities of interaction between sustainable human activity and natural ecosystems. Trees are a primary focus. Natural tree ecosystems (forests), in terms of the overall mass of the biosphere, have been devastated, in the majority of cases by human activity. Humans also have intensively utilized the energetic, biological, and recreational resources of trees throughout their life cycles. The involvement of industrial society in large-scale applications of fossil fuels along with the rapid development of industry has resulted in the urgent current issue of widespread pollution of the ecosphere and the threat of global warming.

The use of trees in ecological technologies is based on their unquestioned importance in maintaining stability in the biosphere as well as on their presence in a number of Earth's biomes and its ecosystems, particularly those of Scots pine growing in urbanized territories and zones affected by pollution sources. This aspect in particular creates favorable conditions for using trees as bioindicators for establishing the properties and levels of contamination and, in some cases, as a measure for reducing pollution. Because the consequences of negative changes occurring in nature can only be minimized once their essential character is understood, this book focuses mainly on trees as biogeochemical objects and discusses a mechanism by which heavy metals enter into trees, the impact of biotic stressors as determinants of entry, the specificity of metal accumulation in certain species of trees and their parts, the biophilicity of heavy metals, and other aspects of biogeochemistry.

Considering the extent of the life cycle of the tree and with respect to wood as an industrial material and an agent for the sequestration of atmospheric carbon dioxide, investigations into thermally treated wood products and the efficiency of their application in the field of environmental protection engineering are presented. Greater focus is shifted to the properties of biochar and to defining its advantages as a packing material of the filters.

Exhaustive treatment of the versatile role of trees in environmental protection technologies is hardly possible without specifically applied research methods. Thus, investigation into heavy metal concentrations and their distribution in tree rings has assisted in advancing technology for wood sampling and evaluating their representiveness. To assess the eco-technological aspect of using trees in environmental protection technologies, a method of dynamic factors that maximizes the elimination of the impact of local environmental geochemical features on the element uptake evaluation has been developed. As an effective method for examining various ecological aspects, a mathematical simulation of the processes of contaminant transport in the environment, including the original models developed by the authors of the book, has been applied.

The novelty of the book is its explication of the sustainable role of the tree in environmental protection technologies, and the book includes reviews, research, and an evaluation of the use of trees.

This publication is dedicated to scientists and experts in the field of environmental protection. Would-be scientists – Ph.D. and M.A. students – may refer to the study as a source of scientific knowledge in the field of environmental protection technologies.

Reviewers
Prof. Dr. Habil Irena Eitminavičiūtė, Vilnius, Lithuania.
Dr. Arūnas Draugelis, Chicago, United Stated of America.
Prof. Dr. Habil Petras Vaitiekūnas, Vilnius, Lithuania.

Vilnius, Lithuania
2016

Edita Baltrėnaitė
Pranas Baltrėnas
Arvydas Lietuvninkas

Contents

Introduction

It is quite natural that the tree is treated in this book as an important part of nature and the environment in which humans live. With respect to form and functions, trees are sacral objects for people. It should be noted that, though the main functions of trees have not changed, different ways of perceiving them through our senses have developed in humans. The cult of the Tree of Life as a worldwide symbol developed in tribal systems based on using such wooden cult objects as totems and considering a tree as an abode of ghosts. The mythological World Tree was the key artifact promoting the formation of a mythological space concept. According to this concept, the World Tree grows in the center of the universe and forms the axis connecting the sky, Earth, and the underground kingdom. The top of the World Tree supports the sky, its branches embrace the whole world, and its roots reach Earth's depths.

In discussing the modern forms of perceiving the functions of the tree, some well-known feature films are worth mentioning. Thus, in the movie Avatar, directed by James Cameron in 2009, the so-called soul (also native or sound) tree plays the lead and most mystical role and is vitally important for the native people of the fantastic planet Pandora. The 3-D version of Star Wars features Endor, a mystical moon covered with gigantic trees, while the Lord of the Rings features a race of creatures similar to trees called Ents.

In our own day, when the problem of sustainability of various processes and objects is under extensive discussion and debate, the sustainability of trees and their functions has become much more important if we consider their life cycle in areas receiving technogenic pollutant loads. The deterioration of the state of Earth's ecosystemss, the growing concentration of greenhouse gases in the atmosphere, and predictions of climate change are also cause for concern. The sustainability of trees in the context of long-term development is primarily associated with maintaining the geochemical status of the carbon cycle and such dangerous products of technogenesis as metals found in the biosphere, which are strongly affected by human activities.

The life of trees and usage of their products are actually closely connected with their life cycle stages, while their functions confirm the sustainability of trees with respect to their use in environmental protection technologies, which can be attributed to their long life and long-term effects.

Two main areas of environmental protection, where the role of trees is particularly important, are associated with the stage of their life and the stage involving the use of their products. In the first stage, the functions of trees are based on their use in ecotechnologies, while the second stage is closely connected with their use in environmental protection engineering. These two stages are related by the use of trees in environmental protection technologies both as animate and inanimate objects. The major stages of a tree's life cycle include the extraction of nutrient materials from the environment (resources) as raw materials and energy (***Stage A***), the processing of resources (***Stage B***), the manufacture of products (***Stage C***), the use of those products (***Stage D***), and waste utilization (***Stage E***) (Fig. 1).

