An Introduction to Systems Geography

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By

Bobushev Temirbek Seitkazievich

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AUTHOR'S PREFACE

The issues considered in this work complement the basic curriculum for the development of theoretical geography.

The author assumes that the reader is already familiar with the classic course in general geography. The integrative approach taken here allows the reader to cover the entire problem area. The proposed systems approach to geography will be useful not only for graduate students, but also for researchers and for anyone interested in general issues in the field of Systems Geography.

The purpose of the proposed publication is to emphasize the unity of the laws of physics, chemistry, biology and geography and at the same time the clear and obvious nature of certain solutions obtained from geosystem and ecosystem analysis.

I guess that graduate students, who already have a large amount of detailed information, should focus on generalizations rather than encyclopedic knowledge, which inevitably becomes fragmented and selective as the amount of available data increases.

Approaching the subject of geography from the point of view of fundamental scientific knowledge (physics, chemistry and biology) provides a convenient platform for formulating generalizations. That is why the subject of this book has been divided into a number of sections: the structure and functions of landscapes and ecosystems, the importance of energy in the environment, environmental information and decision-making, regulatory processes in the geosystem and ecosystem, the ways in which geosystems and ecosystems interact, and biodiversity, and the evolution of landscapes and the environment, systems approach to environmental change research.

I believe that these generalizations will provide readers, especially those interested in expanding their knowledge beyond the mere academic minimum, with useful knowledge in the field of modern geography. My goal is also to offer a common platform for methods of modeling geosystem dynamics.

It goes without saying that any attempt to generalize the various natural phenomena and processes is associated with the risk of a certain simplification or going beyond the boundaries of geographical science. Such expectations are possible in this work, and the reader should be fully aware of the significance of this fact.

As mentioned above, this study is primarily aimed at graduate students and early career researchers, so the information is presented mostly in the form of a reference book. To encourage readers to try their hand at interpreting the observed events, the last section of the book contains some unsolved hypotheses concerning fundamental natural processes and the phenomenon of nature itself. These include key issues of location and spatial analysis, as well as the problem of developing a concept of coexistence between the environment and humanity. I hope that the presented research will encourage readers to try to develop their own approaches to such issues.

The work is supplemented with references, including to other reference books, selected monographs and periodicals devoted to the main problems of Systems Geography.

INTRODUCTION

The contents of this publication include an analysis of the concepts, structure and functions of the natural landscape and ecosystem. The natural landscape is the original or physical landscape that existed before human culture began to influence it. Moreover, the natural landscape and the cultural landscape are separate parts of the landscape. A natural landscape consists of a set of landforms, such as mountains, plains, and plateaus. Lakes, streams, soils (such as sand or clay), and natural vegetation are other features of natural landscapes. The study of natural landscapes is the subject of physical geography and landscape science, which aim to spatially study natural phenomena that make up the environment, such as rivers, mountains, landforms, weather, climate, soils, plants and other physical aspects of the Earth's surface. There are two main types of landscapes: natural landscapes, which include features such as mountains, forests, rivers, and animals, and man-made landscapes, which include features such as fields, houses, roads, shops, and parks. In this regard, landscape studies (studies of natural landscapes) are aimed at studying the localization, spatial distribution and shape of natural landscape elements in order to understand their structure, processes and dynamics.

Unlike natural landscapes, ecosystems provide habitat for wild plants and animals. They facilitate the development of various food chains and webs and control key ecological processes that help sustain life. They also participate in the recycling of nutrients between biotic and abiotic components.

The evolutionary development of ecosystem structures allows organisms to develop and maintain their architecture, perform activities and store resources necessary for survival on a landscape basis. For this reason, a distinction is made between support structures (akin to building materials), functional structures (acting as tools and machines) and storage structures (necessary to store important substances, providing a compromise between dense packing and ease of access) for self-organization. Continued evolution has led to the emergence of ecological structures capable of using basic physicochemical interactions to support organizational processes, thereby limiting the amount of encoded information needed to perform their functions. The systems approach adopted in this paper focuses on general phenomena and processes in the natural environment. The aim of this approach is to explain the strategies used by natural landscapes and ecosystems based on fundamental concepts of physics, chemistry and information theory. The systems approach adopted in this paper focuses on general phenomena and processes in the natural environment. The aim of this approach is to explain the strategies used by natural landscapes and ecosystems based on fundamental concepts of physics, chemistry and information theory.

