GRASSLAND ECOSYSTEMS OF THE MOUNTAIN PART OF THE CHECHEN REPUBLIC AND THEIR ROLE IN CARBON SEQUESTRATION

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Abstract

The Chechen Republic is characterized by a complex and contrasting landscape structure, owing to its heterogeneous geological and geomorphological structure—the presence of ridges of varying elevations and lithological compositions, separated by intermontane basins in the southern part of the republic, and flat plains of varying levels in the north. A distinctive feature of the territory is the large area of undulating foothill plains located south of the Terek-Sunzhenskaya Upland, with the low Terek and Sunzhensky ranges separated by the Alkhanchurt Valley and the smaller Grozny, Bragunsky, and other ranges. These plains have experienced intense anthropogenic impact over a long period, leading to significant landscape transformations. In recent decades, shifts in land use patterns have been observed here, resulting in active landscape dynamics. Based on field research, new quantitative data were obtained on spatial differences in the biogeocycle and phytomass stocks, making it possible to assess the dynamics of greenhouse gas emissions in mountain forest landscapes of the Chechen Republic. At the local level (at the level of key monitoring sites), new data were obtained on phytomass stocks and their spatial variability. Representativeness of ecosystem sites in the mountainous territories of the Chechen Republic was ensured by creating maps of various components, including climate, biota, and soil cover, which demonstrate differences in natural conditions for carbon accumulation

Keywords: mountain landscapes, forest-steppe ecosystems, carbon accumulation, natural conditions.

I. Introduction

Global climate change has affected every region of the world. In mountainous regions, the consequences of climate change include the degradation of glaciers and snow cover, shifts in the rhythms of natural climate and slope processes, and changes in the boundaries of altitudinal zones. Attempts to understand the cause-and-effect relationships in the complex "climate-biosphere-human" system have led to the study of carbon balance. It is believed that reducing carbon emissions or its long-term sequestration in soils and vegetation can slow the rate of global warming. Without delving into the nature (and ambiguity) of this problem, it is worth considering approaches and methods for assessing carbon balance in different landscapes.

This is especially relevant for mountainous areas, which, according to various estimates, occupy up to 25% of the planet's territory, and in Russia, almost half the country [1,2]. The complex differentiation and diversity of the natural landscapes of the Chechen Republic, coupled with anthropogenic pressure and land use change in recent decades, have highlighted the importance of studying the relationship between carbon accumulation and the specific landscapes involved in a given land use. Only by understanding this relationship can we develop effective measures to optimize land use patterns to enhance sustainability and long-term carbon accumulation.

Currently, in connection with research into the biosphere's role of various landscape components, their productivity, and resilience against the backdrop of global climate change, interest in studying the carbon cycle has revived. Accounting for the cycling of substances in individual blocks is still very rough. A systems approach and the construction of conceptual balance models are widely used as a methodological basis for studying the cycling of substances in biogeocenoses [3,5]. This system of describing a community is used to objectively predict the fate of a community, evaluate various interventions within the community, and select those that will be beneficial for both the development of the community and its practical activities. Research in ecology demonstrates that a systems approach is the most appropriate method for studying the structure and functioning of ecosystems.

In terrestrial ecosystems, carbon sequestration is the removal of carbon dioxide from the atmosphere by increasing the natural uptake, processing, and long-term storage of carbon in vegetation and soils. Carbon sequestration can be achieved by fixing more carbon in plants through photosynthesis, increasing plant biomass per unit area, reducing soil organic matter decomposition, and increasing the area of carbon-storing ecosystems.

Several issues related to time and space scales must be addressed. The desired time scale should be large enough to encompass the entire vegetation and management cycle for a given agroecosystem (e.g., the succession of fallow crops), and these cycles should be considered over several decades.

II. Methods

Landscape structure studies of this vast territory were conducted along several typical elevation profiles. The profiles intersected the most characteristic combinations of landscapes of different types and subtypes (steppe, forest, and meadow), formed on dissimilar rock types and slopes of varying aspect. Particular attention was paid to determining the upper boundary of forests and mountain meadows, the steppe distribution of meadow landscapes, the characteristics of different forest types (small-leaved and broad-leaved), and the influence of rock types on the differentiation of biogenic components. Large-scale topographic maps at scales of 1:50,000 and 1:100,000, available online, as well as Google Maps and satellite imagery of various scales, were used to extrapolate field point data and profiling data. The most informative picture was provided by the results of vegetation interpretation and classification, for which Sentenel-2 imagery was used.

