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Literary review of researches on *Ferula tenuisecta* Korovin — endemic of the Western Tien-Shan

The study of natural flora and its biodiversity, as well as its conservation, is one of the main tasks in the biological sciences. The threat of extinction of rare, endemic and disappearing species of the flora of Kazakhstan indicates the need to develop scientific foundations and methodological approaches to the conservation, restoration and effective use of their genetic reserves. The flora is characterized by the specific composition, soil and climatic conditions of the region, but many components are poorly studied in terms of their phytochemical and biological activity. The issues of phytochemical studies of plants of the local flora are also listed in the priority directions of the program for the development of pharmaceutical production in the Republic of Kazakhstan. Thus, representatives of genus *Ferula* (family *Apiaceae — Umbelliferae*) are known mainly as a source of medicinal properties. Unfortunately, there are few data about useful properties of genus *Ferula* species in the national and international literature. *Ferula tenuisecta* Korovin as the medicinal plant is paramount in the production of medicinal preparations due to its chemical composition. Overall, results of the study on *Ferula tenuisecta* were analyzed in the article. Directions for further study of *Ferula tenuisecta* were determined.

Keywords: Ferula tenuisecta, endem, biological active compounds, cenopopulation, Western Tien-Shan, medicinal properties.

Introduction

Features of flora diversity depend on climatic, geological, soil, and other conditions; are reflected in the archaeological, ecological and taxonomic diversity of plant species. Kazakhstan is located in the center of Eurasia, while most of it belongs to Asia and a small part to Europe. It leads to the formation of ecological systems in a significant part of the territory under the conditions of a continental climate and insufficient humidity. The territory of Kazakhstan is diverse in terms of natural and climatic conditions. The heterogeneity of natural conditions is reflected in the diversity of landscapes presented on the territory: forest-steppe, steppe, dry steppe, semi-deserts and desert zones. The vertical belt of various mountain systems is characterized by desert, semi-desert, steppe, forest-steppe, and forest zones, mountain meadows and the snow belt [1].

In this regard, the entire territory of Kazakhstan is divided into 29 floral districts [2]. In general, the uniqueness of the flora in the steppe and desert regions of the country increases from West to East, in Mountain systems — from North-East to South-West [2–5]. The number of vascular plants of Kazakhstan in various botanical literature includes from 5.5 to 6.0 thousand species, 1067–1118 genera and about 160 families [2–4].

An important component of arid communities is the genus *Ferula*, which has a number of valuable properties and is not sufficiently studied. Among species diversity, the *Ferula tenuisecta* is of interest, as an endemic species with valuable medicinal properties.

The main purpose of the study is to examine the biological, morphological, ecological, and phytocenotic features and phytochemical characteristics of *Ferula tenuisecta* Korovin (family *Apiaceae — Umbelliferae*) in the Kazakh part of the Western Tien-Shan; to search for directions for further study.

Experimental

Object of the research was an endemic plant *F. tenuisecta* on the area — the Kazakh part of the Western Tien-Shan. Climatic conditions are continental and dry. The average July temperature is +20–25 ºC in the lower part of the inter-mountain Okot, +15–17 ºC in the middle zone, 0 ºC in the upper peaks of the mountain. The average January temperature at the foot of the mountain is –2–4 ºC (in the south), –6–8 ºC (in the north). In the winter months, temperature inversions cover a wide area. The annual precipitation is 300 mm at the foot of the mountain, 800 mm at the top of the mountain ranges. The period of maximum precipitation falls in the northern part of the Tien Shan Mountains on summer period (June, August); in the south — on spring (March–April). Due to continental and dry climates, drought landscape types predominate. The pre-mountain slopes, the foothills of most ridges and some inter mountain pits are occupied by semi-desert and desert landscapes.

The mountain range belongs to Tien Shan Mountain system. It stretched from North-East to South-West for 110 km, the wide is about 30 km. The highest point is Sairam peak (4299 m above sea level). It is formed from limestone, sandstone rocks of the lower Carboniferous period. In the South-West, the slope rests on the Shcherbak reservoir (Uzbekistan). The relief is diverse; the lower border is Meadow Plains. In the plains there are many springs. High ridges are covered with glaciers. The territory of Kazygurt and Tole Bi districts includes the North and South-West of the Ugam range. It consists of the Kumkezen, Zhaltyr, Konekty, Zhetiyungir, Shymyrbai, Azarteke, Makpal ridges, Turpakbel, and Maidan. At the intersection of Ugam with the Talas Alatau there is the Aksu-Zhabagly Nature Reserve. From the mountain glaciers originate tributaries of the Ugam and Pezkem rivers: Maydantal, Boldybyr, Sairamsu, Saryaigyr. In the brown, alpine meadow soils of the mountains, at the foot of the mountain, various herbaceous plants, fruit trees with mixed shrubs, juniper species, subalpine, alpine meadows grow in the altitude zone.

The rich composition of plants is concentrated on this territory [5, 6]. In addition, there are forage, medicinal endemic species, meadow, species of ornamental plants, fruit and berry crops [6–8].

The work includes a review of information on medicinal and endemic species *F. tenuisecta* based on available literary sources. Field studies are conducted on the basis of Sairam-Ugam State National Natural Park.

Literature review

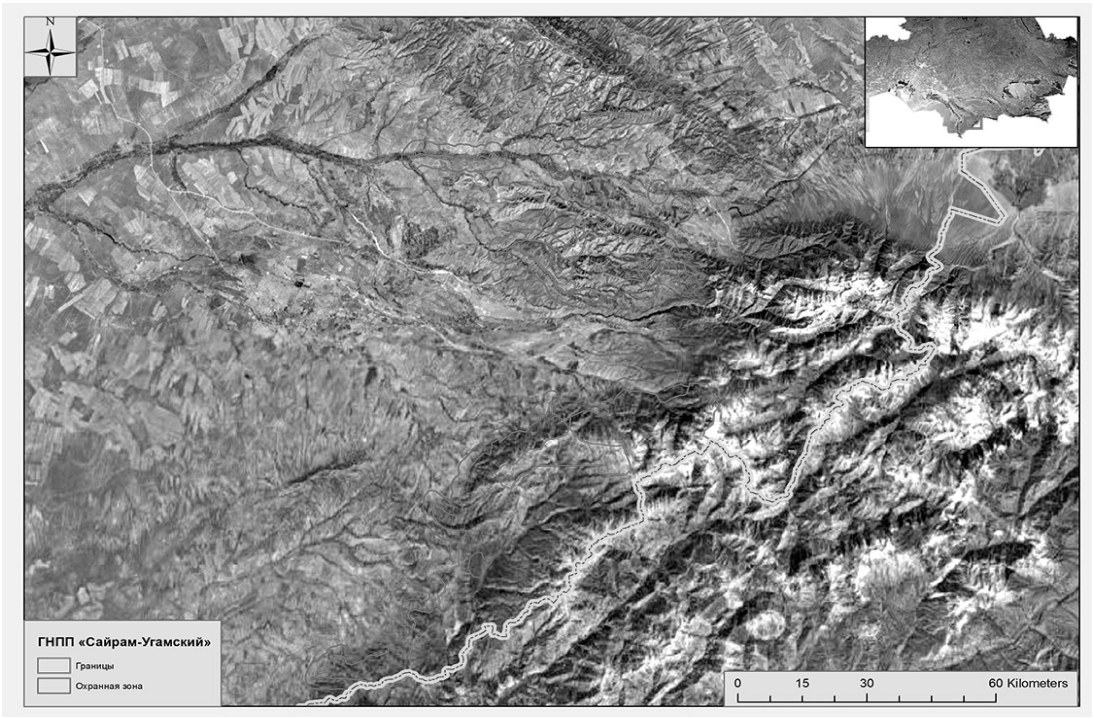
Sairam-Ugam State National Natural Park, established in 2006, covers an area of 149,053 hectares in the Western Tien-Shan Mountains (Ugam, Karzhantau ridges and the Western part of Talas Alatau and Boraldaytau). The territory of the park covers 3 districts: Tulkubas, Tole Bi and Kazygurt districts of South Kazakhstan region. The object is represented by the North-Eastern part of the Western Tien-Shan: the Ugam, Karzhantau and Boraldaytau mountain ranges, as well as the North-Western Spurs of the Talas Alatau. The park is geographically represented by three cluster sections extending from North to South (Fig. 1).

The flora of this territory is insufficiently explored, especially in the Ugam and Karzhantau ranges, which are located near the territory of Uzbekistan.

A.A. Ivashchenko conducted floristic studies on this territory since the beginning of the 80s of the last century. As a result, data on the most interesting floral finds were published [9–11], providing new information about previously unpublished endemic plants and poorly studied plant species [12].

Genus *Ferula* are known mainly for their medicinal properties. In this regard, our interest was aroused by the study of the endemic plant *F. tenuisecta*, which is found on the territory of the Sairam-Ugam State National Natural Park.

In nature, these plants grow primarily in the middle zone of the South-Western Tien-Shan within Kazakhstan, Uzbekistan and Kyrgyzstan, and on soft and gravel slopes in places similar to the climatic conditions of the middle zone [13]. In Kazakhstan, there are 47 species, including tree species, well-studied and used in folk medicine (Table 1).



Red lines — borders; blue lines — protective zone

Figure 1. Territory of Sairam-Ugam State National Natural Park

Table 1

Data from recent studies on the species of genus *Ferula* studied in Kazakhstan

Species	Geographical location	Recent research (authors, year)		
		Kazakhstan	CIS	International
Ferula tenuisecta Korovin	Kazakhstan part of the Western Tien-Shan	–	M.K. Malikova, K.K. Akhmedova, R.K. Rakhmanberdieva, K.S. Zhauynbayeva (2018)	Fadia S. Youssef, M.A. Mamatkhanova, N.Z. Mamadalieva, G. Zengin, S.F. Aripova, E. Alshammari, L. Mohamed (2020)
Ferula iliensis Krasn. ex Korovin	Dzungarian Alatau, Ili Alatau	N.M. Mukhitdinov, A. Ydyrys, A.B. Akhmetova (2013)	N.V. Veselovskaya, Yu.E. Sklyar, M.G. Pimenov (1980)	–
Ferula foetida (Bunge) regel	On the Mangystau Peninsula, Zhambyl and Southern Kazakhstan region	M.S. Sagyndykova (2016)	N.G. Gemedzhieva, E.V. Kuzmin (2015)	–

To begin with the work of Youssef F.S. et al. [14], here information on essential oil composition is given; in the works of R.M. Khalilov et al. [15], data on the extraction of estrogenic drugs, essential oil from the roots are provided. Roots of *F. tenuisecta* described as a source of raw materials for the industrial production of preparation: ferulene, tefestrol and panopherol. Ferutinin and tenuferidine from the roots of *F. tenuisecta* contain essential oil components, such as ferutin, tepherin and prestidine, which are comparable in estrogenic activity. The creation of preparations containing all these compounds leads to an increase in the output of the final product, which is not inferior in pharmacological activity to tefestrol [15, 16]. These preparations are also used in animal husbandry and feed production.

F. tenuisecta is a perennial plant. The roots are thickened, the neck is branched, densely surrounded by fibers of dead leaves, the number of stems is several, the height reaches 80–90 cm [17]. In the upper part, an oblong-ovate inflorescence is branched, the branches of which alternate at the bottom and are collected in several rings at the top. The leaves are serrated, oval-rhombic, oblong petiolate, consisting of short and hard hairs, their plate is three-lobed with 2 additional segments and numerous (up to 5 times) small, divided into 2–5 mm long, linear, carved above, arched, oval-lanceolate, raised, serrated. Tent flowers are of two types: 8–15 rays with a center, sitting or short stem, 6–8 cm wide and 2–5 cm lateral, with long inflorescences exceeding the central umbrella, 10-flowered tent flowers with scaly petals. The flowers are yellow, the cup is pointed, and the petals are oval, narrowed at the top, wrapped inside, elongated, 1.2 mm. The fruits are oblong-oval, the back is convex, with a thickened pale edge, 9 mm long and 5 mm wide, the ribs are rough. The tubes are single, wide between the ribs, and the waxes are 2–6 on the sides. Phase of flowering occurs in May–June, and fruit maturation occurs in June–July [17]. It grows on rocky and meadow slopes of the central mountain belt. It is found in the Shu-Ili Mountains, Karatau, and the Western Tien-Shan. The general distribution is the Central Asia (the Western Tien-Shan within part of Uzbekistan).

From *F. tenuisecta*, which was collected in the Tashkent region, a number of aromatic acid and esters is isolated [18–20]. Scientists of the Institute of Chemistry of Plant Substance named after academician S.Yu. Yunusov developed a method for qualitative determination of esters in the roots of *F. tenuisecta* and quantitative determination of esters in the ferulene substance [16]. The indicators of extraction of esters obtained from the root of thin sorrel were studied and it was found that the size of raw material particles for this process should be 2–6 mm, and the alcohol concentration is 95 %. A new phytopreparation “Ferulene” was developed on the basis of esters of sesquiterpene alcohols. As a result of the conducted experiments, the technology for obtaining this preparation has been developed. It was also found that the greatest loss of the amount of esters occurs during the process with potassium [16].

Roots of *F. tenuisecta* are a source of raw materials for industrial production of ferulene, tefestrol and panopherol preparations [21]. Previously, the preparation “Tefestrol” was developed, which is a natural mixture of esters of sesquiterpene alcohols, which are comparable in estrogenic activity [21].

Based on the obtained data, a technological scheme for the separation of ferulene was developed, as a result of which a ferulene preparation consisting of a set of esters ferutinin, ferutin, teferin, fertidine and tenuferidine was obtained, and a methodology for quantitative determination of Ferulene was developed [21].

Conclusions

The above studies indicate the need for a more detailed study on the cenopopulation of *F. tenuisecta*, found in the Sairam-Ugam National Natural Park. In this regard, by analyzing the previous studies, it is possible to determine the ontogenetic structure of the *F. tenuisecta* cenopopulation, the phytocenotic role and the productivity of communities, to study the structure and composition of the main groups of biologically active substances in various organs of the *F. tenuisecta*, to conduct DNA-identification of populations.

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М.О. Бекебаева, С.Т. Назарбекова

Батыс Тянь-Шаньның эндемигі *Ferula tenuisecta* Korovin туралы зерттеу жұмыстарына әдеби шолу

Табиғи флора мен оның биоалуантүрлілігін зерттеу, сонымен қатар оны сақтау биология ғылымдарының негізгі міндеттерінің бірі болып табылады. Қазақстан флорасының сирек кездесетін, эндемик және жойылып бара жатқан түрлерінің жойылу қауіпі — олардың генетикалық қорларын сақтау, қалпына келтіру және тиімді пайдаланудың ғылыми негіздері мен әдістемелік тәсілдерін жасау қажеттілігін көрсетеді. Флора өсімдіктердің өсу ортасының түрлік құрамымен, топырақ және климаттық жағдайларымен ерекшеленеді, бірақ олардың көпшілігі фитохимиялық және биологиялық белсенділіктері тұрғысында аз зерттелген. Жергілікті флора өсімдіктерінің фитохимиялық зерттелу мәселесі Қазақстан Республикасының фармацевтикалық өндірісін дамыту бағдарламасының басым бағыттар тізімінде де көрсетілген. Ферулалар — туысының өкілдері — (*Apiaceae — Umbelliferae тұқымдасы*) негізінен емдік қасиеттерімен танымал. Өкінішке орай, отандық және халықаралық әдебиеттерде түрлердің пайдалы қасиеттері туралы көп айтылмайды. *Ferula tenuisecta* Korovin. дәрілік өсімдік ретінде химиялық құрамы бойынша дәрілік препараттарды өндіруде өте құнды болып табылады. Мақалада *Ferula tenuisecta* бойынша отандық, шет елдік ғалымдардың зерттеу жұмыстары мен зерттеу нәтижелері жинақталып, сараланып, салыстырылып, талқылау нәтижелері келтірілген.

Кілт сөздер: Ferula tenuisecta, эндемик, биологиялық белсенді қосылыстар, ценопопуляция, Батыс Тянь-Шань, медициналық қасиеті.

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Литературный обзор исследований по эндемику Западного Тянь-Шаня *Ferula tenuisecta* Korovin

Изучение и сохранение природной флоры и ее биоразнообразия является одной из основных задач биологических наук. Угроза исчезновения редких, эндемичных и исчезающих видов флоры Казахстана свидетельствует о необходимости разработки научных основ и методических подходов к сохранению, восстановлению и эффективному использованию их генетических запасов. Флора характеризуется видовым составом, почвенными и климатическими условиями обитания, но многие компоненты мало изучены с точки зрения фитохимической и биологической активности. Вопросы фитохимического изучения растений местной флоры отражены в перечне приоритетных направлений программы развития фармацевтического производства Республики Казахстан. Представители рода *Ferula* (семейство *Apiaceae — Umbelliferae*) в основном известны своими лекарственными свойствами. К сожалению, в отечественных и международных источниках литературы недостаточно сведений о полезных свойствах видов. *Ferula tenuisecta* Korovin, как лекарственное растение, представляет ценность в производстве лекарственных препаратов на основе химического состава. В статье обобщены и проанализированы результаты исследований о *Ferula tenuisecta*. Определены дальнейшие пути изучения *Ferula tenuisecta.*

Ключевые слова: *Ferula tenuisecta*, эндемик, биологически активные компоненты, ценопопуляция, Западный Тянь-Шань, медицинские свойства.

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Интродукционный анализ древесно-кустарниковых растений дендрария Алтайского ботанического сада

В статье приведены многолетние итоги интродукции коллекционных растений арборетума Алтайского ботанического сада. Испытаны древесные интродуценты, привлеченные для первичного испытания из Северной Америки, Сибири, Дальнего Востока, Китая, Японии, Средней Азии, Европы. Объекты исследования представлены 643 видами, формами, сортами из 102 родов и 40 семейств голо- и покрытосеменных древесных растений. Растения привлекались семенным материалом, живыми растениями и зелеными черенками. Оценка интродукционной устойчивости генофонда дендрария сада дана на основе комплексных показателей жизнеспособности растений по данным многолетних экспериментальных исследований. Для определения показателей жизнеспособности, адаптации использовалась методика фенологических наблюдений в ботанических садах. Перспективность таксонов для использования в озеленении региона определена по комплексным шкалам М.П. Косарева, П.И. Лапина и С.В. Аристова. По комплексу биолого-хозяйственных признаков рекомендованы для применения в озеленении региона 370 видов, форм, сортов голо- и покрытосеменных древесных пород. Материалы по мониторингу интродукционных ресурсов дендрария Алтайского ботанического сада можно использовать для расширения интродукционных работ в Казахстане и в региональном зеленом строительстве.

Ключевые слова: интродуценты, систематика, географическое происхождение, фенология, адаптация, жизнеспособность, перспективность, хозяйственно-полезные признаки.

Введение

Высокая степень континентальности климата Казахстана выдвигает культивируемым растениям повышенные требования к адаптационному потенциалу интродуцентов. Процесс введения в культуру растений, находящихся за пределами их природного ареала обитания, занимает довольно длительный период. Он предусматривает предварительный анализ отбора исходного материала, экспериментальное первичное испытание с изучением биоэкологических особенностей растений и оценку интродукционного потенциала объектов исследований, находящихся под воздействием почвенно-климатических и агротехнических условий культивирования [1–4].

Значительная роль в сохранении и распространении генетических ресурсов мировой флоры принадлежит ботаническим садам. Их коллекционные генофонды являются хранилищем природного и культурного биоразнообразия, одновременно становятся базой формирования регионального ассортимента перспективных таксонов для зеленого строительства [5].