Unfortunately, the concept of landscape or natural landscape, in its natural representation, has undergone significant transformation in recent decades. In many publications, it is interpreted so broadly, with significant applications to the social component, that sometimes the thread of the discussion of landscape as a natural territorial formation is lost. Natural landscapes or landscape ecosystems are studied within the framework of landscape ecology. To distinguish between a natural landscape and an ecosystem, it is proposed to use the concept of a natural landscape as a geosystem, which can help eliminate confusion when discussing the differences in the manifestations of geosystems and ecosystems. According to Sochava V.B. [104, 1978], a geosystem is defined as a relatively integral territorial formation, formed in close interconnection and interaction of nature, population and economy, the integrity of which is characterized by direct, reverse and transformed connections developing between the subsystems of geosystems [38, 2005]. Each such system has a certain structure, which is formed from elements, relationships between them and their connections with the external environment. An element is the basic unit of the system, performing a certain function. Depending on the scale ("resolution level"), an element at a certain level is an indivisible unit. As the resolution level increases, the original element loses its autonomy and becomes the source of elements of the new system (subsystem). Three levels of geosystems are distinguished: the global geosystem (synonymous with the geographic envelope), the regional geosystem, corresponding in scale and configuration to the landscape, and the local system, corresponding to the physical-geographical facies, which is a relatively short-lived, rapidly transforming complex.

The science of general ecology explores and studies elements within an ecosystem and these systems can be quite complex. All ecosystems must maintain a delicate balance between all of their constituent parts in order to thrive. Human intervention and extreme natural events can upset this balance and threaten the health of the ecosystem. The broad range of data presented is compiled into combined assessments that describe the current state of an ecosystem, predict future ecosystem state, and evaluate various management strategies that can improve ecosystem health.

Studies of natural landscapes (geosystems) and ecosystems provide us with information to better understand our world's environment. This information can also help us improve the environment, manage natural resources, and protect the health and safety of humans and all life on the Earth.

Since the main goal of education is the fact that the knowledge gained must be applied in practice, linking facts, then thanks to what has been said, it becomes possible to predict the consequences of such use. This can only be achieved by familiarizing students with the rules and mechanisms that control various processes and phenomena in the environment. Since the main goal of education is the fact that the knowledge gained must be applied in practice, linking facts, then thanks to what has been said, it becomes possible to predict the consequences of such use. This can only be achieved by familiarizing students with the rules and mechanisms that control various processes and phenomena in the environment.

CHAPTER 1

STRUCTURE AND FUNCTIONS OF LANDSCAPES AND ECOSYSTEMS

Geographical information about natural landscapes (geosystems) is not so formalized as to speak about the existence of Theoretical geography. However, the content and structure of nature and its main elements, built as systems, allow us to discuss the ideas of Systemic Geography. The essence of this concept is that the concept of natural landscape, by its construction, is a systemic concept or a geosystem of a certain level.

While an ecosystem is homogeneous, a natural landscape as a system is heterogeneous and can be mosaic or zoned. Moreover, with changes in time, changes in the species and habitats of ecosystems may be observed in certain areas. The replacement of one plant community, for example, by another in the process of ecological succession can continue until it reaches the state of a "climax community." Such examples include the formation of forests or forest landscapes or their degradation during forest fires. However, succession can also stop and be in relative equilibrium until a disturbance in equilibrium restarts the succession process. In this regard, understanding how succession occurs in different ecosystems, as well as what types of disturbances and time intervals lead to the formation of different plant and animal communities in a given area of the environment over time as a result of natural factors or human impacts, is important for researchers who want to understand ecosystem dynamics and effectively protect or restore natural communities on a landscape basis.

Like evolution in organisms, succession in ecosystems tends to develop in the direction of increasing independence from environmental changes (increasing autonomy of systems). As an example of the manifestation of such dynamics, one can note the external impact on natural landscapes during their active use in the course of anthropogenic activity. In this case, natural landscapes increasingly lose their regional identity, as external input technologies (impact technologies) become more aggressive and preferable.

It is known that the theory and practice of ecological (organic) agriculture, oriented towards external influence, tends to strengthen the autonomy of local ecosystems along with regional identity. Ecological succession can occur in many contexts and over many time periods. For example, primary succession can occur in lava flows where new land has formed or during the retreat of glaciers. Secondary succession occurs where wildfires have destroyed coniferous forests or where former agricultural land is converted to grassland or shrubland. In general, for all changes, the example is that the "climax community" is not the first to be present on the natural landscape after succession has begun: first, intermediate communities occupy the space, sometimes for many years, creating ideal conditions for subsequent communities.

However, recent research suggests that even in climax communities, changes in available resources can shift the balance of species composition over time, even without formal disturbance [15, 2024]. In this regard, important research findings include the impact of climate change and anthropogenic factors on changes in ecosystem responses, leading to biodiversity loss and invasive species. Ultimately, such changes are accompanied by native species becoming extinct or rare and new species entering ecosystems as a result of changes in the environment, including climate baselines. Studying the nature and content of such changes can provide important information for the restoration of natural landscapes, which are the basis for the development and change of ecosystems.

The use of methods for measuring and assessing ecosystem change indicators can be very useful in studying ecosystems and natural landscapes in general in certain areas. By the way, if there is adequate knowledge of local conditions, represented in the form of inputs and outputs of such an ecosystem, they can be used as indicators of potential sites for restoration of natural landscapes, as well as indicate expected landscape degradation. However, while organic farming, as currently defined by law, has the potential to promote agroecosystem diversity and regional autonomy, it creates opportunities for on-farm conservation of natural landscapes only when the farmer places special emphasis on this as an additional goal of his/her work organic agriculture.