At ***Stage A***, resource materials are considered to be inorganic environmental resources used by trees to support their vital functions. Trees use inorganic materials, assimilating CO_2 from the atmosphere and nutrient materials from soil for synthesizing biomass and developing their compartments while taking an active part in the biogeochemical cycle (Chap. 1). In polluted territories, these processes

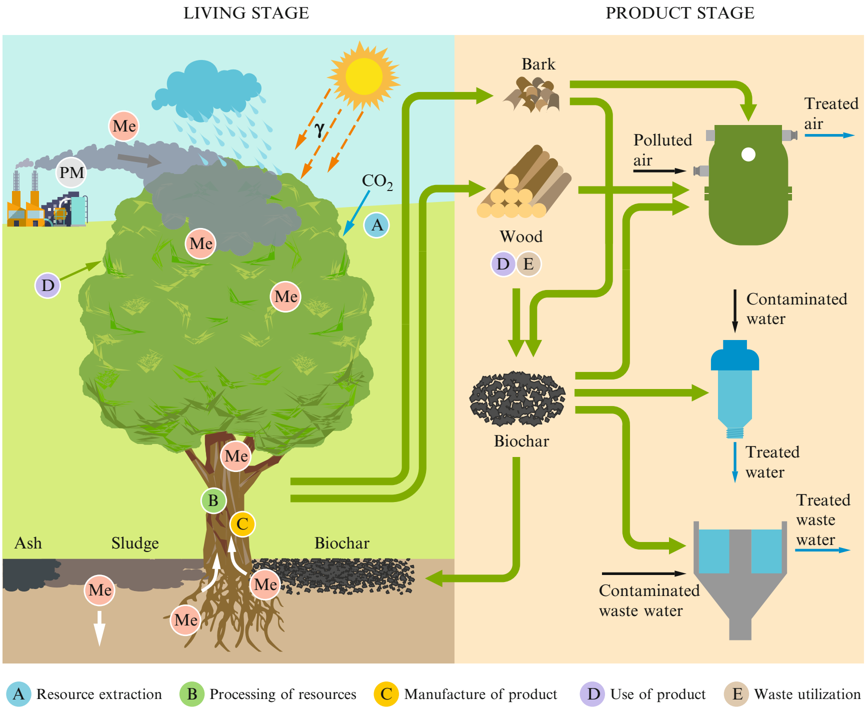


Fig. 1 Major stages of a tree's life cycle

of ecosystems related to trees depend on the type of pollution (Chap. 2) and the transport of pollutants to them. The role of trees as sustainable functional units in areas covered by forests has become particularly important owing to their active participation in biogeochemical carbon circulation in the biosphere. Trees assimilate carbon dioxide from the atmosphere, thereby reducing its concentration as a causal factor of the greenhouse effect. The sustainability of trees is also associated with their role in removing such pollutants as metals from the surroundings and accumulating them in their systems, thereby limiting their mobility and possible negative effects on ecosystems for a long time.

The function of trees associated with stabilizing metals is discussed in Chap. 3, which also partially describes ***Stage B*** of the tree life cycle (resource processing), dealing with the transport of metals and their transformation and accumulation in trees, though in these cases, processes can be strongly affected by biotic factors.

Stage C is associated with the manufacture of the product of biomass synthesis and its increase in the tree's life cycle. In a technogenic environment, a growing tree is subjected to aerogenic and edaphic pollution, causing both quantitative and qualitative changes in biomass properties. The biogeochemical properties of trees are associated with qualitative changes, while functional characteristics determine their qualitative changes (Chap. 4).

At ***Stage D***, relating to the use of the product, a wider range of application of trees besides biomass their use is discussed. In ecotechnologies, these are the functions of bioindication and phytoremediation, involving relatively cheap and effective innovative technologies, which take advantage of the environment's capacity to reduce pollution and risks over the long term (which represents the main sustainable development principles). In environmental protection engineering, the natural and processed products of trees are used. Mathematical models of these processes have become tools that are extensively used in practice (Chaps. 5–7).

At ***Stage E***, the waste materials of trees, including both natural (e.g., bark, wood shavings) and processed (e.g., ashes, biochar, wood fibers) products, which can be practically used, are categorized with waste products. In most cases, these products meet the needs of a specific application and satisfy technical requirements. Their market is being expanded, which helps to avoid negative impacts on the environment and human health. Thus, natural resources are managed in a sustainable way, and materials recovered from trees are used more efficiently (Chaps. 6 and 7).

This monograph aims to demonstrate the links between trees' functions and sustainable development at each stage of the tree's life cycle. The use of trees in environmental protection technologies confirms the ability of humans to expand their knowledge of nature, to have respect for it, and to better understand the role of trees in their lives. Besides the well-known ecological significance of trees, we would like to mention that the role of trees has increased through extensive use of environmental protection technologies. The areas of practical application of trees are as follows: (1) the use of trees and their products in ecotechnologies and the development of predictive models of processes and (2) the evaluation of practical applications of wood products in environmental engineering systems.

The description of the environmental protection role of trees at various stages of their life cycle presented in this book aims to emphasize their ability to improve the state of the environment from both ecological and environmental protection engineering perspectives. Trees can reveal changes taking place in the environment, stabilize the spread of pollution, and protect the environment. When a tree completes the stage of its existence as a living organism, the period of its indirect participation in engineering environmental protection solutions follows.