Со дня основания Алтайского ботанического сада в 1935 г. и по настоящее время Отделом дендрологии активно ведется привлечение инорайонных видов, проводится их акклиматизация, изучается поведение в условиях резко континентального климата, рекомендуются перспективные виды для возможного применения в озеленении городов. Многолетний опыт в работе по интродукции растений позволил значительно расширить видовой состав инорайонных древесно-кустарниковых пород для декоративного садово-паркового строительства Восточно-Казахстанской области.

Цель работы — анализ эколого-биологических итогов многолетних интродукционных испытаний древесных растений различного происхождения при выращивании в горнолесных условиях Восточного Казахстана для разработки научных основ прогнозирования и оценки перспективности таксонов для использования в зеленом строительстве.

Материалы и методы исследования

В состав дендрария входят: коллекционный участок, посевное и школьное отделение, парники для черенкования и территория естественной растительности. Объектами исследования являются го-

ло- и покрытосеменные древесные растения представленные 40 семействами [6], из 6 районов доноров [7]: *Aceraceae* Juss., *Actinidiaceae* Hutch., *Anacardiaceae* Lindl., *Aquifoliaceae* Bartl., *Apocynaceae* Juss., *Araliaceae* Juss., *Aristolochiaceae* Juss., *Berberidaceae* Juss., *Betulaceae* S.F. Gray, *Buxaceae* Dumort., *Bignoniaceae* Juss., *Caprifoliaceae* Juss., *Celastraceae* R. Br., *Cornaceae* Dumort., *Cupressaceae* Bartl., *Elaeaqnaceae* Juss., *Ericaceae*Juss., *Euphorbiaceae* Juss., *Fabaceae* Lindl., *Faqaceae* Dumort., *Grossulariaceae* DC., *Hippocastanaceae* DC., *Hydrangeaceae* Dumort., *Juglandaceae* A. Rich. ex Kunth, *Menispermaceae* Juss., *Oleaceae* Hofmqq. et Link, *Pinaceae* Lindl., *Ranunculaceae* Juss., *Rhamnaceae* Juss., *Rosaceae* Juss., *Rutaceae* Juss., *Salicaceae* Mirb., *Schisandraceae* Blume, *Solanaceae* Juss., *Staphyleaceae* Dumort., *Taxaceae* Gray, *Thymelacaceae* Juss., *Tiliaceae* Juss., *Ulmaceae* Mirb., *Vitaceae* Juss.

Для выполнения поставленной цели сотрудниками Алтайского ботанического сада проанализированы многолетние данные фенологических наблюдений и сезонной динамики развития древесных интродуцентов в горно-лесных условиях.

Характеристика почвенно-климатических условий дана на основании почвенно-климатических карт [8] и метеорологических данных [9]. Многолетние фенологические наблюдения проводились раз в две недели в период вегетации растений [10, 11]. Интродукционный анализ древесно-кустарниковых растений Алтайского ботанического сада дан на основании проведенных наблюдений оценки перспективности интродуцентов по основным параметрам адаптации видов — зимостойкость, ритм развития, способность к генеративному возобновлению, декоративность [12–18].

Результаты и их обсуждения

Дендрарий Алтайского ботанического сада расположен на окраине города Риддер в межгорной котловине Убинского и Ивановского хребтов на площади 12 гектар в пойме реки Быструхи, захватывая юго-западный склон горы Белкина. Почвы представлены горными черноземами различной мощности с содержанием гумуса от 6 до 8 %. Горный рельеф за счет температурных инверсий смягчает низкие температуры зимой и высокие летом. Погодные условия зимнего периода определяет Монголо-Сибирский антициклон, приносящий холодные воздушные массы, способствуя вынужденному покою древесных пород. Вегетационный период фенологического развития растений насчитывает 5,9–6,4 месяцев [9]. Средняя температура зимы составляет –12,6 ºС с кратковременными морозами до –35–45 ºС. Средняя высота снежного покрова на открытых пространствах достигает 50–60 см, с глубиной промерзания почвы 40–119 см [9]. Весна поздняя и продолжительная. Для нее характерны периодические весенние заморозки. Особенно неблагоприятны последствия заморозков в конце мая – начале июня. Понижение температуры до –3–5 ºС вызывают существенные подмерзания молодых побегов, распустившихся листьев и генеративных органов, что приводит к нарушению нормального физиологического развития. Лето короткое, умеренно теплое — регион находится под влиянием центра низкого давления с господством сухих континентальных тропических масс. Средняя температура самого теплого месяца составляет +16,6 ºС. Особенностью лета является ограниченный безморозный период с суммой активных температур в 1000–1800 ºС, длительностью 82–121 день. Вся территория находится в области с достаточным увлажнением в летний период, с выпадением осадков 140–300 мм. Осень ранняя, с резкими перепадами суточных температур, влияющих на физиологическое состояние растений при прохождении фаз закаливания. Первые заморозки на почве возможны уже в третьей декаде августа. Зимний период наступает при устойчивом переходе среднесуточных температур ниже 0 ºС в третьей декаде октября – первой декаде ноября [9].

Как показала практика, ведущими факторами естественного отбора при формировании коллекции дендрария Алтайского ботанического сада являются высокая зимостойкость и морозоустойчивость растений, раннее начало и окончание вегетации, динамичное прохождение ростовых процессов и репродуктивной фазы развития, что, в целом, необходимо для сохранения природного габитуса и вызревания семян в условиях ограниченного безморозного периода.

По состоянию на 2021 г. Коллекционный фонд дендрария насчитывает 644 вида, форм, сорта, относящихся к 40 семействам и 103 родам. В формировании коллекции древесно-кустарниковых пород участвуют голо- и покрытосеменные растения, систематический состав которых представлен на рисунке 1.

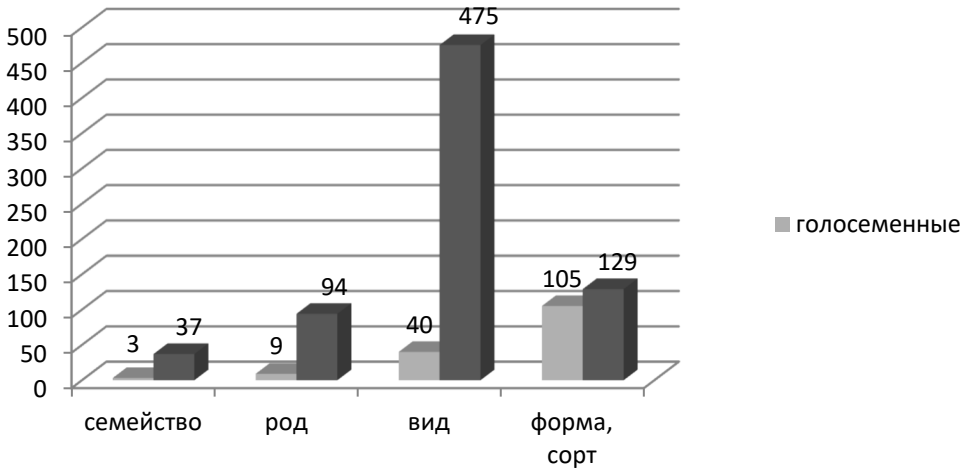

Рисунок 1. Систематический состав арборетума Алтайского ботанического сада по состоянию на 2021 г.

В основу размещения растений в дендрарии положен географический принцип, состоящий из интродукционных популяций, собранных в виде небольших групп или отдельных солитеров из разных ботанико-географических областей (Дальний Восток, Северная Америка, Сибирь, Средняя Азия и Европа) (рис. 2).

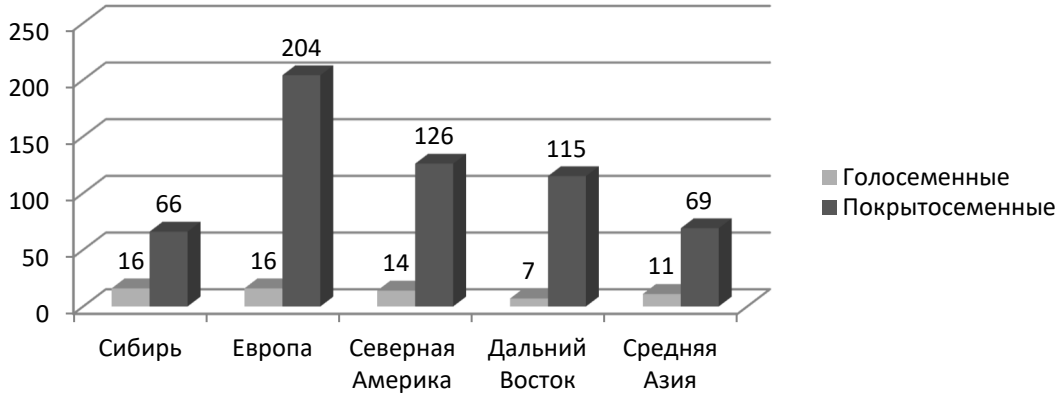

Рисунок 2. Географическое происхождение интродуцентов Коллекционного фонда дендрария Алтайского ботанического сада

Основная часть (65 %) коллекционных растений дендрария сохраняет природную форму роста, обладает устойчивым годовым приростом с законченным циклом сезонного развития. Анализ многолетних фенологических наблюдений позволил выявить наиболее перспективные ботанико-географические области для интродукции древесных пород к почвенно-климатическим условиям в горно-лесном поясе — это умеренная зона Северной Америки, Дальний Восток, Сибирь и горные районы Европейской части Евразии.

Голосеменные породы представлены 3 семействами, относящимися к 9 родам, 40 видам, 24 формам и сортам (9,9 % от общего числа культиваров). Из них по жизненной форме 37 таксонов относятся к деревьям, и 27 — к кустарникам. Основная часть коллекции хвойных пород достигла 20–30-летнего возраста. Наиболее зрелые насаждения представлены лесообразующими породами, входящими в состав местной дендрофлоры: *Picea obovata* Ledeb., *Abies sibirica* Ledeb., *Larix sibirica* Ledeb., *Juniperus sabina* L., *Pinus sibirica* Du Tour, *Pinus silvestris* L. В количественном соотношении в коллекцию привлечено по 16 таксонов из Европы и Сибири; из Северной Америки –14 видов, произрастающих в хвойных лесах Атлантическо-Североамериканской области.

Из Восточно-Азиатской и Бореальной дендрофлористической областей Дальнего Востока интродуцировано 7 видов (рис. 2). По видовому составу наиболее широко представлены таксоны из ро-

дов: *Pinus* L. — 11 видов и 2 формы; *Picea* Dietr. — 8 видов и 8 форм; *Juniperus* L. — 7 видов и 8 форм, сортов; *Abies* Hill. — 4 вида. В генеративную стадию развития вступили 24 вида, из них периодически плодоносят — 22.

Picea schrenkiana Fisch. et Mey., *Abies holophylla* Maxim., интродуцированные из регионов с более теплым климатом, изменили форму роста с древовидной на кустовую при увеличении прироста в нижней части кроны.

Многолетние наблюдения за сезонным развитием выявили у хвойных интродуцентов в коллекции определенный фенологический консерватизм биоритмов, обусловленный морфофизиологической специфичностью вида. Интродуценты медленнее изменяют сезонный цикл развития, хуже переносят зимние повреждения, вегетация и семенная репродукция ослаблены, с переменой экологических условий произрастания проявляют ограниченный уровень адаптированности. Наиболее высокие показатели устойчивости, зимостойкости и декоративности показывают хвойные растения Сибири, ряд таксонов Северной Америки, Дальнего Востока и горных областей Восточной Европы. Среди перспективных культур 16 видов и 19 форм, сортов, которые позволяют расширить потенциальный ассортимент вечнозеленых пород для применения в озеленении региона: *Pinus mugo* Turra*, Pinus banksiana* Lamb., *Pinus sibirica* DuTour, *Picea obovata* Ledeb. и ее формы, *Picea jezoensis* (Sieb. et Zucc.) Carr., *Picea pungen*s Engelm.*, Picea abies* (L.) Karst., *Picea engelmannii* Engelm., *Larix decidua* Mill., *Juniperus sabina* L., *Juniperus sibirica* Burgsd., *Juniperus davurica* Pall., *Microbiota decussate* Kom.

Покрытосеменные растения дендрария включают 580 видов, форм, сортов, что составляет 90,1 % от всей коллекции дендрария. Из них деревья насчитывают 230 таксонов, кустарники и лианы 350 соответственно. Преобладающее количество кустарников в коллекционном фонде связано с более широкой экологической пластичностью данной формы роста, позволяющей им адаптироваться к широкому диапазону изменений внешней среды. Среди культивируемых растений выделяются семейства: *Rosaceae* Juss., включающее 22 рода, 176 видов и 13 форм, сортов; *Caprifoliaceae* Vent. — 6 родов, 48 видов, 4 формы; *Oleaceae* Hoffmgg. et Link — 5 родов, 28 видов и 32 формы, сорта; *Fabaceae* Lindl. — 5 родов и 14 видов с 2 формами. Богатое разнообразие таксонов представлено среди рода: *Crataegus* L. — 38 таксонов, *Lonicera* L. — 32, *Spiraea* L. — 29, *Rosa* L. — 25, *Salix* L. — 22 вида.

По географическому происхождению в коллекционном фонде дендрария преобладают виды из Северной Америки — 19,6 %, Дальнего Востока — 17,8, Европы — 16,5, Средней Азии — 10,7 и Сибири — 3,1 %. Растения, произрастающие в смежных ботанико-географических областях Евразии, насчитывают 52 таксона — 24,3 % от числа растений арборетума. Существенный процент культивируемых древесных растений сада приходится на систематические единицы в пределах вида — гибрид, форма, сорт. Обладая разной филогенией и амплитудой изменчивости ритма развития, покрытосеменные растения коллекционного фонда дендрария показывают разную степень жизнеспособности. Североамериканские виды представлены в коллекции 126 таксонами. Основная часть растений относится к Канадской хвойной провинции Скалистых гор, Ситхи и Британской Колумбии. Благодаря удовлетворительной зимостойкости и показателям жизнеспособности, данные районы можно причислить к перспективным территориям при интродукции в экологические условия Алтайской горной страны. Введение в культуру интродуцентов для северных и восточных областей Казахстана рекомендуется 64 видов из Североамериканской флоры. Среди них *Crataegus flabellate* (Bosc) C. Koch, *Crataegu spunctata* Jacg., *Viburnum lentago* L., *Mahonia aguifolium* (Pursh) Nutt., *Padus pensylvanica* (L. f.) Sok., *Amelanchier spicata* (Lam.) C. Koch, *Spiraea menziesii* Hook., *Physocarpus opulifolius* (L.) Maxim. и др. С флоры Дальнего Востока, охватывающего северо-восточную окраину материка Азии, в коллекционный фонд арборетума интродуцировано 115 видов.

Результаты наблюдений свидетельствуют о разной устойчивости древесных пород. Наиболее высокие показатели жизнеспособности характеризуют виды из континентальных ареалов Охотско-Камчатской и Маньчжурской дендрофлористической провинции, а также нескольких районов Среднесибирской и Забайкальской провинций, находящихся под влиянием муссонного климата Тихого океана. Наименее слабые адаптивные показатели характерны для растений островной части Сахалино-Хоккайдской и Японо-Корейской провинций. Но, в целом, положительные результаты интродукции позволили рекомендовать в культуру 89 видов — *Acer ginnala* Maxim., *Juglans mandshurica* Maxim., *Euonymus maackii* Rupr., *Pyrusus suriensis* Maxim., *Ulmus lasiniata* (Trautv.) Mayr, *Crataegus dahurica* Koehne, *Crataegus pinnatifida* Bunge, *Populus maximowiczii* A. Henry и др. Из Западной, Восточной Европы и Кавказа испытано 106 видов.

Генотипическая особенность растений региона способствует продолжительному росту и сезонному развитию культур в горнолесных условиях района интродукции. Вынужденное окончание вегетации в условиях резкого возрастания суточных амплитуд осеннего периода не позволяет древесным породам в полной мере подготовиться к зимнему периоду и перейти в морозоустойчивое состояние. Поэтому после перезимовки характерны различные повреждения органов и частей растений от низких зимних температур.

У ряда древесных пород Европейского региона феноритмическая гетерогенность в пределах природного ареала обеспечивает высокие адаптационные показатели, что позволило выделить более 40 перспективных видов для региональной культуры: *Quercus robur* L., *Alnus incana* (L.) Moench, *Picea abies* (L.) Karst., *Rhamnus cathartica* L., *Euonymys europaea* L., *Acer tataricum* L., *Syringa josikaea* Jacg. Fil., *Berberis vulgaris* L., *Genista tinctoria* L., *Cornus alb*a L. Из районов Средней Азии культивируются 69 видов. Многие из них недостаточно зимостойки и поэтому малопригодны для интродукции на территории Восточного Казахстана. Несмотря на это, ряд интродуцированных видов проявляют достаточную жизнеспособность к условиям среды и вполне пригодны для практического применения в культуре: *Malus sieversii* (Ledeb.) M Roem., *Populus bolleana* Lauche., *Caragana aurantiaca* Koehne, *Crataegus* × *almaatensis* Pojark., *Aflatunia ulmifolia* (Franch.) Vass., *Sorbus tianschanica* Rupr., *Lonicara lanata* Pojark. Древесные породы Сибири и Алтая представлены 66 видами. Из них около 70 % растений входят в состав дендрофлоры умеренного пояса Евразии. Данная группа наиболее адаптирована к особенностям климатических условий региона. Они обладают высокой степенью зимостойкости, сохраняют присущую им в природе жизненную форму и побегообразовательную способность, дают семенное потомство, обеспечивающее приспособительную изменчивость при смене поколений. Относятся к группе рано или поздно начинающих и рано заканчивающих вегетацию при полном одревеснении побегов. В озеленении области традиционно используются такие виды, как *Crataegus altaica* Lange., *Tilia sibirica* Bayer, *Populus nigra* L., *Betula pendula* Roth, *Pentaphylloides fruticosa* (L.) O. Schwarz, *Spiraea media* Friedr. Schmidt, *Sibiraea altaensis* (Laxm.) C.K. Schneid.

В составе Коллекционного фонда сада представлено 156 таксонов гибридов, форм и сортов древесных растений. Сравнительный анализ показывает, что многие из них характеризуются пониженной жизнеспособностью к лимитирующим факторам среды по сравнению с типичной формой вида, но повышенные декоративные качества и отбор устойчивых культиваров к условию произрастания дают возможность использовать 83 таксона при создании разнообразных садово-парковых композиций.

Заключение

Соотношение филогении вида с особенностями климатических условий произрастания определяет устойчивость интродуцентов и их способность к акклиматизации. Процесс перестройки ритмов сезонного развития и формирование жизненных форм позволяют создавать устойчивые интродукционные популяции, являясь базой для формирования регионального ассортимента для использования в зеленом строительстве и иных сферах хозяйственной деятельности.

Коллекционный фонд дендрария сада представляет собой ценный научный материал для познания биологии и экологии интродуцированных видов в природно-климатических условиях Восточного Казахстана. Основная часть культивируемых пород проходит все этапы сезонного развития, обладает повышенной зимостойкостью, устойчивым ростом, цветет и плодоносит с формированием жизнеспособных семян. Результаты многолетних наблюдений за зимостойкостью, ритмом сезонного развития и декоративными качествами позволили рекомендовать не менее 370 видов, форм, сортов древесных пород для практического использования в культуре. Дальнейшие научно-исследовательские работы направлены на привлечение и испытание новых видов мировой дендрофлоры, разработки научных основ прогнозирования и оценку перспективности таксонов в резко континентальном климате Казахстана при повышенной антропогенной нагрузке.