Thus, natural landscapes are defined as a complex of geographically, functionally and historically interconnected ecosystems [23, 1997]. To understand the content and mapping of natural landscapes, knowledge of the ecological patterns of such development is crucial. The sustainability of the landscape as a natural structure, as well as the multiple and interdependent functions of its ecosystems, require careful definition at the macro-, meso- and micro-levels of such a structure.

General Properties and Functions of Ecosystem

An ecosystem is defined as a community of life forms that coexist with nonliving components and interact with each other as a single system. In other words, an ecosystem is a chain of interactions between organisms and their natural environment.

The structure of an ecosystem is characterized by the organization of both biotic and abiotic components (Fig. 1.1) and the distribution of energy in the environment. It also includes the climatic conditions prevailing in that specific environment.

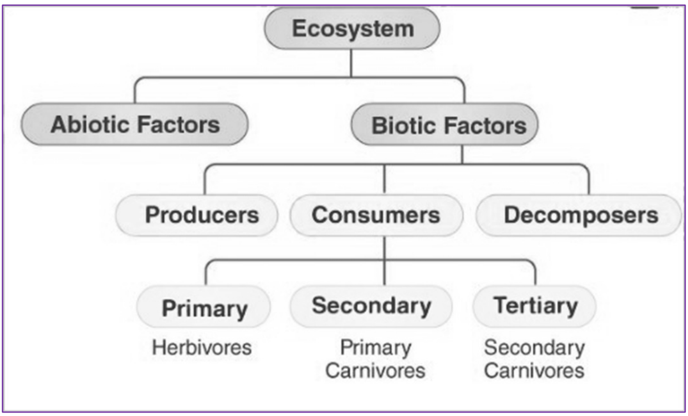

Fig.1-1. Structure of the ecosystem (adapted for this publication).

Abiotic and biotic components are interconnected in an ecosystem. An ecosystem is generally defined as an open system where energy and components can interact with each other across boundaries.

Biotic components refer to all living components in an ecosystem. Abiotic components refer to non-living components of an ecosystem. They include: air and water, assessed through appropriate turbidity indicators, soil and minerals. A special role in the content of abiotic components of ecosystems belongs to climatic indicators, such as air temperature gradients, sunlight, which in combination are manifested through the location of certain ecosystems.

The dynamics of the "life activity" of ecosystems are closely related to and determined by their functions. The active manifestations of ecosystem functions include the cycling of nutrients between biotic and abiotic components. It allows for the regulation of basic ecological processes, supporting life systems and ensuring ecosystem stability. At the same time, abiotic components, participating in the synthesis of organic components, ensure the exchange of energy between the components of the ecosystem and the environment, which helps maintain the balance between different trophic levels in the ecosystem and the circulation of minerals in the biosphere.

The main parameters of an ecosystem, represented graphically in the form of an ecological pyramid, include the number, energy and biomass of successive trophic levels of the ecosystem. The base of the ecological pyramid is usually made up of producers, followed by primary and secondary consumers. Tertiary consumers take the top spot. In some food chains, quaternary consumers are at the very top of the food chain. At the same time, producers, as a rule, outnumber primary consumers, and, similarly, primary consumers outnumber secondary consumers. Finally, apex predators also follow the same trend as other consumers, but their numbers are significantly lower than secondary consumers.

Thus, the study of the relationship of organisms with each other and with the environment is the subject of ecology. However, when we talk about types of ecosystems, we are essentially discussing the content of natural landscapes, which is the goal of landscape ecology. In this case, the ecological approach may produce different results in representing the ecological characteristics of the landscape. Hence, the allocation of ecological units by ecologists will emphasize the ecological interrelationship of landscape attributes [125, 1989]. The introduction of land systems mapping techniques since the early 1950s has been successful in compiling biophysical data over large areas. The results obtained have been useful in assessing the natural resources of new areas and regions [14, 1990].

Features and Contents of the Landscape Structure

Natural landscape structure refers to the quantitative description of the arrangement of elements in a landscape, such as land cover types, connectivity, and fragmentation. It involves the use of landscape metrics to analyze patterns and processes occurring in the landscape. In the natural environment, the structure and function of the landscape as a single system are closely intertwined. This phenomenon is closely related to the principles of evolution. Evolutionary development has created structures that allow landscape elements to develop and maintain their architecture, perform actions, and store resources necessary for existence. For this reason, a distinction is made between support structures, functional structures and storage structures.