The present work links nature and technology, ecology and engineering, principles for knowing the world and the application of knowledge, and discusses implications and benefits because, in nature as in life, everything makes sense, while, according to Barry Commoner, everything is connected to everything else.

About the Authors

Edita Baltrėnaitė Doctor of Sciences in the scientific field of environmental engineering and landscape management, Associate Professor, acting professor at Vilnius Gediminas Technical University, Department of Environmental Protection, obtained diploma of Bachelor and International (in English) Master of Sciences at Vilnius Gediminas Technical University. In 2007, she defended her thesis titled *Investigation and Evaluation of the Transfer of Heavy Metals from Soil to the Tree*. Since 2007, Edita has been a scientific secretary of the international *Journal of Environmental Engineering and Ecological Science*, a member of the editorial board of a journal published by Romanian Academy of Science, *Annals—Series on Chemistry Sciences*, a member of the Environmental Institute of Scientific Networks (EISN-Institute), and a representative for Lithuania in the EU research programs COST859: *Phytotechnologies to Promote Sustainable Land Use Management and Improve Food Chain Safety*, COST FA0905: *Mineral-Improved Crop Production for Healthy Food and Feed*, and COST TD1107: *Biochar as an Option for Sustainable Resource Management*.

Areas of interest: application of biogeochemical processes to environmental protection technologies, evaluation of metal transport in the ecosphere and thermal processing, and the application of lignocellulosic products in environmental protection engineering.

E. Baltrėnaitė gives lectures to master's students about environmental protection technologies, anthropogenic impacts on the environment, waste utilization, soil recovery technologies, clean technologies, and soil remediation technologies and supervises doctoral students. She is also a member of the Committee for the Research Area of Environmental Engineering and a chair or member of committees for seven defended theses.

E. Baltrėnaitė was a supervisor of studies of 24 bachelor's and 12 master's degree students as well as Erasmus trainees from Finland, Italy, and Latvia. She also lectures at Helsinki University (Finland), Valencia Polytechnic University

(Spain), Aalto University (Finland), and Southern Denmark University. She has made research visits to the Norwegian University of Life Sciences, the Jozef Stefan Institute in Slovenia, and the Latvian State Wood Chemistry Institute. She maintains close ties and with high schools in Europe and other countries around the world, such as State Montclair University (USA), Swiss Federal Technological Institute in Zurich, Illinois Institute of Technology (USA), Helsinki University (Finland), Tomsk State University (Russia), Barcelona University (Spain), and Ancona University (Italy).

Major publications: author or coauthor of 92 papers (27 of which are published in Web of Science refereed journals with citation index), the author of the textbook *Manufacturing Industries and Environmental Impact*, chapters in the books *Phytoremediation: Management of Environmental Contaminants*; *Plants, Pollutants and Remediation* published by Springer, and *Plant Production Technologies* published by Elsevier.

She is a reviewer of papers for international journals, such as the *Journal of Environmental Management*, *Environmental Science and Pollution Research*, *Environmental and Experimental Botany*, and *Dendrochronology*.

In 2013–2014, Edita Baltrėnaitė was granted a young researcher grant for the work *The Evaluation of Heavy Metals' Stability in Biochar* and, in 2007, a prize for the work *Investigation and Evaluation of the Transfer of Heavy Metals from Soil to the Tree* by the Lithuanian Academy of Sciences.

Pranas Baltrėnas Professor, Dr. Habil, Director of the Environmental Protection Institute of Vilnius Gediminas Technical University (VGTU), a member of three international Academies of Sciences, chief editor of the international *Journal of Environmental Engineering and Landscape Management*, ISSN 1648-6897, a member of the editorial boards of five international journals, chief editor of the *Proceedings of the Conference for Junior Researchers* based on the material of the annual conference *Science—Future of Lithuania*, chair of the organizing committee for the *Environmental Engineering* conference, chair of the Committee of Doctoral Studies in the scientific field of environmental engineering, head of the Public Environmental Protection Commission in the Vilnius City Council, member of the Council of the Union of Lithuanian Scientists, chair of the Environmental Protection Committee No. 36 of the Lithuanian Standardization Department, member of the Noise Prevention Council at the Public Health Ministry, and project evaluation expert on the Research Council of Lithuania. His areas of research include complex theoretical and experimental studies of the technosphere, process modeling and the development of environment protection technologies, including regulation of stationary and mobile air and soil pollution sources and waste and effluents, the investigation of noise sources and electromagnetic fields, and the development of pollution-reducing technologies and equipment. He established the Department of

Environmental Protection, the Institute of Environmental Protection, and the laboratory of the Environmental Protection and Work Conditions in VGTU and pioneered the field of environmental protection engineering in Lithuania. P. Baltrėnas has conducted research visits to Weimar and Mikkeli universities and to Rostock (Germany), Dresden (Germany), Hamburg–Harburg (Germany), Lulea (Sweden), Illinois (USA), and Ancona (Italy) universities and is a Lithuanian representative (coordinator) of international programs such as COST, INTERREG, Seventh Framework, BPD, MUNDUS, and TEMPUS.

Under Prof. Baltrėnas' supervision, 19 doctoral theses have been defended. In 1994, P. Baltrėnas was the winner of the Lithuanian Republic prize for achievements in research, and in 2000, he was awarded the medal of M. Lomonosov and in 2003 awarded an honorary doctorate at the Saint Petersburg Academy of Sciences. In 2007, he was awarded the World Intellectual Property Organization (Geneva, Switzerland) Award Certificate in recognition of his outstanding achievements as an author of inventions.