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Алтай ботаникалық бағының дендрариясындағы бұталы өсімдіктердің интродукциялық талдауы

Мақалада Алтай ботаникалық бағы арборетумындағы коллекциялық өсімдіктер интродукциясының көпжылдық нәтижелері келтірілген. Солтүстік Американдан, Сібірден, Қиыр Шығыстан, Қытайдан, Жапониядан, Орта Азиядан, Еуропадан алғашқы сынаққа тартылған ағаш интродуценттер сыналды. Зерттеу нысандары жалаңаштұқымды және жабықтұқымды ағаш өсімдіктердің 40 тұқымдасы мен 102 түрінен 643 түр, форма, сорт ретінде ұсынылған. Өсімдіктер тұқым материалдары, тірі өсімдіктер және жасыл сабақтар арқылы зерттелді. Бақша дендрариясындағы гендік қордың интродукциялық тұрақтылығын бағалау көпжылдық эксперименттік зерттеулерге сәйкес өсімдіктердің өміршеңдігінің күрделі көрсеткіштері негізінде берілген. Өміршеңдіктің, бейімделудің көрсеткіштерін анықтау үшін ботаникалық бақтарда фенологиялық бақылау әдісі қолданылды. Аймақты көгалдандыруда қолдануға арналған таксондардың болашағы М.П. Косаревтің, П.И. Лапиннің, С.В. Аристовтың кешенді шкаласы бойынша анықталған. Биологиялық және экономикалық сипаттамалардың кешені бойынша аймақты көгалдандыруда жалаңаштұқымды және жабықтұқымды ағаш түрлерінің 370 түрін, формасын, сортын қолдану ұсынылған. Алтай ботаникалық бағы дендрарийінің интродукциялық ресурстарының мониторингі бойынша материалдарды Қазақстандағы интродукциялық жұмыстарды кеңейту және оларды өңірді көгалдандыру үшін пайдалануға болады.

Кілт сөздер: интродуценттер, жүйелілік, географиялық шығу тегі, фенология, бейімделу, өміршеңдік, перспектива, шаруашылық-пайдалы белгілері.

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Introduction analysis of tree and shrub plants of the arboretum of the Altai Botanical Garden

The article presents the results of the long-term introduction of collection plants of the arboretum of the Altai Botanical Garden. The authors of the article collected woody introduced species for primary testing from North America, Siberia, the Far East, China, Japan, Central Asia, and Europe. The objects of the study were 643 species, forms, varieties of woody plants from 102 genera and 40 families of gymnosperms and angiosperms taxa. Plants were collected by seed material, living samples and green cuttings. The assessment of the introduction resistance of the garden arboretum gene pool was given based on complex indicators of plant viability according to the data of long-term experimental research. To determine the indicators of viability, adaptation, the method of phenological observations in botanical gardens was applied. The prospect of taxa for use in the landscaping of the region was determined according to the integrated scales of M.P. Kosarev, P.I. Lapina, S.V. Aristova. According to the complex of biological and economic characteristics, 370 species, forms, varieties of coniferous and angiosperms are recommended for use in landscaping of region. Materials for monitoring the introduction resources of the arboretum of the Altai Botanical Garden can be used to expand the introduction work in Kazakhstan and in regional green construction.

Keywords: introduced species, taxonomy, geographical origin, phenology, adaptation, viability, prospects, economically useful signs.

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Investigation of the effect of acetylation on the physicochemical properties of grain starches

Use of acetylated starches in the production of composite biodegradable materials is a promising direction, since acetylation increases the water-resistant properties of starches. This article presents the results of studies on the effect of acetylation of wheat A and corn starches with glacial acetic acid on the physicochemical properties of polysaccharides and the study of the potential of using modified starches to obtain a composite mixture of biodegradable films. Comparative studies of the physicochemical properties of polysaccharides and their modifications have illustrated that acetylation leads to a decrease in the proportion of amylose in starch, and also reduces the swelling of starch. It has been revealed that the degree of substitution in starches increases only at the initial stages of the acetylation reaction, which is possibly associated with the rheology of starches common to corn and wheat A during swelling and gelatinization. With a decrease in the amount of acetylating agent, a more uniform course of the reaction is observed, the granules destroyed after absorbing the maximum amount of moisture still have access points for replacement with acetyl groups, the reaction proceeds more slowly, but deeper. Solubility depends more on the reaction time. The optimal technological parameters for obtaining acetylated starches have been determined. For wheat starch A, the following are optimal: the concentration of glacial acetic acid is 1: 6, the reaction time is 40 minutes; for corn starch: concentration of glacial acetic acid 1: 5, reaction time 60 minutes. Samples of acetylated starches obtained under such conditions are convenient for preparing a composite mixture of biodegradable materials.

Keywords: wheat A starch, corn starch, amylose, swelling, solubility, acetylation, rheology, starch modification.

Introduction

The packaging materials, mainly polyethylene, which is durable and degradable for more than hundred years, creates a serious problem for the environment all over the world. This problem is also highly relevant in Kazakhstan. In addition, according to the EU Directive (EC 94/62 “SDA-Green Mark”), the responsibility of the packaging manufacturer for the life cycle of the packaging put into circulation on the market is determined. As a member of the World Trade Organisation (WTO) being fully compliant with its requirements, the problem of packaging recycling is also arised in our country.

The most attractive alternatives to petroleum-based or synthetic-based plastic packaging are polymers derived from a variety of renewable natural resources such as starch, cellulose, chitosan, plant and animal proteins. An affordable, inexpensive, renewable, and degradable natural polymer is starch. However, poor water resistance and low strength are limiting factors for the use of materials made from starch. These problems are solved by chemical modification of starch, which allows obtaining optimal functional properties for packaging materials.

Despite a plenty of studies being done on biodegradable starch-based materials, there are still challenges and opportunities to improve productivity and reduce costs, in particular to improve the recognized weakness of starch-based materials: moisture sensitivity.

Starch is a polysaccharide that can be synthesized by plants and is found mainly in fruits, root tubers, legumes and cereals, usually its content varies from 25 to 90 %. Unlike other polysaccharide polymers, which are harvested or recovered by destroying plants, starch can be harvested in most cases without destroying them [1]. Starch is stored by plants in a partially crystalline, water-insoluble granule form, the size and composition of which depends on the plant source [2, 3]. Due to its complete biodegradability [4], low-cost and renewability [3–5] starch is considered as a promising candidate for the development of environmentally friendly materials. The hydrophilic nature of starch is a major limitation that severely limits the development of starch-based products, so chemical modification is a way to solve the problem when making waterproof materials [6]. Acetylation is one of the best studied and implemented chemical

modifications on the industrial level and is based on the esterification of starch with acetyl groups (–$COCH_3$) to form starch acetates [7]. The introduction of acetyl groups helps to reduce interactions between the outer chains of amylopectin and amylose chains, imparting new properties to the polymer. Authors found that the introduction of acetyl groups during acetylation reduces the bond strength between starch molecules and thereby increases the swelling and solubility of starch granules, reduces starch coagulation, and provides improved freeze-thaw stability. As with all chemical reactions, acetylation depends on factors such as reagent concentration, reaction time and pH, which finally determine the number of acetyl groups [8].

Aim of this work is to study the potential of wheat A and corn starches acetylated with glacial acetic acid to obtain a composite mixture of biodegradable materials.

Experimental

Materials. Industrial samples of starches were used in the work: corn starch was purchased from Zharkent Starch Plant LLP, Zharkent, wheat A starch was provided by BioOperations LLP, Taiynsha. All used chemicals were of analytical grade.

The total protein content was determined on a semi-automatic complex (Keltron 4005, Sibagropribor, Russia), which includes a digestor, a scruber, and a distillation unit, titration was carried out manually, according to the Association of Official Agricultural Chemists (AOAC) method 2011.11 “Protein (crude) in animal feed, plant tissues, grain and oilseeds”, the method of block ashing using a copper sulfate catalyst with steam distillation into boric acid.

Lipid content was determined on an automated Buchi device (Extraction Unit E–812). To carry out the analysis with an error of no more than 0.1 g, a sample of starch 25–50 g was transferred into a disposable cellulose cartridge and weighed. Then the cartridge was placed in an extraction sleeve and mounted on the device. Chloroform in a volume of 100 ml was used as a solvent. The analysis was conducted in three stages: 1. Extraction takes place at 100 % heating and lasts 60 minutes, includes 6 cycles; 2. Drying lasts 60 minutes at 100 % heating; 3. Rinsing lasts for 25 minutes at 70 % heat. After the completion of the extraction, the cartridge was weighed with an error of not more than 0.001 g and the percentage of lipids was calculated.

Content of amylose and amylopectin was identified according to the method described by Juliano [9].

Determination of phosphate content. The content of phosphates in native and oxidized starches was determined according to GOST 7698–93 “Starch. Acceptance rules and methods of analysis”.

Preparation of acetylated corn and wheat A starch

Acetylated starch was prepared according to the study by Kumoro, Amalia, Budiyati, Retnowati, and Ratnawati with modifications. 100 g of starch was dispersed in 500 ml of distilled water to obtain a starch suspension with a concentration of 20 %. A magnetic stirrer was applied to get a uniform suspension. Then the pH from the suspension was raised to a value of 8 by adding a solution of 1 M NaOH, after which the temperature was raised to 50 °C. Then, to the reaction suspension was added a predetermined amount of glacial acetic acid (1:5, 1:6, 1:7), which led to a sharp decrease in pH. The pH was returned to its original state by the addition of 1 M NaOH. The reaction proceeded from 40 to 60 min, after which the reaction was stopped by bringing the pH to 5.5 by adding 1 M HCl, the acetylated starch after precipitation was washed three times from acid with distilled water, and then dried at room temperature, after which the degree of substitution, the ability to swell and solubility was increased [10].

Determination of Acetyl Group Content (%) and Degree of Substitution (DS)

To determine the degree of substitution (DS), the percentage of acetyl groups (% Ac) ((1), (2)) was determined by titration according to the method of Würzburg (1986). Acetylated starch (1.0 g) was placed in a 250 ml flask and 50 ml of 75 % diluted ethanol in distilled water was added. The samples were heated in a water bath at 50 °C for 30 min, and after cooling, 40 ml of 0.5N hydrochloric acid was added. NaOH, then the mixture was kept under stirring at 200 rpm for 72 hours. The excess alkali was titrated with 0.5 N. HCl, using phenolphthalein as an indicator. The neutralized solution was stirred for 2 h and the excess alkali was titrated. A control sample was also used with the original unmodified starch [11].

$$\text{Acetyl groups}\,\% = \frac{[(\text{Control Sample}(\text{ml}) - \text{Sample}(\text{ml})) \times \text{Molarity HCl} \times 0.043 \times 100}{\text{Sample weight}(\text{g})}, \quad (1)$$

$$DS = \frac{163 \times \text{Acetyl groups}(\%)}{[4300 - (42 \times \text{Acetyl groups}(\%))]}. \quad (2)$$

Determination of solubility and swelling

Water solubility (WS) and swelling power (SP) of native and acetylated starches were analyzed based on the method of Li and Yeh (2001). A 1.0 g starch sample (W0) was accurately weighed and quantitatively transferred into a clear dried tube and reweighed as W1. Then the starch was dispersed in 50 ml of distilled water. The resulting suspension was heated at 60 °C for 30 min with constant stirring. The mixture was cooled to 30 °C and centrifuged at 100 x g for 15 min.

Aliquots (5 ml) of the supernatant were dried to constant weight at 110 °C and designated as WC. The residue, obtained after drying the supernatant, represented the amount of starch dissolved in water. Solubility was calculated as g per 100 g starch based on dry weight according to formula 3.

$$WS = \frac{WC}{WO} \times \frac{50}{5} \times 100 \ . \qquad (3)$$

The supernatant was separated, the swollen starch was weighed as a precipitate. The residue, obtained in the aforementioned experiment (after centrifugation) with the water stored therein, was quantitatively transferred to a clean drying test. The previously used tube was weighed (W2). To calculate the swelling capacity, the weight of the residue was divided by the original weight after subtracting the solubility [12].

Rheology of Acetylated Starch

The rheology of starches was determined using a Rapid Visco Analyzer (RVA 4500, Perten Instruments, Sweden). Distilled water (25 ml) was added to starch weighed portions weighing 3 g (in dry form), then the samples were first equilibrated at 50 °C for 1 min, then heated to 95 °C at a rate of 12 °C/min, held for 2.5 min, then cooled to 50 °C at 12 °C/min, held for 2 min.

Statistical Analysis

The results of experimental studies are represented by the average values determined from three parallel measurements. Mathematical processing of measurements was performed using standard computer programs MS Office Excel 2010, IBM SPSS Statistics.

Results

Currently, most of the starch acetylation is carried out using acetic anhydride and vinyl acetate, which are expensive and hazardous to human health. In this work, glacial acetic acid was used as a modifying agent.

Acetylation of wheat and corn starch was conducted by the suspension method using distilled water as a dispersing agent and sodium hydroxide as a catalyst at a temperature of 53 °C. The influence of the mass fraction of glacial acetic acid on the solubility in water and the swelling power of acetylated starch are presented in Table 1.

Table 1

Influence of different ratios of glacial acetic acid and wheat A starch on water solubility (WS), swelling power (SP) and degree replacement of acetylated starch at pH 8

Time (minutes)	1: 5			1: 6			1: 7		
	WS g/100 g	SP %	DS	WS g/100 g	SP %	DS	WS g/100 g	SP %	DS
0	4.05 ± 0.178	5.39 ± 0.001	0	4.05 ± 0.178	5.39 ± 0.001	0	4.05 ± 0.178	5.39 ± 0.001	0
40	5.49 ± 0.204	5.28 ± 0.0007	2.08 ± 0.017	4.06 ±0.011	4.89 ± 0.0003	1.2 ± 0.026	3.45 ± 0.495	5.45 ± 0.0006	1.93 ± 0.0422
50	3.30 ± 0.127	5.55 ± 0.004	2.02 ± 0.077	4.06 ± 0.138	4.96 ± 0.0008	1.97 ± 0.031	3.56 ± 0.575	5.46 ± 0.0009	2.13 ± 0.0178
60	3.28 ± 0.128	5.88 ± 0.001	1.95 ± 0.004	7.73 ± 0.149	6.18 ± 0.0006	2.05 ± 0.044	2.86 ± 0.691	5.67 ± 0.0007	2.15 ± 0.009

The values of the degree of substitution in starches increased only at the initial stages of acetylation reaction, which is possibly associated with the rheology of starches common to corn and wheat A during swelling and gelatinization. The granules absorbed water and retained it while swelling and increasing the viscosity, since the acetylation process was carried out in an environment with a temperature of 53 °C. This effect was pronounced in samples, where the reaction medium had a greater amount of glacial

acetic acid, absorbing the medium inside the granules undergoing a violent reaction, but with an increase in the reaction time, the supramolecular structures holding the structures of the granules were destroyed and the acetylating agent could no longer carry out the acetylation reaction, since the reaction surface was already acetylated due to the aggressive initial reaction. With a decrease in the amount of acetylating agent, a more uniform course of the reaction was observed, the granules destroyed after absorbing the maximum amount of moisture still had access points for replacement with acetyl groups, the reaction proceeded more slowly, but deeper. This phenomenon was also discovered by a group of scientists led by Kumoro et al. [10].

As can be seen from Table 1, native wheat A starch has a low swelling power and solubility in water, which are 5.39 (%) and 4.05 (g/100 g), respectively. The amylose content in wheat A and corn starch is 23.51 and 24.32 %, respectively.

Table 2 indicates that native corn starch, as well as native wheat A starch, has a low swelling power and solubility in water, which are 5.28 (%) and 4.4 (g/100 g), respectively.

Table 2

Influence of different ratios of glacial acetic acid and corn starch on water solubility (WS), swelling power (SP) and the degree of substitution of acetylated starch at pH 8

Time (minutes)	1: 5			1: 6			1: 7		
	WS g/100 g	SP %	DS	WS g/100 g	SP %	DS	WS g/100 g	SP %	DS
0	4.40 ± 0.251	5.28 ± 0.001	0	4.40 ± 0.251	5.28 ± 0.001	0	4.40 ± 0.251	5.28 ± 0.001	0
40	5.66 ± 0.025	7.44 ± 0.001	0.69 ± 0.009	4.92 ± 0.185	7.42 ± 0.002	0.77 ± 0	4.35 ± 0.421	7.99 ± 0.001	0.8 ± 1.1102
50	4.91 ± 0.688	5.49 ± 0.002	0.91 ± 0.008	5.34 ± 0.574	7, 54 ± 0.002	0.79 ± 0.004	2.01 ± 0.124	6.64 ± 0.004	0.84 ± 0.009
60	8.09 ± 0.109	5.93 ±0.0008	0.88 ±0.018	4.41 ± 0.176	8.14 ± 0.0008	0.86 ± 0.008	1.99 ± 0.728	5.47 ± 0.003	0.86 ± 0.013

The high content of amylose in starch granules leads to the fact that amylose molecules in crystalline form become more compact and intertwined with amylopectin. These structures form a surface; the starch granules become almost solid and prevent the diffusion of water molecules into the starch granules [13].

These patterns are also observed in corn starch, but the degree of substitution in corn starch is less than that in wheat A, perhaps this is due to the increased content of amylose in native corn starch, since amylose is destroyed during acetylation and the destroyed molecular structure of amylose is not further exposed to acetylation, which reduces the overall degree of substitution.

Tables 1, 2 also show that the use of more glacial acetic acid for acetylation does not always increase the solubility of starch in water. Solubility depends more on the reaction time. A similar result was also obtained by Singh et al. on the acetylation of corn and potato starches and Raina et al., who studied the acetylation of rice starch. From the data in Tables 1 and 2, it follows that increasing the reaction time does not always improve the solubility of starch in water in accordance with an increase in the degree of substitution. The high content of amylose in corn starch slows down the rate of the acetylation reaction, as well as an increase in the degree of acetylation. At a low degree of substitution, starch granules of starch are predominantly crystalline or retrograde, which are insoluble in water at ambient temperatures. The slow rate of the acetylation reaction with increasing amylose content may be due to crystals or complexes of amylose [7–14].

According to the data of Tables 1 and 2, DS in starches obtained by acetylation with acetic acid at different concentrations and at different times can be considered high since their limit ranges from 0.69 to 2.15. In this connection, the increase in the swelling of the granules after acetylation was not proportional to the introduction of acetyl groups. Josiane Bartz et al. also illustrate in their studies that acetylation increased the swelling of granules in all modified starches; however, the increase in pellet swelling after acetylation was not proportional to the introduction of acetyl groups, which were more significant in starches with low DS (0.047 and 0.098) and less significant in starch with higher DS (0.125) [15].

Since research is conducted in order to obtain raw materials for the production of biodegradable films, the following samples of acetylated starches were selected for further research: wheat A obtained under conditions: concentration 1:6, reaction time 40 minutes; corn: concentration of glacial acetic acid 1:5, reaction time 60 minutes. This choice is based on the authors' statements that the degree of substitution above 3 leads

to the fact that films obtained on the basis of acetylated starches with this degree of substitution do not undergo degradation in vivo, and the degree of substitution above 1.9 leads to a two fold increase in the decomposition time. Films compared with samples with a degree of substitution of 1.2 [1, 16].

Comparative studies of the physicochemical properties of native wheat A, corn starch and their modifications (Table 3) demonstrated that the amount of amylose in corn and wheat A starch is approximately at the same level, 24.3 % and 23.5 %, respectively.