Perhaps the most important property of natural landscape structures is their capacity for self-organization. Continued evolution has resulted in landscape structures that are able to use basic physical-chemical interactions to support directed organizational processes, thus limiting the amount of encoded information required to perform their function. In general, the landscape structure in combination with the characteristics of the life cycle of the species allows us to determine the existence of this species as a single large population, as a mega-population of demes associated with the movement of individuals, or as a set of individual isolated populations, which determines the heterogeneity of the landscape, as mentioned above.

The use of measurements in landscape science allows us to describe the landscape structure by composition and configuration. Composition consists of the number of different types of habitats in a natural landscape.

For example, the cover of different crops, forests or grasslands or the overall diversity of habitat types that can be found represent what is present in a natural landscape. Configuration, on the other hand, refers specifically to the size, shape and spatial arrangement of individual habitat patches [27, 2011]. Research findings suggest that increasing heterogeneity in both of these dimensions of landscape structure can improve biodiversity and ecosystem services, and that their effects are often interactive [60, 2019; 61, 2015; 101, 2019].

The structure and function of the landscape can change for many reasons and in many ways. Changes can occur at different scales and over different time periods [22, 2001].

Vulnerability or sensitivity to change varies from landscape to landscape. The level of vulnerability or, conversely, resilience is usually divided into two components: resistance and resilience. Resilience is defined as the ability of a landscape to remain unaffected by disturbance or to recover relatively quickly from disturbance. For example, pastures can be much more resistant to wind damage than forests because grasses can bend in the wind without breaking. At the same time, temperate forests recover much faster after cutting down than tropical forests, which, by the way, may never recover due to differences in the depth of tree roots and soil fertility.

Changes in the landscape can also be caused by manifestations of both external and internal factors. Internal factors of population change of a species include recruitment, growth, mortality, and spread or migration, which can lead to invasions or extinctions, as well as changes in the boundaries of a site or the entire landscape. Other factors appear to be external to the natural landscape and are influenced by external forces such as climate change and others. Anthropogenic impacts on natural landscapes or specific areas include deforestation and reforestation, urbanization, construction of transport corridors and agricultural land conversion.

As environmental conditions change, the configuration of the natural landscape may also change. Landscapes may be structured by other landscape types; i.e. large landscape areas may be fragmented into several smaller areas. Landscape fragmentation, particularly in the tropics, has significant impacts on species biodiversity. However, some of the potential consequences of fragmentation may include the loss of patch types and their characteristic species, resulting in reduced connectivity with implications for species movements and a reduction in landscape interior area.

System Approach and Landscape Dynamics Modeling

The presence of various indicators or indicators of individual elements of the natural landscape makes it possible to use a systematic approach that involves modeling the "behavior" of the landscape in the event of changes in both external and internal factors of landscape development. The systems approach assumes that "structure, function, and process are three aspects of the same thing, and with the environment they form a complementary set" [31, 2006, p. 23]. Integration of entities of increased complexity, in which simple entities are integrated to form more complex entities, allows us to consider the natural landscape as a system. The elements of such a system can be characterized as follows: a) the structure of the system determines its components and relationships, b) the function determines the results or products of the system, c) the process determines the activity in which the components of the system are involved, and d) the environment is the interdependent setting in which these aspects of the landscape "behavior" exist [40, 2011].

Because the time scales of landscape change can be quite long, studies of landscape-level dynamics are often conducted using ecological models. There are four general classes of models that are used to predict landscape dynamics: transition probability models, individual models, ecosystem process models, and biogeographic models.

Transition process models are useful when the factors causing landscape change are not represented mechanistically. If we assume that a landscape with three patch types was sampled twice, before and after an event, we can plot a graph showing the percentage of each patch type that remained the same or was converted to another patch type in this hypothetical landscape. In Figure 2-1 shows the predicted change over 25-time steps if this initial landscape had 50 units of forest, 25 units of agriculture, and 10 units of developed land.

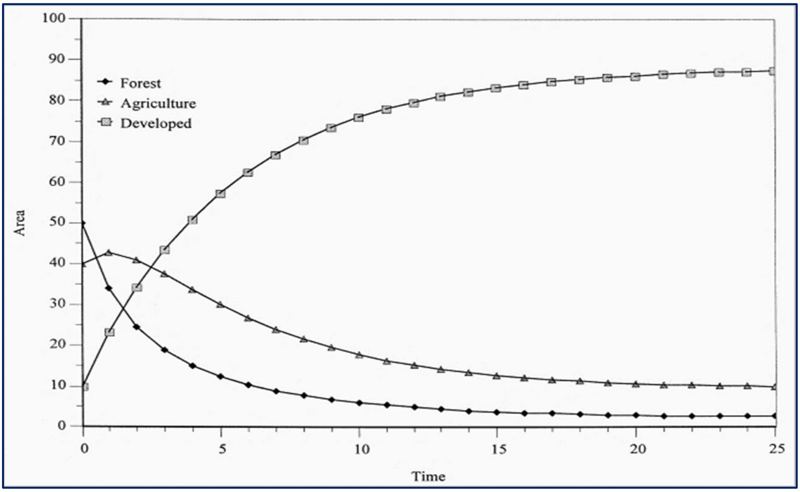

Fig. 2-1. Analysis of the transition matrix of a hypothetical landscape with three types of sites of different densities: forest, 50 units; agriculture, 25 units; and developed territories, 10 units [22, 2001].