III. Results

The biogeochemical carbon cycle and its study in landscapes, especially mountainous ones, is quite complex, as it involves not only the functioning of all life forms on Earth but also the transfer of inorganic substances both between and within various carbon reservoirs. Its study deserves special attention, as this process plays a crucial role in the sustainable functioning of ecosystems. The main carbon reservoirs are the atmosphere, terrestrial biomass, including soils, the hydrosphere, and the lithosphere.

Studies of the soil-plant cycle in forestry began in the late 19th century, leading to the conclusion that tree species have little need for additional nitrogen. This conclusion was based on data on the low nitrogen content of annual tree growth and the return of significant amounts of nitrogen compounds to the soil with litterfall. Only after the adoption of the International Biological Program in the 1950s and 1960s did extensive research on the cycling of organic matter and mineral nutrients in various ecosystems begin in many countries. A summary of studies on nutrient cycling in forest ecosystems was completed in 1965. Most studies provide data on total phytomass, annual phytomass production, and its carbon and nitrogen content. When assessing carbon and nitrogen cycling in forests, the total phytomass and its content of these elements are widely used as indicators of the productivity of the biogeocenosis. This indicator fluctuates depending on the age of the stand, the composition of the stand, and the growing conditions.

The phenomenon of introzonality in the republic is represented by soil types such as solonetz, bog, and alluvial soils, which intersect in patches or strips within zonal soils. This gives the soil cover a complex character. It reaches its greatest diversity on the Terek-Sunzhenskaya Upland, the adjacent Nadterechnaya Plain, and the Gudermes Flatland, where solonchaks and solonetz soils are found. On the Chechen Sloping Plain, the diversity is created by alluvial soils, and in the zone of mountain-forest brown soils, by bog soils.

In addition to the noted geographical and geomorphological phenomena, landslides and subsidence processes occur in the republic's soil cover, complicating its nature [4,7]. Mountain-meadow and mountain-forest brown soils, formed on clays of the Maikop Formation and clay shales of the Middle Jurassic, are most susceptible to landslides.

Soil subsidence due to a decrease in soil mass caused by the leaching of soluble salts is observed on the Nadterechnaya Plain and in the Alkhanchurt Valley, where irrigated agriculture is developed.

The vegetation cover of the meadow-steppe in the Chechen Republic extends from 1,330–1,400 to 2,000–2,500 meters, depending on the elevation of the mountain ranges. Its lower and upper boundaries rise somewhat higher on the southern slopes. Meadow formations predominate here, but shrub and tree communities are also found.

Along with the predominant forb-grass communities, there are grassy, predominantly forb and sedge meadows. The dominant species of subalpine meadows are variegated fescue (*Festuca varia*) and variegated brome grass (*Zerna variegata*), which determine the overall appearance of the subalpine meadows. About half (50%) of the meadow communities are Festuca tumvaria and variegated fescue, with variegated brome grass accounting for 25–30%. The remaining 20–25% are meadows with bent grass (*Agrostis*), Caucasian reed grass (*Calamagrostis saucasica*), reed grass (*C. arundinacea*), and ground reed grass (*C. epigeios*), as well as marshy meadows.

The predominance of variegated fescue communities is explained by its poor palatability by livestock due to its very tough leaves. They are confined primarily to wetter, northern-facing slopes. They are also found on southern slopes, but in areas with a better water regime. On shallower, rockier, and less moist soils, the valuable forage plant, variegated brome grass (*Bromopsis variegata*), dominates. Many species found in the subalpine zone also contribute to the formation of the herbage of alpine meadows, but the dominant ones are Festuca supina and Nardus stricta (*N. glabriculmis*). Variegated fescue and variegated brome grass are also found, often accompanied by Colpodium versicolor, and species of foxtail grass – Alopecurus arundinaceus, and vaginal (*A. vaginatus*) and others, ovate paniculate trisetum (*Trisetum ovatipaniculatum*), Bush's slender-legged grass (*Koeleria albovii*), Caucasian bluegrass (*K. caucasica*), various species of bluegrass (Poa) - alpine bluegrass (*Poa alpina*), Caucasian bluegrass (*P. caucasica*), blue bluegrass (*P. glauca*), Prima's bluegrass (*P. primae*) and purple barley (*Hordeum violaceum*).