Prof. Baltrėnas is the author or coauthor of 625 publications, including 15 monographs, 3 textbooks, 26 analytical and review methodological works, and 345 research papers, including 60 papers published abroad and 92 certificates and patents.

Arvydas Lietuvninkas Doctor of physical sciences (volcanology and petrology), professor. His life and work (1956–2006) were associated with scholarship and, later, with Tomsk State University (Russia, West Siberia). A. Lietuvninkas was born when his father, a peasant, was in exile. He completed secondary school in exile in the Krasnoyarsk region with a silver medal and graduated from Tomsk State University, Faculty of Geology and Geography, with honors. He began his career at Tomsk State as a junior researcher, then Lecturer, Assistant Professor, Vice Dean, Chair of the Department of Mineralogy and Geochemistry, and Professor.

A. Lietuvninkas published 5 monographs, 13 teaching aids and textbooks, and authored or coauthored more than 160 papers. He is also an honorary research worker in the Russian system of higher professional education and has received several medals and prizes for his achievements in research and pedagogy.

A. Lietuvninkas has been living in Lithuania since 2006. Currently retired, he collaborates with colleagues from the Department of Environmental Protection of Vilnius Gediminas Technical University in areas of his research interests. Additionally, he is a member of the editorial board of the *Journal of Environmental Engineering and Landscape Management*.

Basic research interests: metamorphism and metamorphic rock, geology of sources of minerals and geochemical methods of their exploration (1961–1988), ecological geochemistry and application of its methods to evaluating the ecological state of ecosystems and their components, and the spread of pollutants in the environment and their accumulation in geochemical barriers.

Areas of activity: practical application of university-level methods, introduction of information technologies and ISO 9001 quality standards at Tomsk State University, application of geochemical methods to the evaluation of ecosystems and their components' ecological state, spread of pollutants and their accumulation in the air, water, and soil, theory and practice of geochemical anomalies in soil, snow cover, and biological objects, application of advanced technologies to environmental protection, and preservation of Earth's mineral wealth.

His major works include *The Stages of Postmagmatic Formation of Minerals*. Tomsk, Tomsk State University, 1977, 110 pp.; *The Stages of Hydrothermal Mineral Formation*. Tomsk, Tomsk State University, 1999, 216 pp.; *Technogenic Pollution and Children's Health*. Tomsk, Tomsk State University, 1993, 92 pp., *The Environmental Problems of the Western Industrial Tomsk Region and Ways to Their Solution*. Tomsk, Tomsk State University, 1994, 260 pp. (with co-authors); *Anthropogenic Geochemical Anomalies and the Environment* (teaching aid). Tomsk, a publishing house of scientific and technical literature, 2002, 290 pp. (2nd edition, 2005); *Geochemistry of the Environment* (textbook). Vilnius. Technika, 2012, 312 pp.

Chapter 1
The Tree in Earth's Terrestrial Ecosystems

This chapter briefly reviews the main functions of the tree in Earth's ecosphere and analyzes the overall geological carbon cycle, rates of Earth's biogeochemical circulation, the main reservoirs of carbon in the lithosphere and ecosphere, and the assessed expected carbon leakage to the stratosphere. Approximately 90 % of the world's carbon (900 Gt) accumulated by terrestrial vegetation is absorbed by forest ecosystems, which represent a short-term reservoir of the world's terrestrial carbon and serve as an additional means of preventing the accumulation of CO_2, a component of the greenhouse effect in the atmosphere. Without going into a detailed description of forest functions, which are discussed thoroughly in specialized works, attention should be paid to the three closest topics of the book: the phytoremediation function of forests, the ecological soil protection function of forests, and the use of wood and wood products as structural materials and fillers in modern air and water treatment equipment. The life cycle of the tree is analyzed as a universal tool for assessing the impact of manufactured products and technologies. The chapter presents a technological scheme for afforestation, which is the remediation of soil contaminated with metals, a comparison of phytoremediation costs and environmental protection benefits for forests, and a summary diagram evaluating the costs and benefits of the life cycle of the tree as applied to forests planted for the purposes of phytoremediation and biochar production.

The sustainable role of the tree in environmental protection technologies is based on at least three essential aspects of using them: reforestation, which actually entails the transfer of a part of atmospheric CO_2 to biomass (wood) and the pedosphere, i.e., the stabilization of carbon in the atmosphere; the long-term stabilization of atmospheric carbon accumulated by wood in biochar as a soil amendment; the use of wood, which is a natural, durable, and ecological material used in construction, ornamentation, and interior decorating, and therefore its wide application in this particular field may cause a substantial leakage of carbon dioxide into the technosphere and, with regard to resources, in part should replace some intensive materials, for example, metal, concrete, plastic, and glass.

E. Baltrėnaitė et al., *The Sustainable Role of the Tree in Environmental Protection Technologies*, DOI 10.1007/978-3-319-25477-7_1

1.1 Functions of the Tree in the Biogeochemical Cycle of Materials

The chapter briefly reviews the basic functions of the tree in Earth's ecosphere and describes changes in conditions for implementing them in the context of modern civilization.