Thus, such a natural landscape stabilizes with a high proportion of developed land and very little forest area. The transition analysis is very simple to perform and can be useful for studying the effects of different probabilities and initial conditions. However, I note that the simple form of landscape change presented here did not take into account variations in the rate of change, and did not include any specific spatial component.

Individual simulation models are useful when information is known about the mechanisms underlying changes in the structure of a natural landscape. These models incorporate life history traits of individuals and the mechanisms by which they interact with their environment to predict landscape-level dynamics. Landscapes are modeled by linking sites together into a grid or transect. Plots can be spatially interactive through processes such as seed dispersal. Interactive individual models can spatially represent different environmental conditions, including differences in soil properties, climate, and disturbance regimes [11, 1997]. These models are most often used to assess changes in the diversity of groups of similar species (i.e. the functional types) rather than species diversity.

Linking a spatially interactive individual model to an ecosystem model has great potential for modeling the dynamics of natural landscape structure and function, as well as changes in species diversity. An important first step was illustrated by linking a non-spatial individual model to a nutrient cycling model to study the importance of soil heterogeneity in forest responses to global climate change.

The third class of models simulates ecological processes, including nutrient cycling rates, water balance, and primary production. These models have been linked to geographic information systems (GIS) to simulate large regions. The effects of climate, soil texture, and management on soil organic carbon dynamics were modeled for central grasslands of the United States [9, 1991]. In this large region, soil organic carbon increased with precipitation and decreased with temperature and percent sand content.

Biogeographic models are a fourth class of models that can be used to study vegetation responses to environmental heterogeneity. These models incorporate large-scale climate and soil changes, as well as water and energy limitations on plant growth, to simulate continental and global patterns in vegetation. Biogeographic models are most useful for simulating the responses of plant functional types at large spatial scales to both equilibrium and transient environmental conditions [79, 1992; 67, 1998].

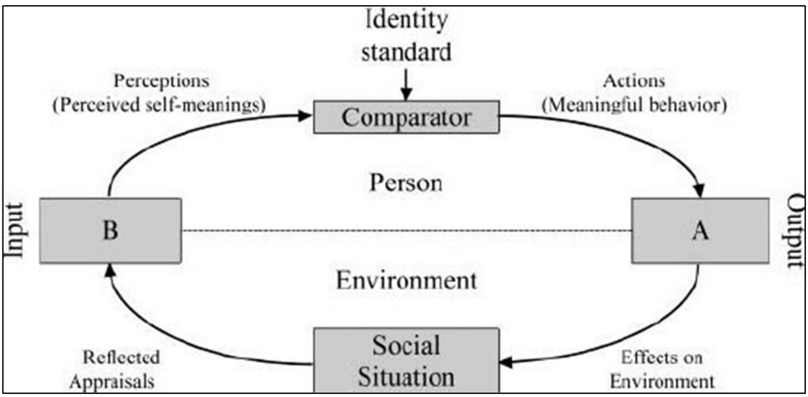

Fig. 3-1. Model of the identity process [9, 1991].

These models do not explicitly include landscape-scale processes or fluxes between sites.

Although each of these models has traditionally been used independently, linking different models together is a recent development that has significant potential to address problems associated with natural landscape diversity. Because of the important feedbacks between species and rates of ecosystem processes [96, 1994]. Incorporating natural landscape-scale water, carbon, and nutrient fluxes into a spatially interactive individual model is an important area of research for predicting diversity dynamics in natural landscapes. Establishing connections between biogeochemical and biogeographic models is another area of potential application to the study of natural landscape diversity, especially if plant functional types become more defined and landscape-scale processes such as disturbance regimes are included.

Landscape Structure and Ecosystem Functions

The analysis of natural landscapes and the use of various models are the basis for studying how landscape patterns influence ecological processes and ecosystem functions. This approach to research is important in terms of continuous monitoring of the state of the environment, landscape planning and conservation of species. Changes in natural landscapes due to active land use lead us to the problem of the relationship between anthropogenic disturbances and the regime of natural landscape changes.

Landscape structure can influence the viability of species and the functioning of ecosystems. In this regard, it is important to study how natural landscape structure can influence ecosystem structure and functioning, and how natural landscape heterogeneity is in turn created or maintained by the redistribution of nutrients or organisms within and between ecosystems.

The results of studies of the dynamics of the natural landscape have shown [48, 2019] that in some cases, under certain conditions, landscape functions can be disrupted and lead to irreversible consequences of the state of the landscape, which in turn has a significant impact on the processes and functions of the ecosystem.