Carbon sequestration in grassland-steppe ecosystems is either the pure removal of CO_2 from the atmosphere or the prevention of net CO_2 emissions from terrestrial ecosystems into the atmosphere. Atmospheric carbon dioxide concentrations can be reduced either by reducing emissions or by removing carbon dioxide from the atmosphere and preserving terrestrial, oceanic, or freshwater ecosystems.

Anthropogenic impacts have led to imbalances in the biogeochemical carbon cycle in terrestrial ecosystems. These include deforestation, forest fires, and cultivation. Human needs have been and continue to be met through intensive land use, which significantly influences climate change and carbon cycles [8,10]. A consequence of this type of activity is a decrease in soil carbon content, which also disrupts the ecological stability of terrestrial ecosystems (Fig. 1, Table 1).

The amount of carbon and nitrogen removed annually by plants to build their growth varies widely and depends on age, composition and growing location.

A. B.

Figure 1. Selection of phytomass in the Makazhoy depression

Table 1 Reserves of above-ground phytomass in the observed areas of mountainous and lowland landscapes

Landscape zonal type and subtype	Observed areas in landscapes	Ground phytomass reserves (t/ha)
Mountain-meadow, meadow-steppe	Makazhoy Basin	0,8-1,3
Forest and forest-steppe landscapes	Old Sunzha Massif	0.2-142
Low-mountain-forest, forest-steppe landscapes	Ulus-Kert Tract	10-92

When assessing nitrogen cycling, the amount of nitrogen required to form a unit mass of dry matter is used. The contribution of different plant parts to the total nitrogen removal from the soil varies. There is extensive literature on this topic. The highest nitrogen content is observed in tree leaves and grasses, with lower nitrogen content in pine and spruce needles and even lower levels in wood. Birch leaves contain 2-2.5% nitrogen, pine needles 1.0-1.5%, and wood 0.1-0.2%. The herbaceous and dwarf shrub layer also participates in the nitrogen cycle in the forest, with nitrogen content in the aboveground phytomass ranging from 2 to 4 kg/ha [11,12].

Living plant parts typically contain no more than 10% of the total fixed nitrogen in biogeocenoses. A significant portion of the nitrogen accumulated by plants in their phytomass during the growing season returns to the soil with litterfall. The mass of litterfall depends more on the stand and growing conditions than on age. For example, in 30- and 80-year-old birch forests, the mass of litterfall is approximately the same. Litterfall returns approximately one-third of the total nitrogen consumed by plants during the growing season. According to some authors, in taiga forests, litterfall returns 20 to 50 kg of nitrogen per year.

As grass stands age, carbon sequestration tends to increase, and the conversion rate may be higher. Equilibrium carbon dioxide levels in forage reservoirs (accumulation equals losses) are reached after 30-70 years of moderate natural resource management. However, meadow soils with low organic matter content can sequester more carbon over a longer period.

The nature of carbon sequestration in pastures is less predictable. In natural pastures, biomass is partially returned with livestock organic matter, resulting in sequestration, on average, not exceeding 4% of net primary production. It is only known for certain that the type of livestock grazed and the intensity of grazing are factors that significantly influence the level of biomass sequestration. Moderate grazing under rotational grazing does not impede the absorption of CO_2 from the atmosphere by pastures, since rotational grazing in different areas potentially stimulates biomass growth. The meadow-steppe ecosystems of the Chechen Republic, like other natural areas, are subject to intensive and unsystematic grazing, even on mature pastures. This leads to the destruction of the stability and strength of the root system, preventing it from acting as active carbon sinks, which is often the dominant source. Consequently, degradation of the root system, which accounts for 80-90% of the total phytomass, leads to the release of additional CO_2 from the primary carbon storage reservoir.