Table 3

Physical and chemical properties of starch

Indicator	Native wheat A starch	Acetylated wheat starch A	Native maize starch	Acetylated maize starch
Moisture, %	9.42 ± 0.0823^{b}	8.6700 ± 0.1356^{c}	10.006 ± 0.0541^{d}	9.2200 ± 0.0096^{a}
Ash, %	0.2463 ± 0.0162^{a}	0.2351 ± 0.0228^{s}	0.2061 ± 0.0223^{b}	0.1753 ± 0.0128^{b}
Phosphate content, %	0.0375 ± 0.0006^{a}	0.0165 ± 0.0021^{b}	0.0416 ± 0.0014^{s}	0.0359 ± 0.0004^{a}
Protein content, %	1.7066 ± 0.0644^{b}	1.2103 ± 0.0488^{b}	1.4300 ± 0.0133^{c}	1.0006 ± 0.0511^{a}
Amylose content, %	23.5100 ± 0.3399^{a}	22.5266 ± 0.4444^{a}	24.3233 ± 0.6147^{a}	23.2126 ± 0.2135^{a}
Content, %	0.3347 ± 0.0168^{a}	0.2101 ± 0.0102^{c}	0.5769 ± 0.0127^{b}	0.3659 ± 0.0230^{bc}

Note. $p < 0.05$; Mean value ± SD from three repetitions.

The content of phospholipids in starch granules of cereal starches is proportionally related to the content of amylose, since phospholipids, as a rule, form complexes with amylose and long branches of amylopectin and affect the solubility of starch [13]. Physicochemical properties of native starches will have a significant effect on the properties of derivatives, which must be taken into account when modifying starch.

Table 3 designates that the amount of phosphates and lipids correlates with the amount of amylose. The highest amount of amylose (24.32 %), as well as phosphates (0.0416 %) and lipids (0.5769 %), is observed in native corn starch. Wheat A-starch contains amylose (23.51 %), lipids (0.3347 %), phosphates (0.0375 %), and proteins (1.7 %) and ash content (0.2463 %).

Whereas in acetylated starches all these indicators, albeit to an insignificant extent, but decrease. This is due to the use of glacial acetic acid and the constant maintenance of the pH of the suspension at an alkaline level during the acetylation process. A high alkaline environment washes out lipids. Since lipids and phosphates are interconnected and form a phospholipid complex, lipid loss leads to a decrease in phosphate content.

Thus, studies have shown that acetylation of starch leads to a decrease in the proportion of amylose, as well as the swelling of starch. At the same time, with an increase in the mass fraction of amylose, the solubility of acetylated starches decreases and vice versa.

From the data presented in Table 4, it follows that the highest viscosity index achieved during gelatinization has corn starch, but after acetylation, this indicator decreases, perhaps, this is due to the fact that acetylation of starch leads to the destruction of the supramolecular structure of starch because of substitution by acetyl groups.

Table 4

Rheological properties of native and acetylated wheat A and corn starches

Sample	Peak 1	Trough 1	Breakdown	Final Visc	Setback	Peak Time	Pasting Temp
Wheat A starch	3059 ± 12.52	2363 ± 25.66	696 ± 12.66	3589 ± 45.66	1226 ± 28.33	6.40 ± 0.01	81.50 ± 0.00
Acetylated wheat A starch	2046 ± 22.23	1703 ± 17.46	343 ± 15.69	2270 ± 52.33	567 ± 29.33	6.80 ± 0.03	88.05 ± 0.05
Native cornstrach	3753 ± 37.66	1743 ± 19.33	2010 ± 45.23	3510 ± 66.66	1767 ± 25.66	4.53 ± 0.02	76.70 ± 0.00
Acetylated corn starch	3036 ± 38.33	1298 ± 26.33	1738 ± 42.66	2967 ± 48.33	1669 ± 15.95	4.47 ± 0.02	75.15 ± 0.00

Note. $p < 0.05$; Mean value ± SD from three repetitions.

After all the starch granules are completely destroyed, amylose and amylopectin are completely released from the crystal structure and are in free movement in the Breakdown suspension, the lowest viscosity

is observed in acetylated samples, that is 343.00 and 1738.00 for wheat and corn starches, respectively, which is possibly due to the higher degree of substitution in wheat A starch, which, in comparison with native starch, lost two times in viscosity, while acetylated corn starch with a lower relative degree of substitution lost 15 % compared to native starch.

The value of the final viscosity achieved after the end of gelatinization followed by cooling. Wheat A starch has the highest final viscosity, which is 3589.00 versus corn 3510.00 for native starch (Fig. 1, 2). However, with acetylation, this indicator changes in the opposite direction and is 2270.00 for wheat versus 2967.00 for corn starch.

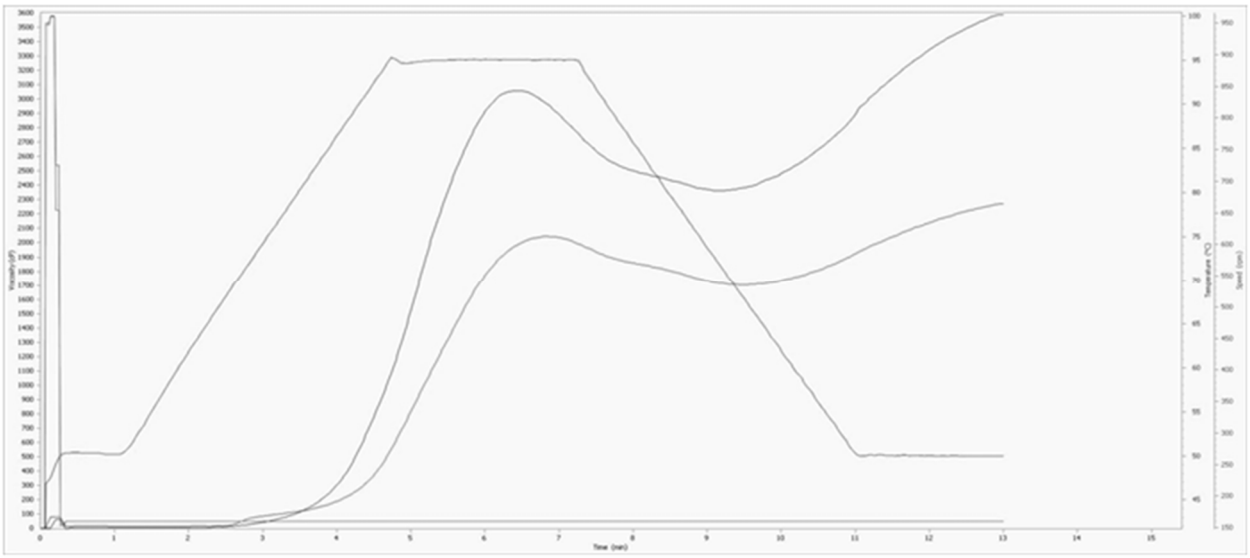

Figure 1. Viscograms of native and acetylated wheat A starch

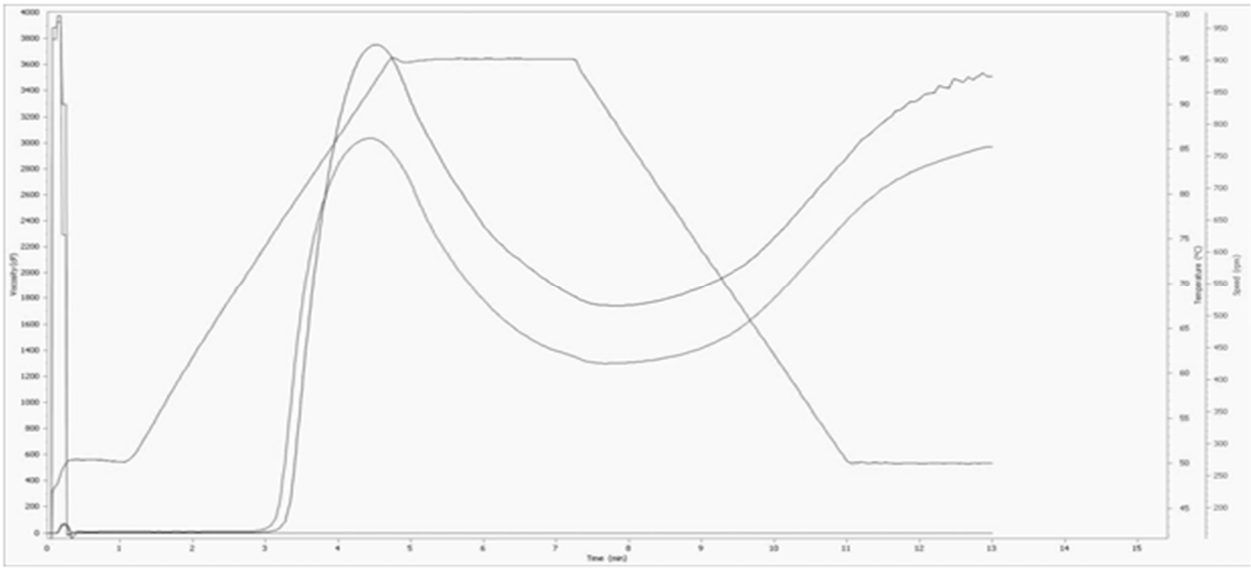

Figure 2. Viscograms of native and acetylated corn starch

Greatest difference between peak and viscosity after disintegration of wheat starch A granules probably due to the large size of the granules.

Accelerated peak viscosity (4.53) is noted for corn starch, which indicates that corn starch is easier to gelatinize. Relatively, low gelatinization temperature of corn starch at 76.7 ºC in native starch is probably due to the small size of granules.

Conclusions

Comparative studies of the physicochemical properties of polysaccharides and their modifications have shown that acetylation leads to a decrease in the proportion of amylose in starch, and also reduces swelling.

It was found that with a decrease in the amount of the acetylating agent, a more uniform course of the reaction is observed, the granules destroyed after absorbing the maximum amount of moisture still have access points for replacement with acetyl groups, the reaction proceeds more slowly but deeper. Solubility depends more on the reaction time.

During the research, the optimal technological parameters for obtaining acetylated corn and wheat A starches were determined. The optimal acetylation parameters for wheat A starch are: the concentration of glacial acetic acid is 1:6, the reaction time is 40 minutes; for corn starch: concentration of glacial acetic acid 1:5, reaction time 60 minutes. The samples of acetylated starches obtained under these conditions are suitable for the formation of biodegradable materials from them in terms of their physicochemical properties.

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Ацетилендірудің дәнді крахмалдардың физика-химиялық қасиеттеріне әсерін зерттеу

Композитті биологиялық ыдырайтын материалдарды өндіруде ацетилденген крахмалдарды қолдану перспективті бағыт болып табылады, өйткені ацетилдеу крахмалдардың суға төзімді қасиеттерін арттырады. Мақалада А бидайын және жүгері крахмалдарын мұзды сірке қышқылымен ацетилдеуде полисахаридтердің физика-химиялық қасиеттеріне әсері және биологиялық ыдырайтын пленкалардың композициялық қоспасын алу үшін модификацияланған крахмалдарды қолдану әлеуетін зерттеу бойынша нәтижелері келтірілген. Полисахаридтер мен олардың модификаттарының физика-химиялық қасиеттерін салыстырмалы зерттеу ацетилдеудің крахмалдағы амилозаның үлесінің төмендеуіне әкелетінін, сонымен қатар, крахмалдың ісінуін төмендететінін көрсетті. Крахмалдардағы алмастыру дәрежесі ацетилдеу реакциясының бастапқы кезеңдерінде ғана өсетіні анықталды, бұл ісіну және клейстеризация кезінде жүгері мен А бидайының крахмалдарының ортақ реологиясымен байланысты болуы мүмкін. Ацетилдеуші агент мөлшерінің азаюы кезінде реакцияның біркелкі ағымы байқалады, ең көп мөлшерде ылғалды өз бойына сіңіргеннен кейін ыдыраған түйіршіктер ацетил топтарын алмастыру нүктелеріне ие, реакция баяу, бірақ тереңірек жүреді. Ерігіштік реакцияның жүру уақытына байланысты. Ацетилденген крахмалдарды өндірудің оңтайлы технологиялық параметрлері анықталды. Сонымен, А бидайы крахмалы үшін: сірке мұз қышқылының концентрациясы 1:6, реакция уақыты 40 минут; жүгері крахмалы үшін: сірке мұз қышқылының концентрациясы 1:5, реакция ұзақтығы 60 минут. Осындай жағдайларда алынған ацетилденген крахмалдардың үлгілері биологиялық ыдырайтын материалдардың композициялық қоспасын алу үшін жақсы сәйкес келеді.

Кілт сөздер: А бидайы крахмалы, жүгері крахмалы, амилоза, ісіну, ерігіштік, ацетилендіру, реология.

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Исследование влияния ацетилирования на физико-химические свойства зерновых крахмалов

Использование ацетилированных крахмалов в получении композитных биоразлагаемых материалов является перспективным направлением, так как ацетилирование увеличивает водорезистентные свойства крахмалов. В статье представлены результаты исследований по влиянию ацетилирования ледяной уксусной кислотой пшеничного А и кукурузного крахмалов на физико-химические свойства полисахаридов и изучению потенциала использования модифицированных крахмалов для получения композиционной смеси биоразлагаемых пленок. Сравнительные исследования физико-химических свойств полисахаридов и их модификатов показали, что ацетилирование приводит к снижению доли амилозы в крахмале, а также набухаемости крахмала. Выявлено, что степень замещения в крахмалах растет только на начальных этапах реакции ацетилирования, что, возможно, связано с реологией крахмалов, общих для кукурузного и пшеничного А, во время набухания и клейстеризации. С уменьшением количества ацетилирующего агента наблюдается более равномерное течение реакции, гранулы, разрушенные после вбирания в себя максимального количества влаги, все еще имеют точки доступа для замещения ацетильными группами, реакция протекает медленнее, но глубже. Растворимость больше зависит от времени прохождения реакции. Определены оптимальные технологические параметры получения ацетилированных крахмалов. Так, для пшеничного А крахмала оптимальными являются: концентрация уксусной ледяной кислоты 1:6, время реакции 40 мин; для кукурузного крахмала: концентрация уксусной ледяной кислоты 1:5, длительность реакции 60 мин. Полученные при таких условиях образцы ацетилированных крахмалов хорошо подходят для получения композиционной смеси биоразлагаемых материалов.

Ключевые слова: пшеничный А крахмал, кукурузный крахмал, амилоза, набухаемость, растворимость, ацетилирование, реология.

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Current state and future development potential of the oak forests in the floodplain of the Ural River (West Kazakhstan)

The article provides information on the current state of the oak forests of the Ural River floodplain (West Kazakhstan) based on the analysis of forest inventory materials (as of 01.01.1992 and 01.01.2016) and field surveys. The study of the dynamics of the oak forests (*Quercus robur* L.) is timely and relevant due to the important ecological role of the oak forests as the most resilient among floodplain forests, and the need to preserve their biological diversity near the south-eastern limit of the natural distribution range. Over a 24-year period, the area of the oak forests decreased by 98.7 hectares (4 %). During the study there has been a decrease in the stand density and site productivity, as well as the predominance of mature stands reproduced through re-sprouting. Pure oak forests or oak forest with an insignificant admixture of *Ulmus laevis* Pall., *Populus alba* L. and *Acer negundo* L. are the most common oak forest types. Natural regeneration of *Q. robur* is unsatisfactory or absent altogether. The total projective cover of the grass layer is up to 90 %, however, its floristic diversity is low. Authors of the article present estimates of the carbon balance of the oak forests under various management scenarios, obtained by using the EX-ACT tool. We stress the need to develop measures aimed at preserving these unique forests, including promotion of the natural regeneration of *Q. robur* and the creation of sustainable forest plantations. To reduce the impact of anthropogenic factors on oak forests (felling, grazing, recreation, etc.), we propose to create a specially protected area in the region.

Keywords: *Quercus robur*, floodplain forest, site quality class, age composition, stand density, natural regeneration, EX-ACT, anthropogenic impact.

Introduction

Protection of forests in general and preservation of their biological diversity in particular is a globally paramount task, which is especially relevant for poor forest countries such as the Republic of Kazakhstan. According to the Committee of Forestry and Wildlife of the Ministry of Ecology, Geology and Natural Resources of the Republic of Kazakhstan [1], as of 01.01.2021 the total area of the state forest fund was 30 047.7 thousands ha, of which 13 316.9 thousand hectares were covered by forest; thus, the forest cover was ca 4.9 %. The most important forest stands are those with the predominance of rare, economically valuable species. The oak forests growing in the floodplain of the Ural River are among such forest stands.

Within its natural distribution range, an oak (*Quercus robur* L.) is an economically valuable forest tree; it is one of the dominant species of deciduous forests in many European countries. In Russia, it grows from St. Petersburg in the north to the steppe zone in the south, and from the eastern country border to the western slopes of the Ural Mountains. In Kazakhstan, the oak grows only in the floodplain forests of the Ural River within the West Kazakhstan region, where it reaches the south-eastern limit of its distribution range [2]. Being a rare type, *Q. robur* is listed in the Red Data Book of Kazakhstan [3]. It has been suggested [4] that oak forests, together with the characteristic elements of the herbaceous layer, penetrated into the territory of Kazakhstan from the Cis-Urals only in historical time.

Oak ecosystems have been extensively studied across the world, from the 19th century onwards. Let us focus on the studies carried out on the territory of Kazakhstan and in the regions of Russia bordering on the West Kazakhstan region.

In the available literature, we found descriptions of the general silvicultural characteristics and growing conditions of the oak forests of West Kazakhstan [5], results of detailed floristic and geo-botanical studies of vegetation in the floodplain of the Ural River, including the oak forests [6–10], and characteristic features of the growth and productivity of forest stands in the region [11]. A typological forest classification was developed, which is still used in forest inventory; according to this classification, the oak stands are described as “oak forests of medium and high levels of the central floodplain” [2]. By origin, they are represented by those reproduced by seed and re-sprouting.

The floodplain forests of the Ural River have a European character [6] that is in their structure and species composition, they are similar to forests in the central regions of the European part of Russian Federation. The ongoing processes of the oak forests degradation and other vegetation of the floodplain are due to changes in the hydrological regime, as well as a high level of anthropogenic impact (fire, grazing, etc.) [12, 13]. Over a fifty-year period, the southern boundary of the distribution of *Q. robur* in the floodplain of the Ural River shifted from 49°40' N to 51°15' N [14]. Nevertheless, in the absence of significant anthropogenic load, oak can be a stable and viable species even in the steppe climate [6].

The ongoing anthropogenic transformation of natural ecosystems makes the problem of decreasing biodiversity of the oak forests more acute [15–17]. Of particular concern is the fact that the reduction in the oak forests area and their condition deterioration under the influence of both climatic and anthropogenic factors is noticeable even in the regions with optimal growing conditions, i. e. in the centre of the distribution range, including European countries such as Slovenia and Serbia**,** as well as the Central regions of Russia [18–21]. Negative factors have a particularly strong influence on the oak forest near the limits of their natural distribution range.

Sustainable forest management plays a significant role in mitigating climate change impacts either by reducing CO_2 emissions or by capturing and storing atmospheric CO_2. The former can be achieved by reducing deforestation and forest degradation rate, introducing improved agricultural practices (limited land cultivation, integrated use of nutrients and water resources); and the latter, by applying methods of conservation agriculture and improving forest management, by afforestation, reforestation and agroforestry, and by improving grassland management and restoring degraded lands.