It should be noted that anthropogenic and natural disturbances of the landscape state are a direct feature of any landscape. In nature, under natural conditions, the dynamics of disturbances in the landscape gradually leads to a change in its structure, which also manifests itself on the spatial scale of the habitat. However, it should be noted that the peculiarity of the temporary immutability of ecosystem functions, determined by interactions between species, allows for the stabilization of the functioning of ecosystems, which is defined, for example, as a manifestation of the effect of successful plant reproduction. This study represents an important advance toward a better understanding of temporal invariance in ecosystem function as determined by species interactions, and suggests continued research to provide additional information on ecological stability in multitrophic communities [57, 2024].

It should be noted that the use of functional models on a global scale for an integrated study of biodiversity and ecosystem functions does not always lead to optimistic results, since they do not always take into account the role of biodiversity in maintaining ecological functions. However, such an approach is very important, since it allows us to clarify the relationship between changes in biodiversity and ecosystem services. Ultimately, they will enable the integration of knowledge between biodiversity, ecosystem functions and ecosystem service modelling [28, 2016]. This can help to improve the provision of a deeper understanding of biodiversity and ecosystem services [92, 2022].

Thus, to assess external impacts on natural landscapes and ecosystems, for example caused by land use or climate change, different models of biodiversity and ecosystem services are used, the effects of which are independent of each other [87, 2017]. As a result, the resulting global projections of biodiversity, ecological functions, and ecosystem services may be overly optimistic because they assume that the remaining biological components of nature will continue to provide the same flow of benefits to people, regardless of how much biodiversity is lost [44, 2015]. At the same time, it is noted that efforts to integrate models of biodiversity and ecosystem functions are increasing but are still insufficient [88, 2020].

Many models of biodiversity and ecosystem function operate at different spatial and temporal scales, creating a challenge for integration [87, 2017]. Moreover, some models include parameters that do not include biodiversity but may depend on biodiversity (e.g., a carbon storage model may account for total biomass but not the diversity of species that make up that biomass). Therefore, before developing integration strategies, scientists need a comprehensive understanding of how existing models work, including which biodiversity attributes and ecosystem functions are considered, the inputs and outputs of each model type, and the spatial and temporal scales at which they operate. This information will allow future researchers to identify areas of overlap between models and determine which integration strategies are most feasible.

CHAPTER 2

THE IMPORTANCE OF ENERGY IN THE ENVIRONMENT

The flow of energy in ecosystems is a fundamental concept that emphasizes how energy moves from one system to another within the natural landscape or geosystem in our environment. This smooth movement sustains life, maintains ecological balance, and controls the dynamics of ecological communities. The flow of energy in an ecosystem is important to maintain ecological balance. Producers synthesize food through photosynthesis. Some of the energy is stored in plants. The remaining energy is used by plants in the process of growth and development.

The laws of physics describe the interaction between energy and mass: energy is conserved in a closed system, and matter can neither be created nor destroyed. Modern physics has shown that reality is more complex at very large and very small scales. This essentially simplistic statement has profound implications when we study how landscapes and ecosystems function. More specifically, the energy present in an ecosystem is collected and distributed by organisms in many different ways. This "distribution" occurs through ecological interactions such as predator-prey dynamics and symbioses. More specifically, the energy present in an ecosystem is collected and distributed by organisms in many different ways. This "distribution" occurs through ecological interactions such as predator-prey dynamics and symbioses. However, when we move to the ecosystem level, we consider the interactions between organisms, populations, communities, and their physical and chemical environments. These interactions have important influences on the structure of organisms, ecosystems and, over geological time, the planet itself [4, 2010].

The main example of such interaction in ecosystems is carbon. The amount and form of carbon present in various natural landscapes and their elements, such as plants, animals, air, soil and water, are controlled by organisms and ultimately affect their ecological interdependence. The amount of carbon dioxide (CO^2) in the atmosphere is the main regulator of the Earth's climate and, along with the effects of anthropogenic activity, is controlled by plants and microorganisms, with a small contribution from animals and periodically important geological sources such as volcanoes.

Use of Energy in Ecosystem Development

It is known that the main source of energy for the dynamics of natural landscapes and ecosystems is the sun. Plants and microorganisms on land and in the sea use photosynthesis to produce biomass or living material. Other organisms, including humans, use the accumulated energy for their activities.

However, nuclear energy, which is used by humans, is not used by other organisms, in natural ecosystems. At the same time, many microorganisms can generate energy themselves, based on chemical reactions that transform organic carbon compounds into various chemical forms and, very importantly, release energy in the process of chemical transformations, which is the main source of energy support for ecosystems on our planet as a whole.