The Carbon Cycle

The tree, as one of the most important components of the present biosphere that carry out biogeochemical metabolism, constitutes a considerable part of Earth's so-called living matter (Lietuvninkas 2012). On the other hand, the existence and evolution of such matter can be characterized by its permanent renewal and improvement as evidenced by the generational changes occurring under conditions of nature and interspecific competition. From the point of view of biochemistry, a change in organisms when they are alive or when they are free following their demise is accompanied by the uptake and release of chemical elements from the environment, which is one of the methods of migration of elements in the biosphere – more precisely, biogeochemical migration. Typically, migration, like the generational change in organisms themselves, is cyclical. In terms of tree, such cycles of migration take place in *tree–soil* space and are known as Liebich biogeochemical cycles of migrating substances or the biological cycle of chemical elements, frequently referred to as the biogeochemical cycle. Because "*everything is related to everything else*" in nature (B. Commoner), the biological cycle of metabolism extends beyond the aforementioned range, affecting the adjacent spheres of Earth, including the hydrosphere, atmosphere, and lithosphere, and forms a geological material cycle (also known as a biogeochemical cycle) (Fig. 1.1).

The activity of tree involved in the biological cycle shows up in their periodical annual changes in separate organs (e.g., leaves, fruit) in deciduous tree and some conifers when biogeochemical migration includes an impressive mass of chemical elements. In the majority of cases, these are biophilic elements –the main chemical elements making up the biomass of terrestrial vegetation in the process of photosynthesis: carbon (C), hydrogen (H), nitrogen (N), calcium (Ca), potassium (K), magnesium (Mg), sulfur (S), phosphorus (P), chlorine (Cl), and sodium (Na). The overall mass of mineral macrocomponents included in biogeochemical migration is close to 8 billion tons, i.e., approximately three times higher than the ionic continental runoff of these macrocomponents, valued at 2.54 billion tons. Thus, terrestrial vegetation annually absorbs approximately 3.1 billion tons of Ca, 2.4 billion tons of K, 0.6 billion tons of Mg, 0.4 billion tons of P, and 0.2 billion tons of Na, which corresponds to 20–26 tons of K and Ca and 3.3–4.6 tons of P and Mg in a land area of 1 km^2. As a matter of fact, along with chemical elements, different

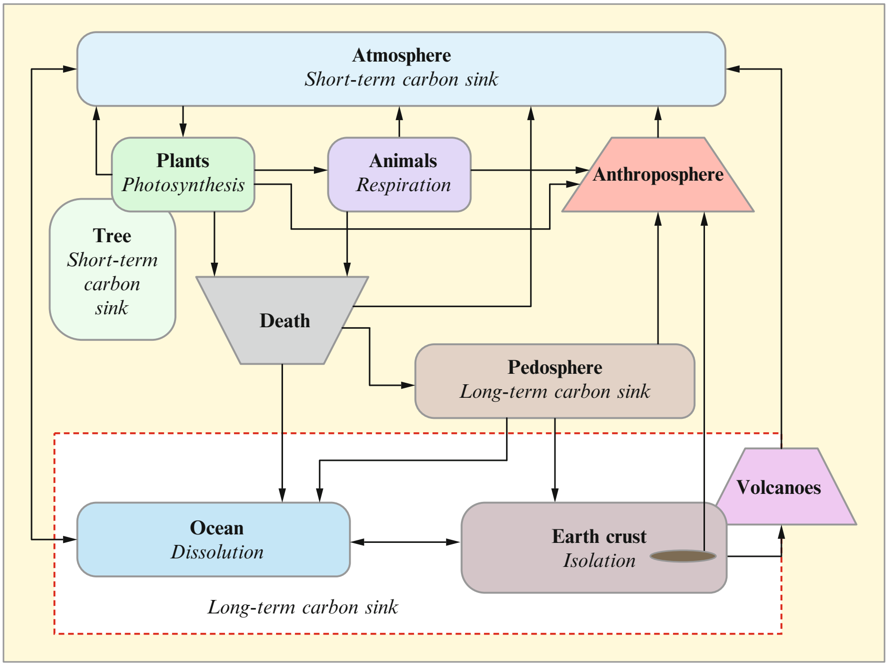


Fig. 1.1 Simplified scheme for geological carbon cycle

microelements, including some metals hazardous to life, are introduced into biological circulation (Table 1.1).

With the help of solar energy, the reaction of photosynthesis to organic compounds causes a bond of carbon dioxide (CO_2) and water. If the overall annual biomass created by the producers (producents) of the organisms of Earth's biosphere makes up 910 billion tons of organic material (430 billion tons of live weight on land and 480 billion tons in the ocean), annual photosynthesis processes remove 125 billion tons of carbon as a component of CO_2 from the atmosphere (Dobrovolsky 2008), including more than 80 billion tons of terrestrial vegetation.

Figure 1.1 shows that, following the destruction of organisms, some free carbon finds its way to natural reservoirs in various ways and remains for a longer or shorter period of time in another form of existence. Earth's atmosphere, the world's oceans, and Earth's crust, its stratosphere in particular, are the well-known global natural reservoirs of carbon.