To conduct a preliminary assessment of the impact of agriculture and forestry projects on greenhouse gas emissions and carbon sequestration, Food and Agriculture Organization (FAO) developed an Ex-Ante Carbon-balance Tool (EX-ACT). This method allows to estimate the overall impact of a project on the carbon balance, compared with the conservative approach scenario (Fig. 1). Carbon balance is defined as the net balance of all greenhouse gases, expressed in carbon dioxide equivalent that was emitted or isolated as a result of the project. EX-ACT is a land-based accounting system that measures carbon stocks, stock changes per unit of land, and CH_4 and N_2O emissions, expressed in tonnes of CO_2 per hectare per year [22–25]. Of particular interest is the use of this method to assess the carbon balance of the oak forests in Western Kazakhstan as the most valuable declining forest ecosystems.

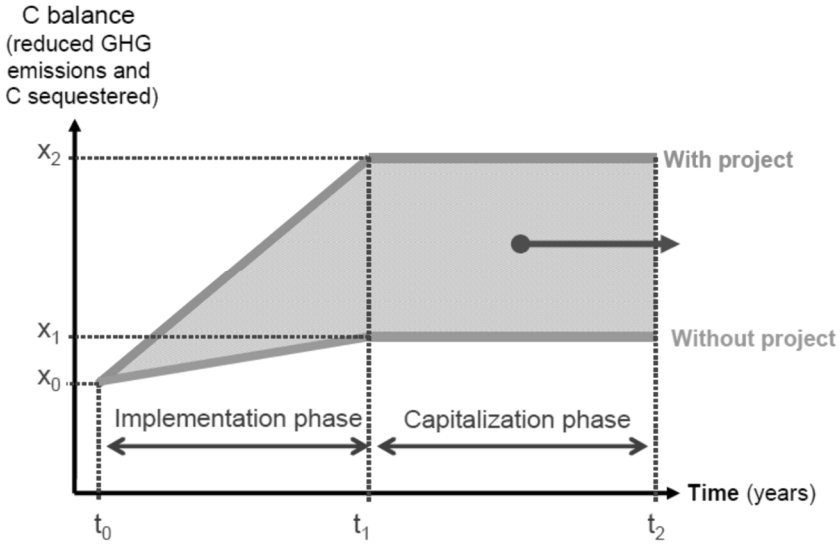


Figure 1. Logic diagram of the EX-ACT method

Taking into account a small forest area, ecological role of forests, as well as the need to increase both, the Strategic Plan of the Ministry of Ecology, Geology and Natural Resources of the Republic of Kazakhstan for 2020–2024 developed the strategic direction “Ensuring the protection, reproduction and rational use of flora and fauna, water resources and specially protected natural areas” [26]. At the same time, special attention should be paid to rare species, especially if they are the main forest-forming species. One of such species is *Q. robur* which forms the most durable floodplain forests in Western Kazakhstan. Therefore, the study

of the oak forest dynamics is timely and relevant. In view of the increasing negative impact of climatic and anthropogenic factors, technologies and methods of sustainable forest management developed with the help of predictive modelling should become a priority. Analysis of the available literature revealed that despite a long period of research, the majority of studies have focused on the geo-botanical and floristic features of plant communities in the Ural River floodplain, and only a few, on the silvicultural characteristics and dynamics of the oak forests; the carbon balance of the oak forest has never been estimated.

The specific research objectives of the present study are: i) to assess the current state of the oak forests in the floodplain of the Ural River (West Kazakhstan) using forest inventory materials and our own experimental data; ii) to estimate the carbon balance of the oak forests using various management scenarios; iii) to develop recommendations for the protection and regeneration of these unique natural objects.

Experimental

1. Characteristics of the study area and analysis of the forest inventory materials

The studies were carried out in West Kazakhstan. This region is located in the subzone of light chestnut desert-steppe (semi-desert) soils. The strongly continental climate of the region is characterized by wide temperature fluctuations between day and night, and between winter and summer, as well as by a rapid seasonal change, especially from winter to summer. The climate is also characterized by little rainfall and thin snow cover, also by low air humidity. Annual precipitation is 239–273 mm. The isotherms of January and July are –11 °C and +24 °C, respectively. The main part of the territory is occupied by the basin of the Ural River, which divides the region into two approximately equal parts. Within the study region, the length of the river is 781 km, and within the country, 1084 km [27]. To study the dynamics of the main forest inventory parameters (the forested area by forest owner, age class, basal area, and site productivity class), the materials of the Republican State Treasury Enterprise (RSTE) "Kazakh Forest Management Enterprise" were analyzed. Specifically, we focused on the characteristics of the oak forests in the West Kazakhstan region as of 01.01.1992 [28] and of 01.01.2016 [29].

2. Survey of the sample plots

During the growing season of 2021, we carried out detailed studies of the oak forests using sample plots with a size of 50 m × 50 m. On the sample plots, the following parameters were measured: tree diameter at breast height (using a caliper), tree height (using a Haglof altimeter), tree age (by taking cores), and basal area. The natural regeneration of tree species and undergrowth were studied using sample plots with a size of 1 m × 1 m established within the main sample plot according to the standard methods [30, 31]. On each sample plot, we measured the total projective cover of all plants and all species [32]. We also identified all plant species found on the plots. The taxonomic affiliation of plants was determined in compliance with the Flora of Kazakhstan (1956–1966) [33]. The nomenclature of species followed the International Plant Names Index (IPNI) [34]. Species were assigned to the category of rare according to the Red Data Book of Kazakhstan [3]. In total, five sample plots were established in the Burlinskiy and Yanvartsevskiy communal state institutions (CSI) for the protection of forests and wildlife of the Department of Natural Resources and Environmental Management of West Kazakhstan region. The coordinates of the sample plots were established by GPS.

3. Development of the carbon balance scenarios

The EX-ACT V9.0 tool [35–36] was applied to assess the carbon balance of the oak forests under various management scenarios. The tool used the following region-specific coefficients: climate, moisture regime, dominant regional soil type, and vegetation type. Two scenarios were taken as examples [37].

Scenario 1. Potential carbon benefits were calculated based on the following assumptions:

– Silvicultural activities involve tree planting in areas that have previously not been forested, and include land preparation, planting of oak and other species, and sustainable management of the created forest areas. The total area to be planted is 30 ha (6 ha of mixed oak stands to be planted over five years) [28]. It should be emphasized that in 1992–2016, in the West Kazakhstan region oak plantations were created and registered as forested lands in a satisfactory condition in an area of only 2.9 ha, which, in our opinion, is inadequate.

– Forestry activities aimed at restoration of degraded forested areas without planting trees imply an improvement of the state of the oak forests and their management. Restoration of degraded forests will be achieved through the promotion of natural regeneration, better protection and conservation of the oak forests, enforcement of relevant laws, and by use of modern management practices. The "moderate" degradation level is to be changed to the "low" over 20 years. According to the available forest management data

[28], the area of the oak forests of 3–5 site productivity classes, including reproduced through re-sprouting oak forests, was 2 318.5 ha. This area was taken as the one with the "moderate" level of degradation (Table 1).

Scenario 2. Calculation of carbon benefits was made for 2 318.5 ha of degraded oak forests, where the initial level of degradation was "moderate" and changed due to the 15-years sustainable management to the "very low" level of degradation (Table 1).

Table 1

Methodology for calculating the carbon balance according to the proposed Scenarios

Module of the EX-ACT_V9.0 tool	Scenario 1 Module: Land-use changes. 2.2 Afforestation and reforestation. Module: Forest management. 5.1 Forest degradation and management	Scenario 2 Module: Forest management. 5.1 Forest degradation and management
Continent	Central Asia	
Country	Kazakhstan	
Climate	Cool Temperate	
Moisture	Dry	
Soil type	High-activity clay soils	
Implementation phase, years	5	25
Capitalization phase, years	15	15
Total duration of accounting, years	20	40
Type of forest vegetation	Temperate continental forest	
Module 2: data entry		
Fire used	NO	-
Initial land-use	Annual cropland	-
Module 5: data entry		
Scenario 1		

2.2 AFFORESTATION & REFORESTATION — If country-sp

Final land-use	Fire used? (y/n)	Initial land-use	Initial agroforestry systems	Reforested area (ha) Without		With	
Temperate continental forest	NO	Annual cropland	Please select	0	D	30	D

5.1 FOREST DEGRADATION & MANAGEMENT — If country-sp

Type of forest vegetation that will be managed	Forest degradation level			Fire occurrence		Fire periodicity		Impact (% burnt)		Forested area (ha)			
	Start	Without	With	Without (y/n)	With (y/n)	Without (year)	With (year)	Without	With	Start	Without		With
Temperate continental forest	Moderate	Low	Very low	NO	NO	1	1	100%	100%	2 319	2 319	D	2 319

Scenario 2

5.1 FOREST DEGRADATION & MANAGEMENT — If country-sp

Type of forest vegetation that will be managed	Forest degradation level			Fire occurrence		Fire periodicity		Impact (% burnt)		Forested area (ha)			
	Start	Without	With	Without (y/n)	With (y/n)	Without (year)	With (year)	Without	With	Start	Without		With
Temperate continental forest	Moderate	Low	Very low	NO	NO	1	1	100%	100%	2 319	2 319	D	2 319

Results and Discussion

1. The oak stand parameters according to the forest inventory data

As of 01.01.2021, the forest fund total area of the West Kazakhstan region was 220 thousand ha, including the forested area of 89.7 thousands ha; the forest cover was 0.6 %, one of the lowest in the country [1]. In the region, the share of the most valuable natural oak stands (*Q. robur*) was diminutive. As a result of the analysis of the data on the oak forests, the West Kazakhstan region obtained from the State Enterprise "Kazakh forestry enterprise" as of 01.01.1992 and 01.01.2016, the following was established.

In 1992, the oak forests total area on the territory of the four CSI for the protection of forests and fauna (Burlinskiy, Uralskiy, Yanvartsevskiy, and Chingirlauskiy) amounted to 2,465.9 ha (Fig. 2). As of 01.01.2016, only the first three forest owners preserved the oak forests with a total area of 2,367.2 ha, which is 2.6 % of the area covered by forests in the region. On the territory of the Chingirlauskiy CSI, the oak forests were absent. It was not possible to establish the exact reason for their absence; perhaps they disappeared under the pressure from frequent droughts and wild fires. On the whole, over 24 years the total area of the oak forests decreased by 98.7 ha, or 4 %.

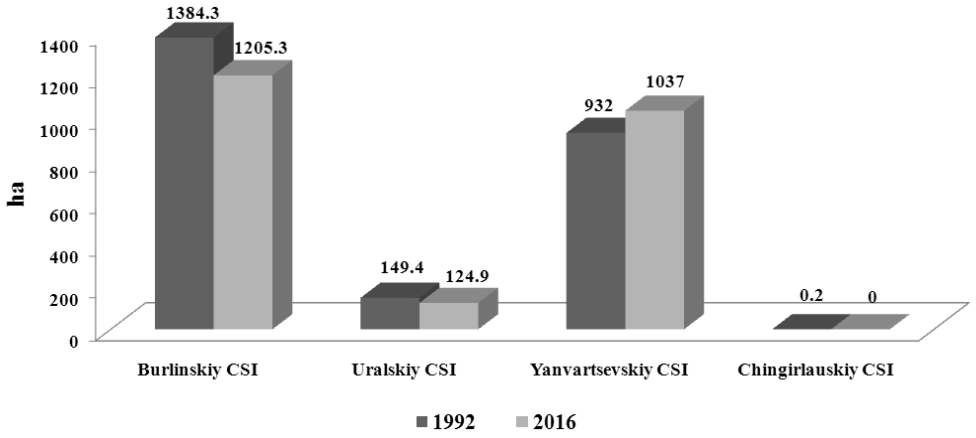


Figure 2. The distribution of the oak forests (ha) by forest owner in the West Kazakhstan region

Changes in the basal area of the oak forests were also recorded. Analysis of the distribution of the oak forests by basal area (Fig. 3) illustrated that as of 01.01.1992, stands with the 0.7 and 0.6 relative basal area dominated and accounted for 56.3 % of the oak forests total area. As of 01.01.2016, stands with the 0.5 and 0.6 relative basal area prevailed and accounted for 64.3 % of the total area of the oak forests. At the same time, the forest stands area with the 0.5 relative basal areas increased, while the oak forests area with the 0.7 basal areas decreased; that is, the tree density decreased since 1992. There were only few high-density stands (with the 0.8 basal area and above), and their area had been decreasing.

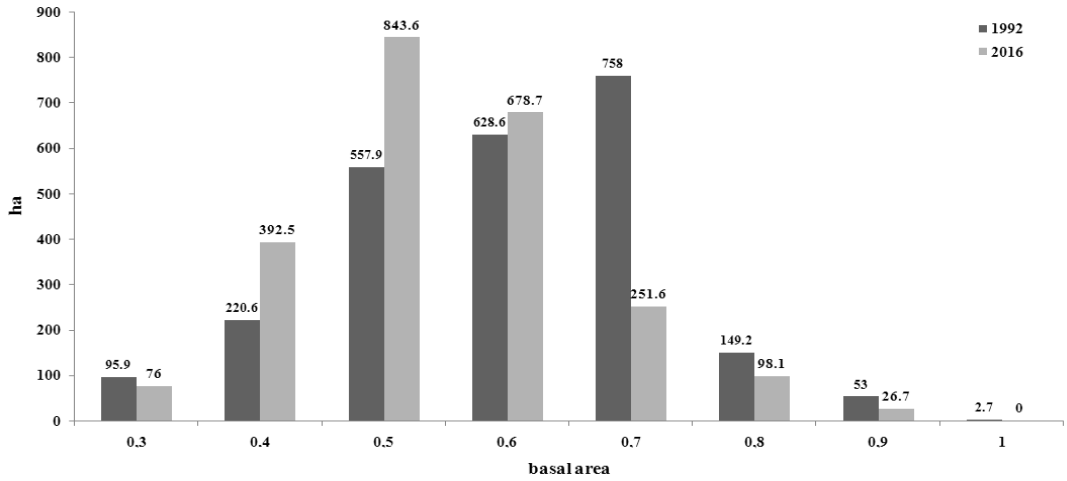


Figure 3. The distribution of the oak forests (ha) by basal area

Analysis of the distribution of the oak forests by the site productivity class (Fig. 4) revealed that as of 01.01.1992, stands of the second site productivity class predominated, which accounted for almost 50 % of the oak forest area. As of 01.01.2016, oak stands of the fourth site productivity class predominated and accounted for 50.2 % of the oak forest area. This indicates a decrease in the productivity of the oak forests because of deterioration of soils and changes in the climatic conditions.

The analysis of the distribution of the oak forests by age class (taken as 10 year) showed that in 1992, stands of the sixth and seventh age classes dominated, accounting for 65 % of the total area of the oak forests. Stands, younger than 60 years, accounted for 30.7 %, while stands, older than 70 years, — for 4.4 %. In 2016, stands of the seventh and eighth age classes dominated, accounting for 61.1 % of the total area of the oak forests. At the same time, the younger stands area was only 8.5 % of the total area of the oak forests (Fig. 5).

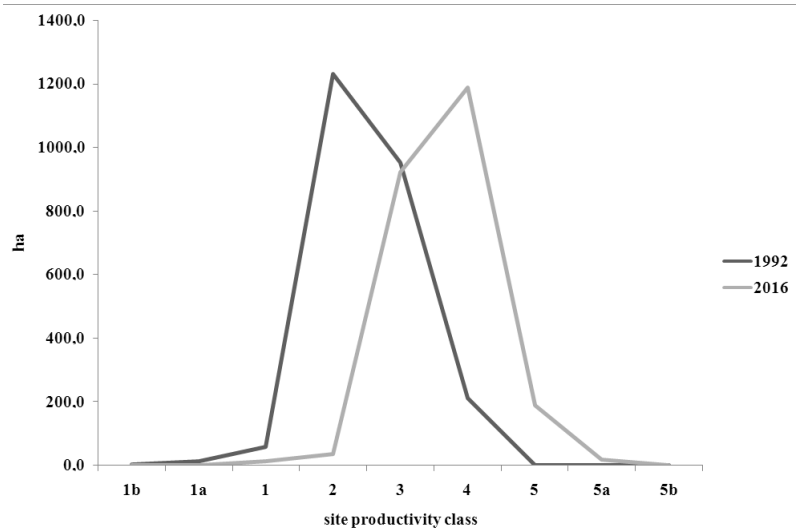


Figure 4. Distribution of the oak forests (ha) by the site productivity class

Presently, mature and over-mature oak stands prevail in the West Kazakhstan region. Changes in the distribution of stands by age class occurred as a result of natural aging and transition from one age class to another, and because of anthropogenic factors, including forest fires. It should be noted that seed regeneration of broad-leaved species, including *Q. robur,* is suppressed at the extreme limit of their natural distribution range due to weakened seed production, intensive development of herbaceous plants in low density stands, and anthropogenic impact. However, owing to reproduction through re-sprouting, forest-forming species can regenerate and are able to persist in the occupied area [6]. This is also observed in the floodplain forests of the region, where the oak forests reproduced through re-sprouting dominate [38] and occupy about 80 % of the oak forest area [29].

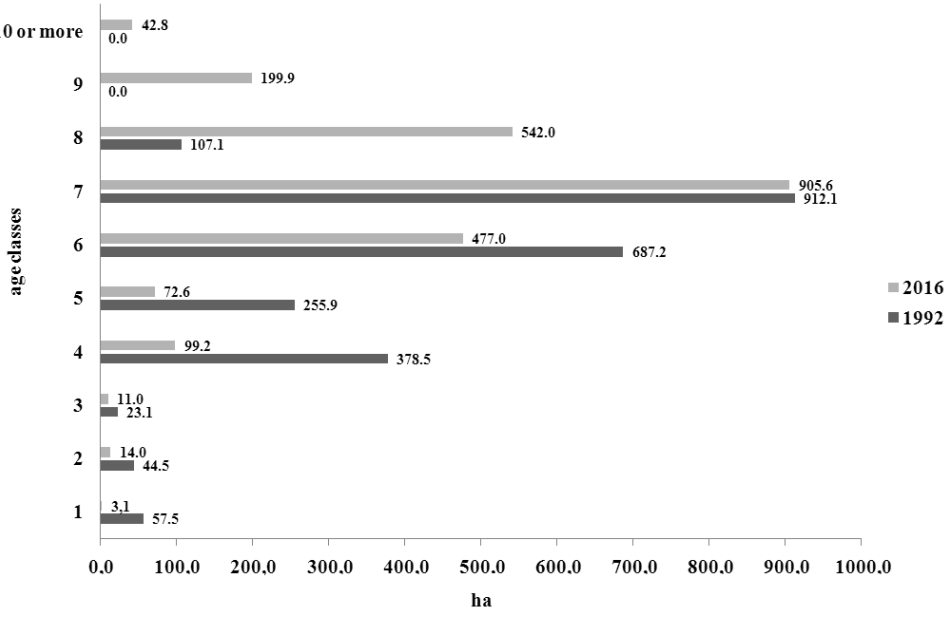


Figure 5. The distribution of the oak forests (ha) by age classes

Thus, the results of our analysis of the forest inventory data on the oak forests of the West Kazakhstan region for 1992–2016 indicate a decrease in the area occupied by 4 % of *Q. robur*, a decrease in stand density and site productivity, as well as the prevalence of mature and over-mature stands reproduced through resprouting.

2. The oak forests' current state according to the sample plot surveys results

To obtain the detailed information on the oak forests' current state, we carried out surveys of five sample plots in the middle reaches of the Ural River valley in 2021. The sample plots layout is demonstrated in Figure 6.