Unfortunately, measuring the growth of plants in a forest or the total growth of phytoplankton in the sea is still an extremely difficult task. This is explained by determining the amount of light energy absorbed. However, it has now been established, thanks to measurements of emitted and absorbed energy using satellite data, that part of the energy absorbed by ecosystems is converted into biomass. The use of such data has revealed broad pictures of the living biosphere that can be used to determine the total amount of production, carbon, and energy that flow through ecosystems (Figure 2-1). Using such maps, it is possible to compare different locations or measure primary production from season to season or year to year. As might be expected, different regions have very different levels of production, with tropical forests being extremely productive and deserts and polar tundra being much less productive. The oceans also show strong differences, from mid-ocean gyres, which are essentially marine deserts, to productive tropical and polar oceans [4, 2010]. These relative proportions vary across space and time, but ultimately the carbon produced by plants is used by the diversity of organisms present in a given landscape.

As we can see in Fig. 4-2, the green shading on land shows the Normalized Difference Vegetation Index (NDVI), which is closely related to plant primary production.

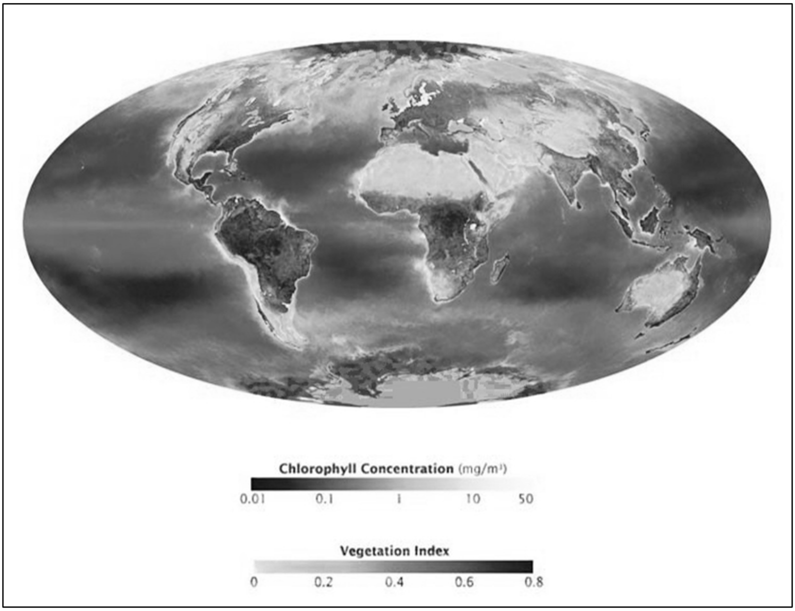

Fig. 4-2. Satellite image of the planet's biosphere [NASA, Earth Observatory, 2008].

The blue shading in the oceans represents the concentration of chlorophyll at the surface. The concentration of chlorophyll is directly related to the abundance of microscopic marine plants, or phytoplankton, and can be used to quantify primary production in the sea. Because primary production, energy and carbon are subsequently used by ecosystems, this leads to even greater differences between them. What is eaten by herbivores becomes biomass, and what is left becomes waste. These relative proportions vary over space and time, but ultimately the carbon produced by plants is used by the diversity of organisms present in a given ecosystem. Even “waste” is a rich source of energy and other nutrients for microorganisms such as bacteria and fungi, and so waste is consumed over time. Most of the fixed carbon can be used as an energy source and is then returned to the atmosphere as CO^2.

Ultimately, all carbon flows are often separated into a kind of "energy nutrient mixture" consisting of: gross primary production (GP, EarthP), net primary production (NPP), plant respiration (R plant), heterotroph respiration (R heterotroph), net ecosystem production (NEP) and net ecosystem exchange (NEE) and converted into a sustainable carbon budget in the landscape. However, changes in the carbon balance or imbalances in the carbon budget in the landscape can be caused by additional processes of anthropogenic activity. For example, draining wetlands, where organic matter accumulates in the soil, releasing carbon and returning it to the atmosphere. Energy and food production from anthropogenic activities can also influence the carbon balance of an ecosystem.

Thus, the carbon balance of an ecosystem is defined as the difference between the gross fixation of CO^2 from the atmosphere through photosynthesis (GPP) and the total metabolism of fixed carbon that is released back to the atmosphere primarily as CO^2 (ER) and/or methane (CH4 emission; ME). In this regard, it is important to distinguish between net primary productivity, usually taken as the difference between photosynthesis and autotrophic respiration, and net ecosystem productivity, which includes heterotrophic respiration.

It is worth noting that one of the areas where the greatest progress has been made in recent years has been understanding the interactions between carbon fixation and nutrient dynamics. Laboratory measurements of leaf photosynthesis rates generally show that maximum leaf photosynthesis rates are closely related to leaf nitrogen concentrations. This led to an assumption supported by analysis of the growth pattern of dry matter production and leaf nitrogen concentration [50, 1997]. Incidentally, nitrogen availability has a major influence on leaf mass and area and affects carbon fixation, since increased leaf area results in greater radiation uptake and hence greater carbon fixation.