The general indexes of biochemical circulation on Earth show (Table 1.2) that the regeneration of the largest part of carbon existing in the form of CO_2 in Earth's atmosphere is stimulated by photosynthetics within a period of 5.5 years. As for the world ocean, where the mass of carbon, mainly in the form of HCO_3^-, dissolved in water is at least 55 times greater than that in the atmosphere, the carbon regeneration cycle is substantially longer, as can be observed in the atmosphere, and takes approximately 300 years. However, it is far shorter than the of carbon in an inactive

Table 1.1 Biological accumulation of chemical elements of terrestrial vegetation and their annual uptake according to Dobrovolskii (2008) (Clark values of Earth's crust according to Solovov et al. 1990)

Chemical element	Clark value of Earth's crust (g/t)	Coefficient of biological accumulation	Uptake by annual increment of phytomass	
			Throughout terrestrial area (thousand tons)	1 km^2 (kg)
Mn	770	6.86	41,400	276.00
Zn	76	19.60	8626	57.50
Sr	290	3.48	6900	46.00
Cu	46	9.09	1725	11.50
Pb	16	3.73	431.2	2.87
Ni	58	1.54	345.0	2.30
Cr	99	1.03	310.5	2.07
V	110	0.39	258.8	1.73
Co	23	2.74	172.5	1.15
Mo	1	9.23	103.5	0.69
As	1.7	1.58	60.37	0.40
U	3	0.15	5.18	0.035
Hg	0.08	7.58	2.16	0.014
Cd	0.2	0.63	0.86	0.006

Table 1.2 General indexes of biogeochemical cycle on Earth (the value of number *n* from 1 to 9) (Lietuvninkas 2012)

Primary production of living matter On Earth In ocean	910×10^9 t/year 430×10^9 t/year 480×10^9 t/year
Total living mass on Earth	6500×10^9 t
Regeneration of biomass on Earth Including xylem Herbaceous plants Plankton in ocean	7.2 years $n \times 10$ years *n* years 0.0*n* years
CO_2 regeneration in atmosphere	5.5 years
Regeneration of CO_2 dissolved in ocean	300 years
Water splitting into O_2 and H_2 in hydrosphere	4×10^6 years
Regeneration of total O_2 in atmosphere	3800 years
Water transpiration carried out by Earth's vegetation	$(5–8) \times 10^{13}$ t/year
CO_2 uptake	430×10^9 t/year
Water splitting into H_2 and O_2	340×10^9 t/year
Segregation of free O_2	320×10^9 t/year

form of migration, which remains in Earth's crust in the form of natural gas, oil, and brown/coal as well dispersed carbon (e.g., bitumoides, amorphous carbon, shungite, graphite) in various rocks from solids containing sludge with organic substances and nonlitificated sedimentary rocks (e.g., clay, silt, sand) to shale, marls, dolomite,

Table 1.3 Main reservoirs of carbon in ecosphere and Earth's crust (Dobrovolskii 2008)

	Carbon mass	
Carbon reservoirs	Gt	%
Atmosphere	700	0.04
Terrestrial area of world		
In biomass of plants up to human impact	1150	
In biomass of today's natural plants	900	
Pedosphere	2500	
Ocean		
In biomass of photosynthetics	1.7	
In biomass of users	2.3	
In dissolved and suspended organic matter	2100	
In ions of hydrocarbonate dissolved in water	38,500	
Earth's crust		99.96
Stratisphere		
Organic carbon	15,000,000	
Carbon in carbonates	81,000,000	
Granite layer of block of continents		
Organic carbon	4,000,000	
Carbon in carbonates	18,000,000	

limestone, sandstone, various metamorphic rocks, and even granite. In such a case, carbon from various original reserves becomes isolated from the biosphere for hundreds of thousands, millions, or even over a billion years.

The aforementioned global and other natural reservoirs of carbon greatly differ in their capacities (Table 1.3). Table 1.3 shows the reservoirs whose major amount of carbon is accumulated in Earth's crust, making up 99.96 %. The total carbon in the reservoirs of the ecosphere (in the atmosphere, terrestrial vegetation, pedosphere, and different forms of carbon in the ocean) makes up less than 0.04 % of the carbon sequestered in the ecosphere and Earth's crust. Moreover, carbon is distributed very unevenly within the boundaries of the ecosphere – almost 91 % of carbon is located in the world ocean, where the form of hydrocarbonate dissolved in water makes up more than 86 % of the total carbon in the ocean, and the overall biomass of photosynthetics and users accounts for only around 0.01 %. The biomass of living organisms in the ocean (4 Gt) is presented in Table 1.3 and can be regarded as an optimistic figure because other evaluations – just 3 Gt – have also been made (Schimel et al. 2000).

Carbon is distributed in the reservoirs of terrestrial areas in as follows: 5.6 % in the pedosphere and approximately 2.0 % in the phytomass of terrestrial areas. The total content of carbon in Earth's atmosphere (700 Gt) makes up less than 1.6 % of the total carbon in the ecosphere. This is carbon in the form of dioxide, with the content and concentration of which in the atmosphere the greenhouse effect is related, thus serving to monitor Earth's climate. And this makes up only 0.00059 %, which is a 6×10^{-6} part of the total content of carbon in all reservoirs presented in

Table 1.3. As for carbon reservoirs in the continental biosphere, it is worth emphasizing that an approximate evaluation shows that the present phytomass of Earth's forests makes up around 30 % of the overall terrestrial biomass, while the mass of the pedomass of forest ecosystems makes up approximately 38 % of the mass of the terrestrial pedosphere.