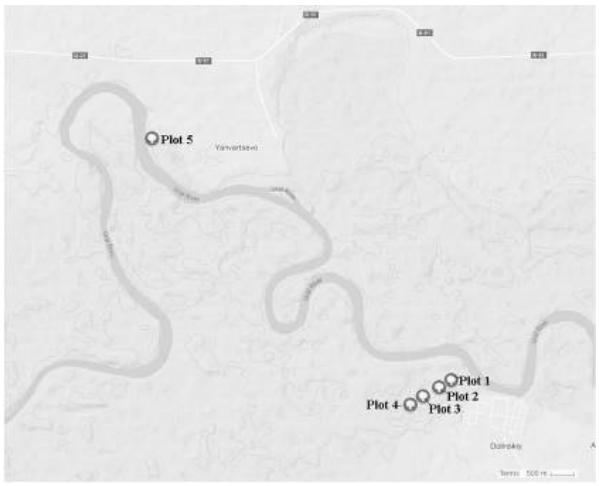


Figure 6. The sample plots layout

The surveyed oak stands were represented mainly by low-density, pure stands of the sixth and seventh age classes (Tab. 2, Fig. 7*a*). Some stands had an insignificant admixture of *Ulmus laevis* Pall., *Populus alba* L., and *Acer negundo* L. Our data are in good agreement with the results of the analysis of the forest inventory materials (see the previous sub-section). Natural regeneration of *Q. robur* (Fig. 7*b*) was recorded in small quantities in one plot (sample plot 1) only. The presence of the invasive species *Acer negundo* L. in all sample plots designates an anthropogenic impact and can lead to undesirable changes in species composition. Lately, several authors have pointed to this problem [9].

a *b*

a — general view of the sample plot 1; *b* — natural regeneration of *Q. robur*

Figure 7. An oak stand

Table 2

Parameters of the sample plots established in 2021

CSI / Forestry unit	GPS coordinates	Tree stand composition	Basal area	Average parameters of *Q. robur*			Undergrowth	Natural regeneration	Total projective cover of herbaceous species, %	Dominant herbaceous species (% of the projective cover)
				Stem diameter, cm	Height, m	Age, years				
Burlinskiy / Dolinskiy	N 51°40′25.40″, E 52°30′37.40″	10 *Quercus robur* L., single plants of: *Ulmus laevis* Pall., *Acer negundo* L.	0.8	30.0	17.0	70	*Cerasus fruticosa* Pall.	*Q. robur,* poor (< 100 individuals /ha)	90	*Convallaria majalis* L. (80), *Aristolochia clematitis* L. (5)
Burlinskiy / Dolinskiy	N 51°40′17.90″, E 52°30′17.20″	10 *Quercus robur* L., single plants of: *Populus alba* L., *Acer negundo*L.	0.5	32.0	17.5	60	*Cerasus fruticosa* Pall.	absent	70	*Aristolochia clematitis* L. (60)
Burlinskiy / Dolinskiy	N 51°40′04.00″, E 52°29′84.20″	8 *Quercus robur* L. 2 *Ulmus laevis* Pall., single plants of: *Acer negundo* L.	0.5	28.0	17.0	60	*Lonicera tatarica* L., *Cerasus fruticosa* Pall.	absent	90	*Aristolochia clematitis* L. (70)
Burlinskiy / Dolinskiy	N 51°39′90.90″, E 52°29′61.40″	10 *Quercus robur* L., single plants of: *Ulmus laevis* Pall., *Acer negundo* L.	0.5	28.5	17.0	60	*Cerasus fruticosa* Pall., *Lonicera tatarica* L.	absent	60	*Aristolochia clematitis* L. (50)
Yanvartsevskiy / Yanvartsevskiy	N 51°44′57.50″, E 52°21′91.50″	10 *Quercus robur* L., single plants of: *Ulmus laevis* Pall., *Acer negundo* L.	0.5	42.2	16.5	60	*Lonicera tatarica* L., *Rosa majalis* Lindl.	absent	95	*Equisetum pratense* Ehrh. (35), *Aristolochia clematitis* L. (30), *Cirsium arvense* (L.) Scop. (10)

The undergrowth contains mainly *Lonicera tatarica* L. and *Cerasus fruticosa* Pall., and less often, *Rosa majalis* Lindl.

The grass layer was abundant with a total projective cover of 60–90 %, but poor in floristic diversity. Only one sample plot was dominated by an early flowering mesophilic forest species *Convallaria majalis* L. (Fig. 8*a*). In other areas, *Aristolochia clematitis* L. is predominated (Fig. 8*b*). Although it is also an element of the mesophilic forest flora, it is less valuable in phytocenotic terms.

a *b*

a — Convallaria majalis L.; *b — Aristolochia clematitis* L.

Figure 8. The dominant herbaceous species of the oak forests

P.L. Gorchakovskii [8] commented on a poor and uniform floristic composition and simplified structure of the oak forests in the Ural River valley. According to B.A. Bykov, *Convallaria majalis* L. and *Aristolochia clematitis* L. are typical representatives of the herbaceous cover of the European forests; they penetrated into the territory of Kazakhstan together with *Q. robur* [4]. The oak forest with *Convallaria majalis* is considered the most widespread oak forest in the region [9]. At the same time, oak forests with *Convallaria majalis* L.*, Euonymus verrucosus* Scop., and *Corylus avellana* L. are listed as relict [7] and require special protection. It should be noted that such rare species as *Corylus avellana* L.*, Euonymus verrucosus* Scop., and *Convallaria majalis* L. are listed in the Red Data Book of Kazakhstan [3].

In 1980, proposal for the need to preserve the unique flora and vegetation of the region was made to create a nature reserve encompassing floodplain poplar and oak forests and meadows [39]. The proposal has not yet been implemented but is still relevant.

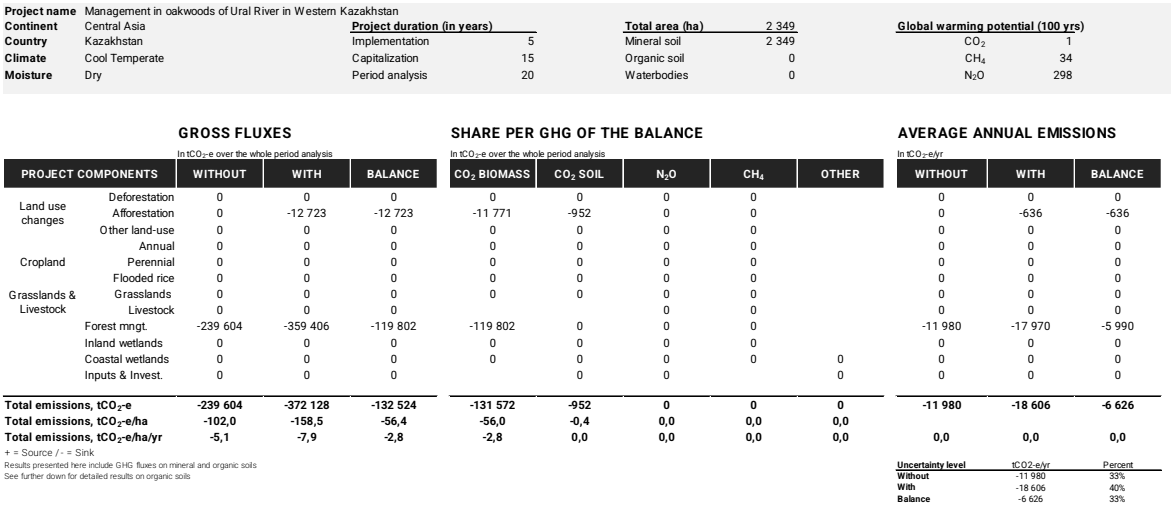
3. Carbon balance

Forests contribute to climate change mitigation by absorbing CO_2 and using it to form aboveground and underground biomass, and to replenish soil carbon. To develop proposals for improving the environmental conditions in the region, we carried out calculations of the carbon balance using various scenarios. According to Scenario 1, the carbon balance was calculated for the oak forests with an area of 2,348.5 ha, which included forest stands of 3–5 ha site productivity classes and future forest plantations (Fig. 9, Tab. 3).

Table 3

Carbon potential of oak forest management in Western Kazakhstan

Type of activity	Area, ha	CO_2-equivalent, ton (with interventions)	CO_2-equivalent, ton / year / ha (with interventions)
Silvicultural	30.0	12 723	21.2
Forestry	2 318.5	359 406	7.75
Total	2 348.5	372 128	7.9



Project name	Management in oakwoods of Ural River in Western Kazakhstan						
Continent	Central Asia	**Project duration (in years)**		**Total area (ha)**	2 349	**Global warming potential (100 yrs)**	
Country	Kazakhstan	Implementation	5	Mineral soil	2 349	CO_2	1
Climate	Cool Temperate	Capitalization	15	Organic soil	0	CH_4	34
Moisture	Dry	Period analysis	20	Waterbodies	0	N_2O	298

GROSS FLUXES (In tCO_2-e over the whole period analysis)

PROJECT COMPONENTS		WITHOUT	WITH	BALANCE
Land use changes	Deforestation	0	0	0
	Afforestation	0	-12 723	-12 723
	Other land-use	0	0	0
Cropland	Annual	0	0	0
	Perennial	0	0	0
	Flooded rice	0	0	0
Grasslands & Livestock	Grasslands	0	0	0
	Livestock	0	0	0
	Forest mngt.	-239 604	-359 406	-119 802
	Inland wetlands	0	0	0
	Coastal wetlands	0	0	0
	Inputs & Invest.	0	0	0
Total emissions, tCO_2-e		**-239 604**	**-372 128**	**-132 524**
Total emissions, tCO_2-e/ha		**-102,0**	**-158,5**	**-56,4**
Total emissions, tCO_2-e/ha/yr		**-5,1**	**-7,9**	**-2,8**

SHARE PER GHG OF THE BALANCE (In tCO_2-e over the whole period analysis)

CO_2 BIOMASS	CO_2 SOIL	N_2O	CH_4	OTHER
0	0	0	0	
-11 771	-952	0	0	
0	0	0	0	
0	0	0	0	
0	0	0	0	
0	0	0	0	
0	0	0	0	
		0	0	
-119 802	0	0	0	
0	0	0	0	
0	0	0	0	0
	0	0		0
-131 572	**-952**	**0**	**0**	**0**
-56,0	**-0,4**	**0,0**	**0,0**	**0,0**
-2,8	**0,0**	**0,0**	**0,0**	**0,0**

AVERAGE ANNUAL EMISSIONS (In tCO_2-e/yr)

WITHOUT	WITH	BALANCE
0	0	0
0	-636	-636
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
-11 980	-17 970	-5 990
0	0	0
0	0	0
0	0	0
-11 980	**-18 606**	**-6 626**
0,0	**0,0**	**0,0**

+ = Source / - = Sink
Results presented here include GHG fluxes on mineral and organic soils
See further down for detailed results on organic soils

Uncertainty level	tCO2-e/yr	Percent
Without	-11 980	33%
With	-18 606	40%
Balance	-6 626	33%

Figure 9. Results of calculating the carbon balance according to Scenario 1

Without project interventions, the carbon balance for the reporting period (20 years) will be 0.24 million tons of CO_2-equivalent or 5.1 CO_2-equivalent/ha/year. Thus, the additional net carbon uptake achieved as a result of the implementation of the measures will amount to 2.8 tons of CO_2-equivalent/ha/year.

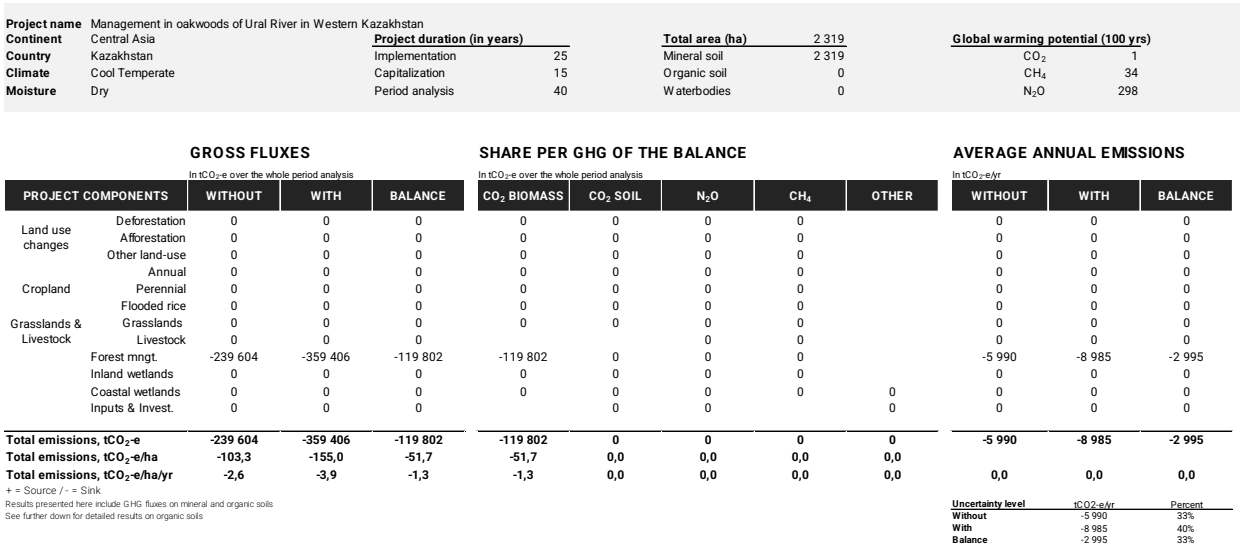
Data on the average and total growing stock per hectare of the oak forests in the floodplain of the Ural River, obtained between 1992 and 2016, demonstrate the degradation dynamics (Tab. 4).

Table 4

The oak forests development in Kazakhstan between 1992 and 2016

Indicators	Measurement unit	Period		Difference	
		1992	2016	m^3	%
Total growing stock	1000 m^3	303.4	292.5	-10.9	3.6
Increment / ha	m^3	1.8	1.8	0.0	0
Growing stock / ha	m^3	123	124	-1	-0.8

An average annual growth rate of about 1.8 m^3 per hectare is considered low. The results of calculating the carbon balance according to Scenario 2 are presented in Figure 10 and Table 5.



Project name	Management in oakwoods of Ural River in Western Kazakhstan						
Continent	Central Asia	**Project duration (in years)**		**Total area (ha)**	2 319	**Global warming potential (100 yrs)**	
Country	Kazakhstan	Implementation	25	Mineral soil	2 319	CO_2	1
Climate	Cool Temperate	Capitalization	15	Organic soil	0	CH_4	34
Moisture	Dry	Period analysis	40	Waterbodies	0	N_2O	298

GROSS FLUXES (In tCO_2-e over the whole period analysis)

PROJECT COMPONENTS		WITHOUT	WITH	BALANCE
Land use changes	Deforestation	0	0	0
	Afforestation	0	0	0
	Other land-use	0	0	0
Cropland	Annual	0	0	0
	Perennial	0	0	0
	Flooded rice	0	0	0
Grasslands & Livestock	Grasslands	0	0	0
	Livestock	0	0	0
	Forest mngt.	-239 604	-359 406	-119 802
	Inland wetlands	0	0	0
	Coastal wetlands	0	0	0
	Inputs & Invest.	0	0	0
Total emissions, tCO_2-e		**-239 604**	**-359 406**	**-119 802**
Total emissions, tCO_2-e/ha		**-103,3**	**-155,0**	**-51,7**
Total emissions, tCO_2-e/ha/yr		**-2,6**	**-3,9**	**-1,3**

SHARE PER GHG OF THE BALANCE (In tCO_2-e over the whole period analysis)

CO_2 BIOMASS	CO_2 SOIL	N_2O	CH_4	OTHER
0	0	0	0	
0	0	0	0	
0	0	0	0	
0	0	0	0	
0	0	0	0	
0	0	0	0	
0	0	0	0	
		0	0	
-119 802	0	0	0	
0	0	0	0	
0	0	0	0	0
	0	0		0
-119 802	**0**	**0**	**0**	**0**
-51,7	**0,0**	**0,0**	**0,0**	**0,0**
-1,3	**0,0**	**0,0**	**0,0**	**0,0**

AVERAGE ANNUAL EMISSIONS (In tCO_2-e/yr)

WITHOUT	WITH	BALANCE
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
-5 990	-8 985	-2 995
0	0	0
0	0	0
0	0	0
-5 990	**-8 985**	**-2 995**
0,0	**0,0**	**0,0**

+ = Source / - = Sink
Results presented here include GHG fluxes on mineral and organic soils
See further down for detailed results on organic soils

Uncertainty level	tCO2-e/yr	Percent
Without	-5 990	33%
With	-8 985	40%
Balance	-2 995	33%

Figure 10. Results of calculating the carbon balance according to Scenario 2

Table 5

Carbon streams with and without project activities

Type of activity Reducing degradation	CO_2-equivalent, ton (without the project)	CO_2-equivalent, ton (with the project)	Balance
Total emissions	239 604	359 406	119 802
Per hectare	103.3	155.0	51.7
Per hectare / year	2.6	3.9	1.3

With a decrease in forest degradation, the net carbon uptake (ha/year) will be 3.9 tons of CO_2-equivalent, which will provide an average potential. Thus, sustainable forest management allows for a positive carbon balance in the future.

Conclusions

According to the data from "Kazakh Forest Management Enterprise", the oak forests occupy 2 367.2 hectares in the West Kazakhstan region, which is 2.6 % of the all forested area in the region. In 1992–2016, the area of oak forests decreased by 98.7 hectares, or 4 %. The analysis of the forest inventory data illustrated the negative dynamics of the oak forests: the decrease of stand density and site productivity, and the predominance of mature and over-mature stands reproduced through re-sprouting.

The above results are consistent with the results of our field studies. A characteristic feature of the surveyed oak forests is a poor natural regeneration and a relatively low floristic diversity, which can be explained by the unfavorable conditions of their existence at the border of the natural distribution range. The presence of an invasive species *Acer negundo* L. in all sample plots indicates the potential undesirable change in the species composition leading to the displacement of the most valuable species.

In view of the paramount ecological role of the oak forests, the reduction of their areas, and poor natural regeneration, we emphasize the need for the special protection and further study of the oak forests, primarily through the development of measures to promote the natural regeneration of *Q. robur* and the creation of sustainable forest plantations.

One of the main ways to preserve the oak forests in the face of climate change is sustainable forest management. Rational management decisions will ensure a positive carbon balance in the oak forests of the West Kazakhstan region.

To preserve the relict forests of the Ural River floodplain, including the oak forests with their biological diversity and rare floristic elements, it is necessary to create a specially protected natural area, which will reduce the negative impact of such anthropogenic factors as felling, recreation, grazing, and wild fires.