It should be noted that there is a strong feedback between foliar nitrogen, litter decomposition rate and release, and the availability of soil nitrogen for tree uptake. This may be an issue of great importance for the long-term carbon balance of forests, particularly in relation to rising atmospheric CO^2 concentrations. However, results from analyzes by other models indicate that the long-term impact of these increases on growth may be small due to limitations imposed by nitrogen availability.

Another area of promising research may be, in my opinion, studies of the service cycles of certain ecosystem molecules. The fact is that during the existence and interaction of various ecosystem molecules, their activity may be disrupted due to various biochemical processes. However, the consequences of such processes may affect different subsystems of the ecosystem. Ultimately, studies of ecosystem dynamics in time and space may allow us to identify certain cycles of the evolutionary development of ecosystems.

Energy Use and Landscape Development

The transformation of resources into energy is a critical condition for the development of natural landscapes, which can be traced back through the centuries, confirming the property of the "energy landscape" to the present day [24, 2014). The scientific community accepts the concept of the "energy landscape" [32, 2014a] as a form that a molecular entity or spatial interaction of molecules and molecular forces can take. However, in addition to the above, the concept of "energy landscape" is also given a broader meaning, recognizing the strategic role of the energy system in modeling and defining the landscape, whether purely anthropogenic or paranatural [33, 2018].

If we turn to the general definition of a natural landscape, which is presented as one of the most important concepts of physical geography, it looks like this. A landscape is a type of terrain, from Land - earth and schaft - a suffix expressing interconnection, interdependence and represents a specific territory, homogeneous in its origin, history of development and indivisible by zonal and azonal features.

The term is borrowed from the general literary German language, where it is usually associated with visual impressions of a landscape, a picture of nature, a locality: a large, easily visible section of a surface, distinguished from neighboring sections by characteristic individual features. The British, and after them the Americans, borrowed their term "landscape" from the Dutch (Landschap) at the beginning of the 17th century. The French synonym for landscape is landscape, first recorded in a dictionary in 1549 by Robert Estienne.

As the science of geography developed, the definition of landscape changed and evolved. Since the last quarter of the 20th century, geographical literature has shown a tendency to gradually replace the term landscape with another term – geosystem [104, 1978], which implies the structure of the landscape as a system.

The structure of any system consists of elements and connections between them. Elements of the system, being features of the object at a given scale of research, themselves can be considered as systems of a lower level at a different scale. If we compare the concept of a natural landscape and a system, we can find that natural landscapes have many properties of a complex dynamic system. Knowledge of properties and their quantitative expression is necessary not only when studying landscapes and classifying them, but also when working with them: using, developing, and restoring them.

The main properties of the landscape as a system include: stability, the degree of isolation of landscapes from each other, direct and feedback connections, and the circulation of matter and energy. The concept of stability is considered, as a rule, in three general forms [37, 1993]: 1) inertia or resistance, 2) recoverability or elasticity and 3) plasticity. At the same time, the more diverse the internal structure of the landscape as a system, the more heterogeneous its components and morphological structure, the more resistant the landscape is to all deflecting influences, including anthropogenic ones. The degree of landscape stability is directly proportional to the taxonomic rank of the territory. The simplest unit in the hierarchical row of the landscape – facies – is the least resistant to external influences and is easily, in the shortest time, subject to change, up to the destruction of the original state. On the contrary, the landscape sphere is characterized by the greatest stability.

The main internal properties of the landscape include its integrity, i.e. the system cannot be reduced to the sum of its parts – components. From the interaction of components something qualitatively new arises, for example, the ability to produce biomass. The "product" of the natural landscape, i.e. the result of its functioning as a single complex mechanism, is, for example, the soil. This is a new component that could not have been formed by the mechanical addition of water, parent rock and organic matter. In this case, the integrity of the natural landscape as a system within the framework of evolution creates the soil. The integrity of the natural landscape also manifests itself in its relative autonomy and resistance to external influences.

The dynamics of the development of the natural landscape, which is a form of oscillatory rhythms, is characterized by evolutionary changes in structure and state. It is determined by the incomplete closure of gyres, genetic predetermination and the type of landscape. Therefore, the study of the full life cycle of a natural landscape in a time frame, their individual elements and stages of development allows us to determine the age of a natural landscape and predict dangerous processes accompanying certain stages of such development.

In the dynamics of landscape development, stages of transformation are distinguished, characterized by gradual, consistent, continuous and directed changes. In contrast to the above, the evolutionary dynamics of the landscape can be determined by slow but long-term directed changes in the external environment, as well as internal spontaneous processes of historical self-development. For evolutionary dynamics to manifest, the duration of directed changes in the external environment must significantly exceed the characteristic time of the dynamics of self-development of the natural landscape.

Thus, the use of energy by the landscape is carried out by radiation, convection, conduction and evaporation. In this case, physical and chemical processes can only occur spontaneously if they generate energy, or not spontaneously if they consume it. In the natural environment, non-spontaneous reactions, including most synthetic processes, consume thermal energy because an important source of energy in living organisms is sunlight, which