One would expect that, over a long period of evolution, the biogeochemical cycle of substances in the biosphere would be perfectly balanced, i.e., the synthesis of organic matter and its decomposition would take place at very similar rates. However, looking at the Earth in general, it is clear that the biosphere, as one of the planet's shells and as a system, is not closed – it rather actively exchanges materials with deeper geological layers of Earth such as the lithosphere and mantle. Without going deeper into all the aforementioned aspects of the geological evolution of the planet, it is worth recalling that hydrogen and various carbon compounds (e.g., methane, hydrocarbons, CO) constantly enter the biosphere from the depths of the Earth. Thus, the annual flow of methane can reach 2.5–3 Gt (Syvorotkin 2001), while the total content of carbon transferred from the mantle at the developmental stage of Earth's biosphere can reach 96×10^{15} tons (Dobrovolsky 2008). The biosphere, in turn, permanently loses a part of the organic carbon present in sedimentary rock, massive accumulations of Ca, and a smaller content of Mg in the form of carbonates. Subsequently accumulated sediments insulate organic carbon present in sedimentary rocks from the biosphere.

Hence, bituminous shale and sandstone, limestone, dolomite, marl, and other carbonaceous sedimentary rocks, as well as shale oil along with coal, oil, and natural gas fields, are widely dispersed in Earth's stratosphere. The total content of the carbon that "escapes" from the biosphere is enormous – the stratosphere alone may contain approximately 96×10^{15} tons of it (Table 1.3). Nevertheless, the overall leakage of carbon from the biosphere to the stratosphere is difficult to assess – it could amount to approximately 150–200 million tons a year, i.e., the occlusiveness of the carbon cycle in the biosphere can be around 0.14–0.17 % (Lietuvninkas 2012). It is assumed (Bashkin 2004) that for the last 570 million years (the Phanerozoic), approximately 71.3×10^{15} tons of carbon as a component of carbonates and 8.1×10^{15} tons of carbon dispersed in the content of organic matter "leaked" from the biosphere to the stratosphere together with sedimentary rock.

Recently, the urgent issue of global warming brings to mind allegations that, in Earth's distant past, warming waves often coincided with volcanic reactivation and an increase in the emissions of carbon dioxide into the atmosphere (Dobrodeev and Suetova 1976; Bashkin 2004). Under conditions of a milder climate, widely spread forests bound a significant part of the CO_2 in the atmosphere into the biomass of xylem and in the soil humus. As a result, CO_2 concentration in the atmosphere decreased and ended in climate cooling, ice spread, and deforestation.

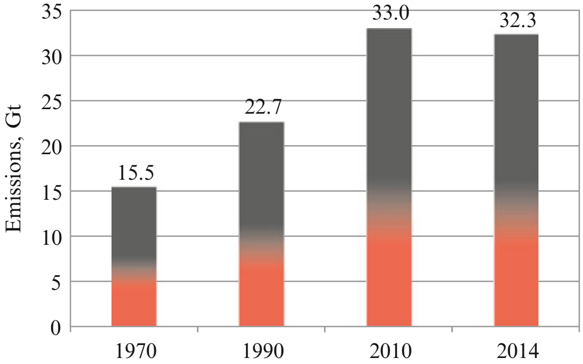
Forests in the Ecosphere

As for already apparently ongoing climate changes, one can nostalgically recall that before the Industrial Revolution, CO_2 concentration in Earth's atmosphere was only 280 ppm. However, since then, the emission of gases (primarily CO_2) causing the greenhouse effect has been constantly increasing and is mostly linked with fossil fuel combustion and cement production. CO_2 concentration in the atmosphere increased and, on 13 May 2013, reached a symbolic point of 400 ppm, following which maintaining a climate warming level of 2 °C on Earth has become increasingly difficult (Carbon Dioxide 2015). Not so long ago, the world reached another milestone: in February 2015, Mauna Loa Observatory in Hawaii recorded an average CO_2 concentration of 400.26 ppm in the atmosphere. In the same month a year earlier, it was lower, at 397.91 ppm (Trends in Atmospheric 2015). Recall that the observatory started functioning in 1958, and then recorded CO_2 concentrations of 85 ppm lower, i.e., during that period of time, concentrations rose by approximately a quarter, which is 1.55 ppm per year on average. In recent years, growth has been significantly higher at 2.75 ppm annually (Global Climate Change 2015).

In recent decades, global CO_2 emissions have grown on average by 45 % at an acceleration of every 20 years (Fig. 1.2).

Yet in 2014, autumn forecasts predicted that global CO_2 emissions would reach 40 Gt in 2014 (Global carbon budget 2014). In reality, it was lower, just 32.3 Gt. Officially, the achievement can be seen as a success on the part of the world in reducing CO_2 emissions rather than a casual fact related to the economic recessions of the early 1980s, in 1992, or 2009 (Rost global'nyh… 2015). The International Energy Agency (IEA) explains the halt to growth in emissions with reference to changes in energy consumption patterns in China and International Economic Co-operation and Development (OECD) countries. In 2014, China increased its production of electricity on the basis of renewable sources. OECD countries have made progress in fostering sustainable growth, including the production of renewable energy and increasing consumption efficiency.