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Жайық өзені жайылмасындағы (Батыс Қазақстан облысы) емен ормандарының қазіргі жағдайы және олардың тұрақты даму келешегі

Мақалада орман шаруашылығының материалдарын талдау (01.01.1992 ж. және 01.01.2016 ж.) және авторлардың далалық зерттеулері негізінде Жайық өзені (Батыс Қазақстан облысы) жайылмасындағы емен ормандарының қазіргі жағдайын көрсететін мәліметтер келтірілген. Жайылмалы ормандар арасындағы ең берік екпелер ретінде емен ормандарының экологиялық маңыздылығына байланысты *Quercus robur* L.-тен тұратын ормандардың жай-күйінің динамикасын зерттеу ғылыми зерттеулердің өзекті бағыты болып табылады, ареалдың оңтүстік-шығысында олардың биологиялық әртүрлілігін сақтау қажеттілігі туындайды. 24 жылдық кезеңде аймақтағы емен ағаштарының ауданы 98,7 га, яғни 4 %-ға қысқарғаны анықталды. Сүрекдіңнің сиреуі, оның бонитетінің төмендеуі, жоғары жастағы сүрекдіңдердің басым болуы үдерістері атап өтілді. Сүрекдіңнің түрлік құрамы бойынша таза емен ормандары басым немесе *Ulmus laevis* Pall., *Populus alba* L., *Acer negundo* L. шамалы қоспасы бар. *Q. robur* табиғи жаңаруы қанағаттанарлықсыз немесе мүлдем жоқ. Шөптер жалпы проекциялық жамылғының жоғары көрсеткіштеріне ие (90 % дейін), бірақ флористикалық құрамы нашар. EX-ACT құралын қолдана отырып, әртүрлі басқару сценарийлерінде емен ормандарындағы көміртегі балансының болжамы келтірілген. Осы бірегей ормандарды сақтауға, соның ішінде *Q. robur* табиғи жаңаруына жәрдемдесу және тұрақты орман дақылдарын құруға бағытталған іс-шараларды әзірлеу қажеттілігі атап өтілді. Емен ормандарына антропогендік факторлардың әсерін азайту үшін (ағаш кесу, мал жаю, рекреация және т.б.) аймақта ерекше қорғалатын табиғи аумақ құру ұсынылды.

Кілт сөздер: Quercus robur L., жайылма орман, бонитет, жас құрамы, сүрекдіңнің толымдылығы, табиғи жаңару, EX-ACT, антропогендік әсер.

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Современное состояние дубрав в пойме реки Урал (Западно-Казахстанская область) и перспективы их устойчивого развития

В статье приведены сведения, отражающие современное состояние дубрав поймы р. Урал (Западно-Казахстанская область) на основе анализа лесоустроительных материалов (на 01.01.1992 г. и 01.01.2016 г.) и полевых обследований авторов. Изучение динамики состояния лесов из *Quercus robur* L. является актуальным направлением научных исследований ввиду важного экологического значения дубрав как наиболее долговечных насаждений среди пойменных лесов, необходимости сохранения их биологического разнообразия на юго-востоке ареала. Установлено, что за 24-летний период площадь дубрав в регионе сократилась на 98,7 га, т.е. на 4 %. Отмечены процессы изреживания древостоя, снижения его бонитета, преобладания высоковозрастных древостоев, преимущественно порослевого происхождения. По видовому составу древостоя преобладают чистые дубняки либо с незначительной

примесью *Ulmus laevis* Pall., *Populus alba* L., *Acer negundo* L. Естественное возобновление Q. robur неудовлетворительное или вообще отсутствует. Травостой с высокими показателями общего проективного покрытия (до 90 %), однако бедный по флористическому составу. Приведен прогноз баланса углерода в дубравах при различных управленческих сценариях с применением инструмента EX–ACT. Отмечена необходимость разработки мероприятий, направленных на сохранение этих уникальных лесов, в том числе по содействию естественному возобновлению *Q. robur* и созданию устойчивых лесных культур. Для снижения влияния на дубравы антропогенных факторов (порубки, выпас скота, рекреация и др.) предложено создать в регионе особо охраняемую природную территорию.

Ключевые слова: Quercus robur L., пойменный лес, бонитет, возрастной состав, полнота древостоя, естественное возобновление, EX–ACT, антропогенное воздействие.

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Chemical composition and biological activity of essential oil of *Nepeta pannonica*

Search for new sources of biologically active substances from plants of local flora is a promising area of modern phytochemical science. The article examines the composition of essential oil samples obtained from *Nepeta pannonica*, growing in the Karaganda region with the use of gas-chromatography-mass spectrometry method. The differences in the chemical composition of the oil depending by the plant organs have been identified. The main component of essential oil is nepetalactone. For the analysis, a unified method for determining the component composition of essential oils, as well as an Agilent Technologies 7890A chromatograph system with a 5975C inert MSD mass spectrometric detector were used. According to the data, the following substances were identified in the essential oils of the plant — 1,8-cineole, nepetalactone, germacrene D, screening of essential oil of *Nepeta pannonica* for antimicrobial and analgesic activity.

Keywords: *Nepeta pannonica*, essential oil, gas-chromatography-mass spectrometry, chemical composition, antimicrobial and analgesic activity.

Introduction

Genus *Nepeta* L. (family *Lamiaceae*) comprises of 279 species; among them in Kazakhstan there are 16 species [1]. Many species belonging to the genus *Nepeta* have traditionally been used as biologically active agents for the treatment of many diseases. Pharmacological effects of plants include antimicrobial, antioxidant, anti-inflammatory, sedative, cholesterol-lowering, anti-asthmatic, diuretic, sweating, antipyretic, glycogenic, and other properties [2–9].

All of these effects are related to a certain chemical composition. Plants of the genus *Nepeta* contain unsaturated lactones called non-tetolactones. Depending on the content of this compound, genus *Nepeta* species can be divided into two groups, one containing nepetolactone (and isomers thereof) with a relatively high content and a second group with low nepetalactone content and major components such as 1,8-cyneol, β-caryophyllene, caryophyllene oxide, β-farnesene, α-citral, β-citronellol [10–11].

Essential oil from *Nepeta* species is characterized by presence of sesquiterpene lactones and their derivates, such as germacrenes, caryophyllenes, caryophyllene oxide [2, 10–11]. Many substances contained in the essential oil of *Nepeta* have pronounced biological activity [12–14].

The prospects for the use of *Nepeta* set us the task of studying the chemical composition of the essential oil of *Nepeta pannonica* L., growing in the Central Kazakhstan, and determining its biological activity.

Experimental

N. pannonica raw material was collected in June, 2020; phase flowering, Spassky hills, Abay district of the Karaganda region (N 49°32′19″; E 73°16′33″). Raw material was dried according to plant drying rules.

Essential oils of aboveground parts (leaves, shoots and inflorescences) were extracted by hydrodistillation method for 3 hours using a Clevenger apparatus.

To study the composition of the essential oil, a chromatograph-mass spectrometry method was used with the help of an Agilent Technologies 7890A Gas Chromatograph with a quadrupole mass spectrometer MSD 5975 C as a detector. The capillary column HP-5MS had a size of 30 m x 0.25 mm (film thickness 0.25 μm). Evaporator temperature was 230 ºC. The gas chromatographic column was kept at 40 °C for 10 minutes; with temperature programming up to 240 °C at a temperature change rate of 2 °C/min, and then held in isothermal mode for 20 minutes. Sample injection mode was flow division 100:1. Sample volume was 0.2 μl. The conditions for recording mass spectra are 70 eV, the mass range is m/z 10–360. For data processing, the MSD ChemStation software, supplied by Agilent Technologies, was used in combination with AMDIS 32 and NIST 2017.

The analgesic activity of the essential oil of *N. pannonica* was studied on an experimental model of chemical irritation of the peritoneum, induced by the introduction of acetic acid in white barren mice. The crusts were induced by intra peritoneal administration of 0.75 % aqueous acetic acid solution at a dose of 1 ml per 100 g of animal body weight. The essential oil was administered by intra-gastric for 30 minutes prior to administration of acetic acid. The number of crusts was calculated in 20 minutes after intra-peritoneal administration of acetic acid for 30 minutes. An essential oil in the form of starch mucus was administered by intra-gastric at a dose of 25 mg/kg by means of a special metal probe for 30 minutes prior to administration of acetic acid. A decrease in the amount of crusts in animals compared to the control group served as an indicator of the analgesic activity of the test substances. As a comparative preparation, sodium diclophenac was used in its effective dose of 8 mg/kg (YeD50 = 8 mg/kg). Control animals received an equivalent amount of starch mucus. Analgesic activity was expressed as a percentage of the reduction in the number of acetic crusts in experimental rats compared to controls [15].

Antimicrobial activity of a sample of essential oil of *N. pannonica* was studied on reference test microorganisms: *Staphylococcus aureus* ATCC 6538, *Bacillus subtilis* ATCC 6633, *Escherichia coli* ATCC 25922, *Pseudomonas aeruginosa* ATCC 27853 and to yeast fungus *Candida albicans* ATCC 10231 method agar diffusion (holes). Comparative preparations are benzyl penicillin sodium salt, gentamicine for bacteria and nystatin for *Candida albicans*. For the study, pure cultures of test strains were taken, which were previously grown on a liquid medium pH 7.3 ± 0.2 at a temperature from 30 to 37 ºC; for 24–48 hours on a beveled meat-peptone agar.

A standard bacterial suspension was prepared by diluting a 1:1000 culture in sterile 0.9 % sodium chloride isotonic solution. The corresponding bacterial suspension was added 1.0 ml each to dishes with appropriate elective, nutritional media for the test strains under study and seeded by a “continuous lawn” method. After drying, 6.0 mm wells were formed on the surface of the agar, into which 20 μl of the test sample was added. In the control, water for injection was used to dilute samples in equivalent amounts. The crops were incubated at 370 ºC for 24 hours for the bacterium and at 300 ºC for 48 hours for the yeast fungus *Candida albicans* [15, 16].

The antimicrobial activity of the sample was estimated by the diameter of the growth delay zones of test strains (mm) around the hole: i) the absence of a growth delay zone — the test culture is not sensitive to this concentration of the sample; ii) diameter of growth delay zones is less than 10 mm and continuous growth in the dish was evaluated as an absence of antibacterial activity; iii) 10–15 mm — weak activity; iv) 15–20 mm — moderately expressed activity; v) over 20 mm — pronounced activity. The essential oil of *N. pannonica* was tested in three parallel runs.

Statistical processing of the results was carried out using the software package Statistica 8.0. Differences at the achieved significance level $p < 0.05$ were considered reliable.

Results and Discussion

Earlier, in the composition of the essential oil of *N. pannonica,* 36 components were identified, more of them from light fractions of monoterpenes and their oxidized forms. The major components in the essential are 1,8-cineole and γ-cadinene. The amount of eucalyptol was 28.9 %, nepetalactone was 14.3 % [14].

Other authors investigated the above-ground part of *N. pannonica*, which was collected in the Aksai gorge of the Transili Alatau (Almaty region) in 2000. The yield of essential oil was 0.2 %. The essential oil composition was examined by chromatograph-mass spectrometry. It was identified 92 components; among them nepetalactone — 41.5 %, 1,8-cineole — 12.2 %, germacrene D — 6.3 %, caryophyllene oxide — 5.2 %, pulegon — 2.9 %, α-terpineol — 1.6 %, and β-terpineol — 1.0 % [15].

The essential oil that we have isolated from *N. pannonica* is a light yellow moving liquid with a pleasant smell. The yield of essential oil is 0.35 % (Tab. 1).

In the essential oil isolated from the aboveground part of *N. pannonica*, 50 components were identified by the GC-MS method, the main ones being 1,8-cineole (11.77 %) and (4aR,7S,7aS)-nepetalactone (18.75 %). The main sesquiterpenoids are represented by caryophyllene (3.53 %) and germacrene D (5.21 %). We have determined the component composition of essential oils depending on the plant organs (Tab. 2).

Table 1

Chemical compositions of essential oil of *Nepeta pannonica*

No.	RT, minutes	Component	Amount of component, in % from whole essential oil
1	10.736	α-pinene	1.19
2	12.208	cis-sabinene	0.66
3	12.280	γ-pinene	1.03
4	12.533	1-octen-3-ol	0.99
5	12.894	β-myrcene	0.77
6	14.272	1,8-cineole	11.77
7	14.856	β-pinene	0.78
8	15.174	γ-terpinene	1.77
9	15.462	trans-4-thujanol	1.11
10	18.500	Pyrocarbon	0.23
11	18.637	cis-sabinene	0.58
12	18.947	terpinen-4-ol	0.41
13	19.366	α–terpineol	0.96
14	19.532	(1R)-(-)-myrtenal	0.15
15	20.686	cis-3-hexenyl isovalerate	0.45
16	22.194	2H-1-benzopyran, 3,4,4a,5,6,8a-hexahydro-2,5,5,8a-tetramethyl-(2“α”, 4a“α”, 8a“α”)	0.15
17	22.367	*n*-cymene-2-ol	0.04
18	22.865	non-identified	
19	24.200	(4aS,7S,7aR)-nepetalactone	2.41
20	24.575	Copaene	0.49
21	24.835	(–)–β–burbonene	3.02
22	25.160	(4aR,7S,7aS)-nepetalactone	18.75
23	25.484	1H-cycloprop[e]azulene	0.21
24	25.593	naphthalene, 1,2,3,4-tetrahydro-1,6,8-trimethyl	0.12
25	25.766	caryophyllene	3.53
26	25.975	α-copaene-4-ol	0.33
27	26.358	isogermacrane D	0.31
28	26.603	Humulene	1.40
29	26.920	β-cubbenen	0.57
30	27.317	germacrene D	5.21
31	27.663	bicyclogermacrene	0.63
32	27.880	β-bisabolene	0.56
33	28.277	1(10),4-cadinadien	0.61
34	29.200	epoxy daristolene	0.72
35	29.222	(-)-norburbonone	0.31
36	29.374	3-hexene-1-ol, benzoate	0.34
37	29.763	caryophyllene oxide	2.49
38	29.987	salvial-4(14)-en-1-one	0.24
39	30.355	humulene epoxide	0.63
40	31.055	Cadinol	0.19
41	31.163	trans-chrysantemal	0.17
42	31.351	α–cadinol	0.37
43	31.726	muurola-4(10)-dien-1-ol	0.27
44	32.065	γ -muurolene	0.29
45	32.180	Geneikozan	0.08
46	40.160	Dokozan	0.16
47	41.950	Hexakozan	0.14
48	43.660	Tetrakozan	0.15
49	45.312	pentakozan	0.18
50	47.181	tetratracontane	0.07

Table 2

The main components of essential oil of *Nepeta pannonica* depending on the plant organs

No.	Component	Content of components in % of whole oil in inflorescences	Content of components in % of whole oil in leaves and stems
1	1,8-cyneol	2.88	13.00
2	(+)-(4aS,7S,7aR)-nepetalactone	3.91	1.38
3	(–)-β–burbonene	3.09	3.87
4	(4aR,7S,7aS)-nepetalactone	46.55	18.0
5	Caryophyllene	5.49	5.23
6	germacrene D	10.69	6.95
7	Humulene	2.24	2.23
8	caryophyllene oxide	2.97	11.0

According to GC-MS, the following substances are determined in essential oils of plant flowers — (4aR,7S,7aS)-nepetalactone (46.55 %), germacrene D (10.69 %). The essential oils of plant leaves contained (4aR,7S,7aS)-nepetalactone (18.0), 1.8-cyneol (13 %), caryophyllene (5.23 %) and its oxide (11 %), germacrene D (6.95 %).

The results of the analysis of the antimicrobial activity of *N. pannonica* essential oil sample by diffusion into agar are shown in Tables 3, 4.

Table 3

Antimicrobial activity of *Nepeta pannonica* essential oil

Testing sample	*Staphylococcus aureus ATCC 6538*	*Bacillus subtilis ATCC 6633*	*Escherichia coli ATCC 25922*	*Pseudomonas aeruginosa ATCC 27853*	*Candida albicans ATCC 10231*
Essential oil of *N. pannonica*	18 ± 0.1*	16 ± 0.1*	15 ± 0.2	–	15 ± 0.1*
Benzylpenicillin sodium salt	16 ± 0.1	14 ± 0.1	15 ± 0.1	–	–
Gentamicin	24 ± 0.1	21 ± 0.2	26 ± 0.1	27 ± 0.1	–
Nystatin	–	–	–		21 ± 0.2

Note: validity of differences $p < 0.05$ compared to comparison group.

Table 4

The screening of *Nepeta pannonica* essential oil for analgesic activity

Testing sample	Doze, mg/kg	Number of crusts	% to control	Analgesic activity
Control	–	105,4± 11,8	100	–
Diclofenac sodium	8	53,6 ± 10,5	50.9	49.1
Essential oil of *N. pannonica*	25	49,2± 10,8*	46.7	53.3

Note: validity of differences $p < 0.05$ compared to comparison group.

An antimicrobial study found that an essential oil sample exhibited moderate antimicrobial activity against the gram-positive test strains *Staphylococcus aureus* ATCC 6538 and *Bacillus subtilis* ATCC 6633, and also illustrated poor antibacterial activity against the gram-negative test strain Escherichia coli ATCC 25922. *N. pannonica* essential oil shows antifungal activity against yeast fungus *Candida albicans* ATCC 10231.

As a result of the study, it was determined that a sample of essential oil of *N. pannonica* at a dose of 25 mg/g demonstrated analgesic activity in a model of chemical irritation of the peritoneum, illustrating a significant decrease in the development of experimental bark in rats by 53.3 %, respectively, in comparison with the control.

Conclusions

The work presented the result of study of *N. pannonica* essential oil, extracted by hydro-distillation method. The essential oil is a light yellow moving liquid with a pleasant odor; the yield was 0.35 %. For the first time, the GC-MS method determined the component composition of *N. pannonica* growing in the Karaganda region (the Central Kazakhstan). 1,8-cyneol (11.77 %), (4aR,7S,7aS)-nepetalactone (18.75 %), caryophyllene (3.53 %), germacrene D (5.21 %) are characterized as the main components.

Screening for antimicrobial and analgesic activity of *N. pannonica* essential oil showed the indicated antimicrobial activity against gram-positive test strains of *Staphylococcus aureus* ATCC 6538 and *Bacillus subtilis* ATCC 6633, and yeast fungus *Candida albicans* ATCC 10231, and also demonstrated poor antibacterial activity against the gram-negative test strain *Escherichia coli* ATCC 25922.

The analgesic activity of *N. pannonica* essential oil is comparable to the diclofenac sodium drug.

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Nepeta pannonica эфир майының химиялық құрамы және биологиялық белсенділігі

Жергілікті флора өсімдіктерінен биологиялық белсенді заттардың жаңа көздерін іздеу қазіргі фитохимиялық ғылымның перспективалы бағыты болып табылады. Мақалада хромато-масс-спектрометрия әдісімен Қарағанды облысында өсетін мажар көкжалбызынан (*Nepeta pannonica*) алынған эфир майы үлгілерінің құрамы зерттелген. Өсімдік мүшелеріне байланысты майдың химиялық құрамындағы айырмашылықтар анықталды. *Nepeta pannonica*-тің эфир майы гидродистилляция әдісімен оқшауланған, олардың химиялық құрамы хромато-масс-спектрометрия әдісімен зерттелген. Талдау үшін эфир майларының компоненттік құрамын анықтаудың бірыңғай әдісі, сондай-ақ 5975 Cinert MSD масс-спектрометриялық детекторы бар 7890A Agilent Technologies хроматографиялық жүйесі қолданылды. Өсімдік гүлдерінің эфир майларындағы мәліметтерге сәйкес мына заттар анықталды: 1,8-цинеол, непетолактон, гермакрен Д. Мажар көкжалбызының эфир майының микробқақарсы және анальгетикалық белсенділігіне скрининг жүргізілді.

Кілт сөздер: *Nepeta pannonica*, эфир майы, газ хроматографиясы, масс-спектрометрия, химиялық құрамы, микробқақарсы және анальгетикалық белсенділігі.

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Химический состав и биологическая активность эфирного масла *Nepeta pannonica*

Поиск новых источников биологически активных веществ из растений местной флоры является перспективным направлением современной фитохимической науки. В статье методом хромато-масс-спектрометрии изучен состав образцов эфирного масла, выделенных из котовника венгерского (*Nepeta pannonica* L.), произрастающего в Карагандинской области. Выявлены различия химического состава масла в зависимости от органов растения. Эфирное масло котовника венгерского выделено методом гидродистилляции, его химический состав изучен методом хромато-масс-спектрометрии. Для анализа использовалась унифицированная методика определения компонентного состава эфирных масел, а также хроматографическая система 7890A Agilent Technologies с масс-спектрометрическим детектором 5975 C. Согласно данным, в эфирных маслах цветков растения определены следующие вещества: 1,8-цинеол, непеталактон, гермакрен Д. Проведен скрининг эфирного масла котовника венгерского на антимикробную и анальгетическую активность.