When harvesting hay, almost all aboveground biomass is removed without excretion, meaning no organic residue remains on the site. If mowing is particularly intensive and occurs intermittently, the amount of plant biomass (carbon) will inevitably decrease. Thus, the amount of accumulated CO_2 varies proportionally to the intensity of biomass removal from the site, depending on the species composition and density of the grass stand. Pastures that are annually overstocked are characterized by a steady accumulation of organic matter, accompanied by increased methane and nitrous oxide emissions from forage lands. Furthermore, intensive trampling of grassland significantly reduces the biodiversity of the grassland, which threatens to reduce biomass (carbon accumulation) and the forage value of pastures. The carbon content of natural forages can be somewhat increased by switching to a rotational grazing system. However, this will lead to a certain increase in the labor intensity of pasture livestock farming and the cost of its production. Therefore, with targeted management, natural grassland ecosystems can make a significant contribution to carbon dioxide accumulation. The largest contribution to carbon sequestration, taking into account the area of forage land, comes from croplands abandoned in recent decades. The average CO_2 content in the organic matter of litter and plant associations of overgrown cropland is 46.1%. Within 4-5 years of being withdrawn from cultivation, soil profiles become more capacious reservoirs for the steady removal of atmospheric CO_2. The rate of carbon dioxide accumulation depends primarily on the soil thickness, the length of time the arable land takes to become established, and the type of fertile horizon.

Along with the supply of nitrogen to forest ecosystems, there are also constant losses from the soil: as a result of leaching by water and in gaseous form due to the activity of certain groups of microorganisms. Some authors have found that losses via soil runoff are generally small (no more than 4-5 kg of nitrogen per year). Nitrate nitrogen is lost in greater quantities than ammonium nitrogen. There is evidence of gaseous nitrogen losses from forest soils as a result of denitrification. Denitrification can occur in poorly aerated soils, as well as in plant rhizospheres. The extent of gaseous ammonium nitrogen losses from forest soils remains controversial.

IV. Conclusion

The main factor shaping landscape diversity in the study area is altitudinal zonation, associated with changes in the ratio of heat and moisture. The following belts are distinguished in the region: nival-glacial (above 3000–3500 m); mountain meadow (2000–3500 m); mountain forest (up to 2000–2600 m) and various variations of mountain steppe and forest-steppe landscapes (up to 1800–2400 m). The identification of the mountain forest-meadow landscape type is primarily associated with the anthropogenic transformation of a significant portion of the mountain forest zone (2000–2600 m). The mountain forest-meadow-steppe landscape type is an ecotone between mountain steppes and forests (up to 1800–2400 m). The boundaries of landscape types and subtypes were clarified through the analysis of Sentinel-2 satellite images. Heterogeneous carbon balance conditions are observed in mountain forest-meadow-steppe and mountain-steppe landscapes [6,8]. These landscapes, especially the steppe ones, located predominantly in intermontane basins, experience precipitation deficits. On southern-facing slopes, high insolation levels result in significant evaporation. Unstable natural moisture conditions are compounded by economic activities such as grazing, haymaking, terraced farming, and artificial irrigation in some areas near settlements. Few untouched steppe areas remain.Steep slopes often experience deceration, soil creep, and the formation of pathlike terrain and landslides. In these cases, the soil and vegetation cover is usually fragmented, and large quantities of organic matter are removed and accumulate at the foot of the slopes or washed into rivers. The use of meadows for grazing significantly contributes to the biogeocycle, from which a significant portion of organic matter is removed through grazing by livestock or haymaking, which affects the carbon balance [13,14]. To identify the conditions of carbon dynamics in the Chechen Republic, field data and analysis of all three types of landscape structure were used. To study the morphological structure of the landscapes, field expedition methods were employed, including constructing complex profiles in various altitudinal zones and belts, interpreting high-resolution satellite images, and geoinformation methods for identifying landscape habitats based on a digital elevation model and creating derivative layers (aspects, slope angles). As a result, landscape maps of various scales were compiled. An analysis of the vertical-temporal structure of key natural complexes on the landscape profiles was conducted. Characterization of the vertical structure included a description of geomasses and geohorizons with simultaneous measurements of temperature and humidity, which were correlated with data series from nearby meteorological stations. To determine phytomass reserves, an important indicator of landscape functioning, haystacks and mortmass were collected from sample plots. A forest inventory was conducted at these sample plots, followed by processing according to the methodology adopted for field research. Data from carbon research sites, most detailed in the low-mountain forest landscape type and the mid-mountain-high-mountain region of the Makazhoy Basin with its heterogeneous landscape structure, were also used to assess, primarily, seasonal carbon dynamics in key natural complexes [10]. Peat soils that form beneath marshy meadows, which are found on gentle, concave slopes composed of clay shales and argillites, serve as carbon reservoirs.

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CONFLICT OF INTEREST.

Authors declare that they do not have any conflict of interest.

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