Fig. 1.2 Global CO_2 emission for period 1970–2014



Without going deeper into the problems of CO_2 emissions and balance in the biosphere, as well as possible solutions to them, attention will be focused on **the tree** as the main object of our research and as potential participants in the fighting for the viability of the biosphere. According to data provided earlier by Dobrovolsky, terrestrial vegetation worldwide has accumulated approximately 900 Gt of carbon (Table 1.3), 90 % of which is contained in forest ecosystems. Therefore, forests can be seen as a short-term reservoir of global terrestrial carbon (Fig. 1.1), into which, according to different sources, as part of the process of the synthesis of new biomass, 35–60 Gt of carbon (130–220 Gt of CO_2 in the atmosphere) is annually absorbed from the atmosphere (Isaev et al. 1995; Dobrovolsky 2008). It is assumed that the pure primary output of forest ecosystems accounts for approximately 60 % of the total terrestrial biological output. Almost half of the primary output consists of the biomass of grass, branches, shrubbery, and leaves whose amount covers only approximately 10 % of the total biomass accumulated by forest ecosystems. According to Dobrovolsky, the annual mass of litterfall in terrestrial areas can account for approximately 40 Gt, while the content of carbon on the forest floor comes to 60 Gt (Bashkin 2004). Another version of carbon accumulation in the forests worldwide is presented in Fig. 1.3.

Carbon in leaves, blossoms, fruits, and roots go back only a few years, whereas that in wood charcoal originated approximately 50 years ago (average rate of destruction of wood in the forest). Following the destruction of phytomass, carbon passes into litterfall and then to the forest floor. The average decomposition time of the latter is 1.5–2 years and is highly dependent on specific geochemical conditions of the landscape. As a summarizing index, Glazovskaya proposed a coefficient of litterfall, K_{np}, which can be understood as the ratio of forest litter to the mass of litterfall in a certain area (Glazovskaya 1988). Under conditions favorable for microbiological activity (optimal humidity and higher temperature), falling objects are rapidly decomposed on the forest floor (humid tropical forests $K_{np} = 0.1–0.2$); under less favorable conditions, the process slows down (oak wood $K_{np} = 4$, juniper groves in alluvial landscapes of the southern taiga $K_{np} = 10$); under unfavorable conditions, the process is slow (alluvial landscapes of boreal forests $K_{np} = 10–20$); and under extremely unfavorable conditions, the process is slower still (alluvial landscapes of tundra shrubs $K_{np} = 90–100$, superaqual $K_{np} = 150–3000$).

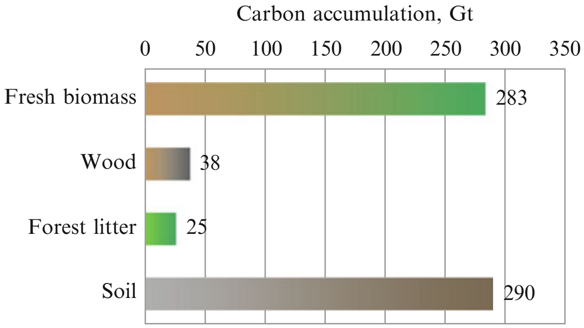


Fig. 1.3 Carbon accumulation in forests worldwide (WHO Global Forest… 2005)

Table 1.4 Carbon found in soil of forests worldwide and in phytomass (according to Olsson 2012)

Biomes	Area (million ha)	Accumulated carbon (Gt)		
		Soil	Phytomass	Total
Boreal forests	1509	**625**	78	**703**
Tropical forests	1756	216	**159**	375
Temperate forests	1040	100	21	121

Maximum values

This means that, for example, the forest floor in humid rainforests may not be formed at all because falling objects mineralize faster than they form. In contrast, in cold climates in the gleyed environment of water-logged forests, the organic matter of falling objects decomposes very slowly, creating favorable conditions for peat formation. The total global stock of peatland carbon is 165 Gt (Bashkin 2004). Moreover, the end of the last century witnessed, in the course of warming, the ecosystems in Alaska and Russia being transformed from carbon sinks into harmful sources of carbon emissions (Oechel and Vourlitis 1994; Zamolodchikov et al. 1997).

The distribution of carbon content in the forests of different biomes is presented in Table 1.4.

Because of the rapid decay of phytomass in tropical forests, soil and the forest floor have accumulated a relatively small amount of carbon, 216 Gt in total. Meanwhile, the soil and forest floor of boreal forests of a similar area (even 16 % less than that of tropical forests) have accumulated 625 Gt of carbon, which is almost three times greater than the level in tropical forests. Naturally, carbon accumulation in the phytomass of forests has the opposite relationship – it is twice as high in tropical forests. Table 1.4 provides a general answer to the question of how carbon distribution and accumulation will change in case of warming in boreal forests, which serve as an important reservoir in terrestrial areas. Under rapid mineralization of the organic matter of falling objects at higher temperatures, carbon accumulation in soil will substantially decrease, i.e., part of the carbon, in the form of CO_2 will "evaporate" into air, further enhancing factors in warming. A similar process, including as a result of fires, has been found to be taking place, for example, in boreal forests in Canada (Juday et al. 2005; Kelman et al. 2009).

However, the tree, as the core component of forest biocenosis in the biosphere and humans, is very valuable as an absorber of carbon from the atmosphere and as a temporary carbon reservoir stabilizing the circulation of gases, primarily CO_2 and O_2, in the ecosphere. Tree-covered terrestrial areas, i.e., forests, are considered in connection with at least three aspects of their importance, generally understood as the ecological, social, and economic functions of forests (Table 1.4).

Without going into the details of numerous and accurately described functions of forests presented in specialized works, only three of those strongly related to the topic of this book will be paid extra attention. Once again, returning to the biosphere function of stabilizing the climate, discussed previously, seems to make no sense.