Ключевые слова: *Nepeta pannonica*, эфирное масло, газовая хроматография, масс-спектрометрия, химический состав, антимикробная и анальгетическая активность.

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Способность экстрактов некоторых съедобных грибов подавлять репродукцию вируса гриппа

В статье описаны способы получения экстрактов из мицелия некоторых ксилофитных грибов: *Pleurotus eryngii, Auricularia auricula-judae, Tremella fuciformis*, дана оценка токсичности полученных экстрактов, а также исследована их противовирусная активность. Вирус гриппа выращивали в аллантоисной полости куриных эмбрионов. Инфекционный титр вируса гриппа определяли титрованием на куриных эмбрионах, наличие вируса — по реакции гемагглютинирующей активности. Гемагглютинирующая активность вирусов выявлялась исходя из стандартной методики с применением 0,75 % взвеси куриных эритроцитов. Титр инфекционности вируса рассчитывался с использованием методики Рида и Менча. Главным показателем при исследовании специфического противовирусного эффекта соединений являлся показатель ТИ (терапевтический индекс), определяемый отношением среднетоксичной концентрации вещества ($ТК_{50}$) к среднеэффективной вирусингибирующей концентрации ($ЭК_{50}$). Противовирусная активность полученных экстрактов была изучена на модели вирусов гриппа человека, животных и птиц, в интервале доз от 0,025 мкг/мл до 1,25 мкг/мл с использованием методических приёмов «Руководства по проведению доклинических исследований лекарственных средств». При исследовании 3-х полученных экстрактов ксилофитных грибов на острую токсичность было установлено, что все исследуемые соединения грибов, при однократном внутрижелудочном введении белым беспородным мышам, не проявляли токсического действия в исследуемом интервале доз. При проведении исследования по способности подавления репродукции различных штаммов вируса гриппа было выявлено, что экстракты грибов *Auricularia auricula-judae* и *Tremella fuciformis* обладают выраженными противовирусными свойствами и превосходят по показателю химико-терапевтического индекса коммерческие противогриппозные препараты.

Ключевые слова: *Pleurotus eryngii, Auricularia auricula-judae, Tremella fuciformis*, мицелий, экстракция, противовирусная активность, вирус гриппа, токсичность.

Введение

Вирус гриппа является самым известным и широко распространенным возбудителем заболеваний из сотни вирусов, поражающих верхние дыхательные пути. Эпидемии гриппа носят сезонный характер, способны поражать до 20 % жителей и уносить 25 000–50 000 человеческих жизней в год [1]. Вирус гриппа А способен образовывать точечные мутации в двух поверхностных гликопротеинах (гемагглютинин (HA) и нейраминидаза (NA)), в связи с этим он обретает способность обходить защитные механизмы иммунной системы человеческого организма [2].

Перед инфекционистами и фармакологами стоит задача — обеспечить контроль над инфекцией вируса, которую можно решить посредством применения вакцин и противовирусных препаратов. Кроме высокой результативности и хорошей переносимости, новые противовирусные препараты должны иметь широкий спектр действия, действовать на лекарственно-устойчивые штаммы.

Ввиду недостаточной эффективности существующих противовирусных лекарственных средств, а также их возможной токсичности ученые-вирусологи всего мира вынуждены проводить исследования для поиска новых, более перспективных препаратов. Важное значение имеет не только аспект поиска принципиально новых механизмов действия соединений, но и источник их происхождения. Одним из актуальных направлений исследований в последнее время является создание довольно перспективных лекарственных средств, полученных на основе биологически активных соединений растительного или микробного происхождения [3–5].

Несмотря на многочисленные исследования в направлении создания безопасных и эффективных противовирусных препаратов, в терапии гриппозной инфекции применяются лишь отдельные препараты, такие как Тамифлю, Ремантадин, Рибавирин, Ксофлюза, Азидотимидин [6–8]. Одной из сложнейших целей является поиск антивирусных препаратов, способных блокировать вирус гриппа, не

повреждая структуру клетки организма-хозяина. По этой причине результаты многолетних поисков противовирусных веществ оказались весьма скудными, остались на уровне открытия лишь единичных химиопрепаратов, имеющих узкий спектр действия. Мало изучены механизмы взаимодействия антивирусных препаратов с мишенями клетки-хозяина, связь между антивирусной активностью и структурными параметрами лекарств.

Лекарственные свойства высших грибов известны с древних времен. К завершению XX столетия был накоплен опыт, показывающий, что грибы, ввиду биохимических особенностей, являются одними из основных продуцентов в биотехнологии, способны стать заменой бактериям и растительным объектам [9, 10], в том числе как источники сырья для создания препаратов, имеющих ранозаживляющий, иммуномодулирующий, противовирусный и антираковый эффект [11–14].

Цель нашего исследования — изучить противовирусную активность некоторых ксилофитных съедобных грибов.

Материалы и методы

Вирус гриппа. В экспериментальных исследованиях был использован эпидемически значимый штамм вируса гриппа человека А/Алматы/8/98 (H3N2), вирус гриппа человека (пандемический вариант, устойчивый к тамифлю) А/Владивосток/2/09 (H1N1), вирус гриппа птиц, A/FPV/36/1 (H7N1).

В работе рассматривались экстракты некоторых съедобных грибов (табл. 1).

Таблица 1

Представители некоторых порядков базидиальных грибов, задействованных в эксперименте

Порядок	Семейство	Вид	Название	Краткое обозначение
Агарикоидные базидиомицеты (*Agaricales s. lato*)	*Agaricaceae*	*Pleurotus eryngii*	Вешенка степная (белый степной гриб)	PE
Аурикудяриевые базидиомицеты (*Auriculariales*)	*Auriculariaceae*	*Auricularia auricula-judae*	Свиное, или иудово, ухо	AA
Тремеллоидные базидиомицеты (*Tremellales s. lato*).	*Tremellaceae*	*Tremella fuciformis*	Серебряное ухо	TF

Культивирование вируса осуществляли на модели куриных эмбрионов в течение 24–48 ч при 37 °С. Для экспериментов использовали аллантоисный вирус в дозе 10^8–10^9 $ЭИД_{50}$/мл. Инфекционный титр вируса гриппа определяли методом предельных разведений по методу Рида и Менча [15]. Наличие вирусов определяли гемагглютинирующим способом при использовании эритроцитов курицы или морской свинки [15].

Мицелий грибов после отмывки среды подвергали спиртовой экстракции с последующим лиофильным обезвоживанием.

Токсичность и специфическая противовирусная активность исследуемых экстрактов была изучена согласно методическим указаниям «Руководство по проведению доклинических исследований лекарственных средств» [16] с расчётом химико-терапевтического индекса (ХТИ), выявляемого отношением среднетоксичной концентрации вещества ($ТК_{50}$) к среднеэффективной вирусингибирующей концентрации ($ЭК_{50}$).

Острая токсичность определялась с использованием методики «доза–эффект», после внутрижелудочного введения готовых экстрактов, аутбредным лабораторным мышам, в разных вариантах дозировок. Учёт результатов проводился согласно Методическим рекомендациям [16–18].

Вирусингибирующие свойства анализируемых препаратов изучали методом построения кривых «доза–активность» [18].

Статистическая обработка была проведена с использованием пакета программ «Microsoft Office». Для табличного и графического изображений полученных результатов использовалась программа Microsoft Office Excel.

Результаты и их обсуждение

Острую токсичность 3-х полученных экстрактов грибов изучали на модели белых беспородных мышей. Отобранные препараты вводили внутрижелудочно с помощью специализированного металлического атравматического зонда в максимально допустимом объеме для мышей весом 18–20 г (0,5 мл). Мышам в контрольной группе вводили фосфатный буфер в аналогичном объеме. Доза для всех препаратов составляла 1, 3, 5 мг.

Наблюдение за животными осуществляли в течение 2-х недель. При вскрытии мышей патологических изменений в органах и тканях, вызванных воздействием исследуемых препаратов, не обнаружено. Установлено, что все исследуемые соединения при однократном внутрижелудочном введении не проявляли токсического действия в исследуемом интервале доз.

Согласно «Согласованной на глобальном уровне системе классификации опасности и маркировки химической продукции» (СГС) (IV пересм. изд., ООН, 2011 г.), исследуемые противовирусные препараты можно отнести к V классу — «Малотоксичные препараты».

Таким образом, при выявлении острой токсичности на модели белых беспородных мышей показано, что полученные экстракты грибов не проявляли острой токсичности при однократном внутрижелудочном введении в дозе до 5 мг.

Изучение противовирусной активности полученных на модели вирусов гриппа человека животных и птиц проводили в интервале доз от 0,025 мкг/мл до 1,25 мкг/мл согласно методическим приемам «Руководства по проведению доклинических исследований лекарственных средств» [18].

На рисунке представлены результаты способности исследуемых экстрактов грибов подавлять репродукцию вирусов. Показано, что все исследуемые экстракты съедобных грибов способны в заданном интервале доз полностью блокировать воспроизводство вируса гриппа независимо от его антигенной структуры. При этом максимальной активностью обладали экстракты *Auricularia auricula-judae* и *Tremella fuciformis*.

Сравнительное изучение противовирусного действия 2-х отобранных экстрактов в сопоставлении с противовирусной активностью коммерческих противогриппозных синтетических препаратов — Осельтамивир (Тамифлю) и Ремантадин при испытании на различных штаммах вируса гриппа представлено в таблице 2.

Таблица 2

Сравнительная оценка ХТИ грибных экстрактов и коммерческих препаратов с противовирусной активностью

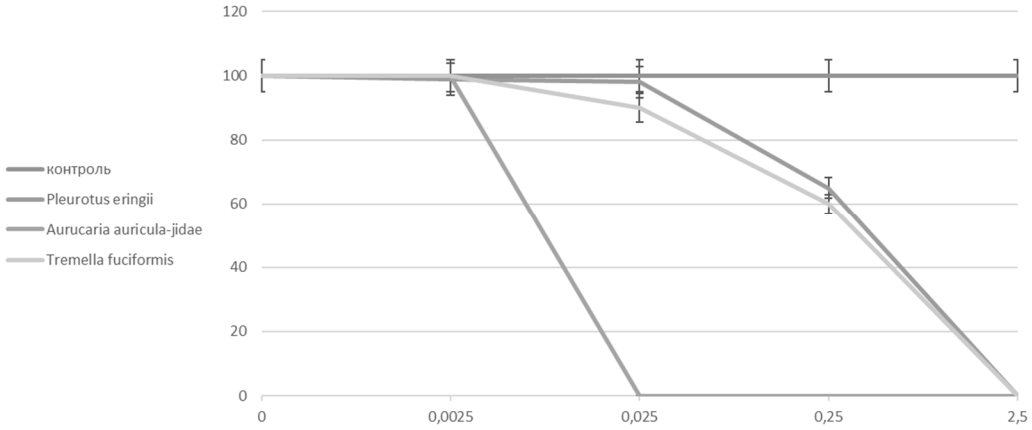
Штамм вируса гриппа	Осельтамивир	Ремантадин	*Auricularia auricula-judae*	*Tremella fuciformis*
A/Владивосток/2/09 (H1N1)	10,3	11,0	>100	>100
A/Алматы/8/98 (H3N2)	29,9	30,1	>100	>100
A/FPV/36/1 (H7N1)	15,3	15,2	>100	>100

В результате сравнительного изучения показателей ХТИ установлено, что исследуемые экстракты грибов превосходят по показателю ХТИ коммерческие противогриппозные препараты при тестировании на различных штаммах вируса.

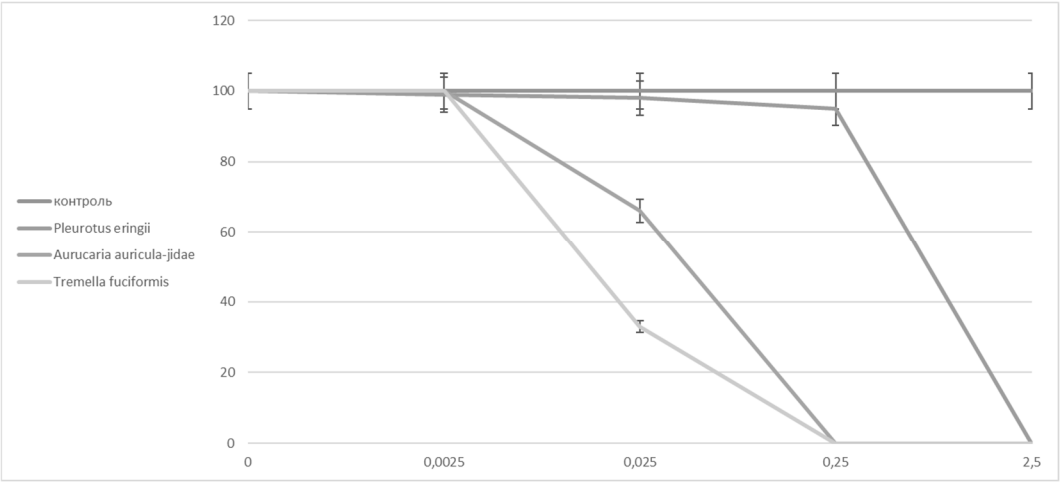
Заключение

Поиск соединений растительного происхождения, способных подавлять репродукцию вирусов, остается весьма перспективным направлением научных исследований. Это можно объяснить рядом причин, главными из которых являются доступность сырья и низкая токсичность. В наших исследованиях изучена возможность применения экстрактов некоторых съедобных грибов подавлять репродукцию вирусов гриппа.

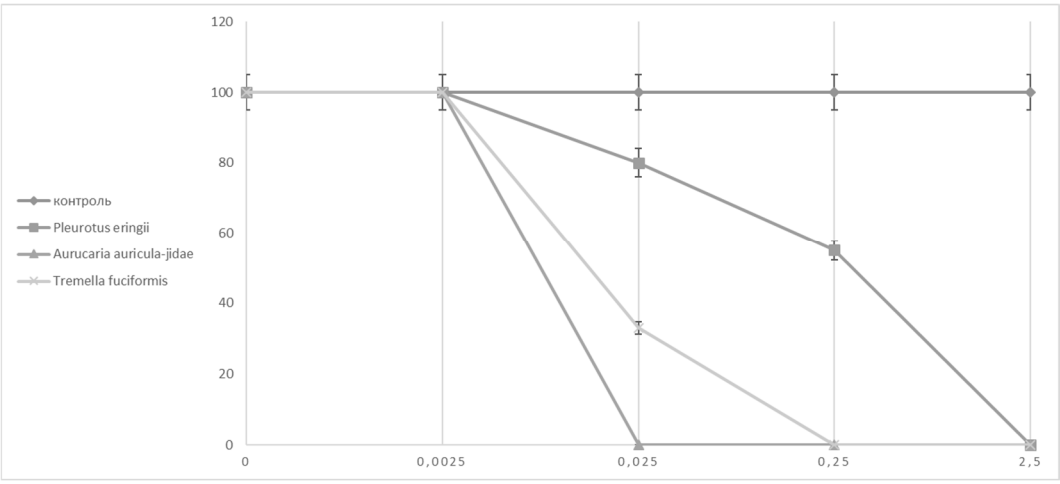
Показано, что экстракты грибов *Auricularia auricula-judae* и *Tremella fuciformis* обладают выраженными противовирусными свойствами, сопоставимыми с коммерческими препаратами.



Вирус гриппа A/Алматы/8/98 (H3N2)



Вирус гриппа A/FPV/36/1 (H7N1)



Вирус гриппа A/Владивосток/2/09 (H1N1)

По оси ординат — подавление репродукции в %, по оси абсцисс — доза препарата, мкг/мл

Рисунок. Изучение дозозависимого эффекта вирусингибирующей активности исследуемых препаратов на модели вируса гриппа человека (пандемический вариант, устойчивый к Тамифлю)

Работа выполнена в рамках проекта грантового проекта Комитета науки Министерства образования и науки Республики Казахстан № AP08855630.

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А.Н. Потехина, П.Г. Алексюк, И.А. Зайцева, Н.С., Соколова, Э.С. Омиртаева, М.С. Алексюк, А.П. Богоявленский, А.С. Кензина, В.Э. Березин

Кейбір жеуге жарамды саңырауқұлақтардың тұмау вирусының репродукциясын басу қабілеті

Мақалада *Pleurotus eryngii, Auricularia auricula-judae, Tremella fuciformis* сияқты кейбір ксилофитті саңырауқұлақтардың мицелийлерінен сығындылар алынды, алынған сығындылардың уыттылығы бағаланды, сонымен қатар вирусқақарсы белсенділік қасиеті зерттелген. Тұмау вирусы тауық эмбриондарының аллантоид қуысында өсірілді. Тұмау вирусының инфекциялық титрі тауық эмбриондарында титрлеу арқылы анықталды. Вирустың бар болуы гемагглютинациялық белсенділік реакциясы арқылы бағаланды. Вирустың инфекциялық титрі Рид және Менч әдісімен есептелді.

Вирустардың гемагглютинациялық белсенділігі тауық эритроциттерінің 0,75 % суспензиясын қолдана отырып, стандартты әдіс бойынша зерттелген. Қосылыстардың вирусқақарсы ерекше әсерін зерделеу кезінде негізгі критерий заттың орташа уытты концентрациясының ($ТК_{50}$) орташа тиімді вирусингибирлеуші концентрациясына ($ЭК_{50}$) қатынасымен айқындалатын ТИ (терапиялық индекс) көрсеткіші болды. Алынған сығындылардың вирусқақарсы белсенділігі «Дәрілік заттардың клиника алды зерттеулерін жүргізу жөніндегі нұсқаулықтың» әдістемелік ұсынымдарын пайдалана отырып, 0,025 мкг/мл-ден 1,25 мкг/мл-ге дейінгі дозалар аралығында адамдар, жануарлар мен құстардың тұмауы вирусының моделінде зерттелді. Алынған 3 саңырауқұлақ сығындысының өткір уыттылығын зерттеу кезінде барлық зерттелген саңырауқұлақтар қосылыстары ақ тұқымсыз тышқандарға бір рет интрагастралық енгізу кезінде зерттелетін дозалар аралығында уытты әсер көрсетпегені анықталды. Тұмау вирусының әртүрлі штамдарының көбеюін басу қабілеті бойынша зерттеу жүргізу кезінде *Auricularia auricula-judae* және *Tremella fuciformis* саңырауқұлақтарының сығындылары айқын вирусқақарсы қасиеттерге ие екендігі және химиялық-терапиялық индекс көрсеткіші бойынша тұмауғақарсы коммерциялық препараттардан асып түсетіні белгілі болды.

Кілт сөздер: *Pleurotus eryngii, Auricularia auricula-judae, Tremella fuciformis*, мицелий, экстракция, вирусқақарсы белсенділік, тұмау вирусы, уыттылық.

A.N. Potekhina, P.G. Aleksyuk, I.A. Zajceva, N.S, Sokolov, E.S. Omirtayeva, M.S. Aleksyuk, A.P. Bogoyavlenskij, A.S. Kenzina, V.E. Berezin

The ability of extracts of some edible fungi to suppress the reproduction of influenza virus

In this work, extracts from the mycelium of some xylophytic fungi: *Pleurotus eryngii, Auricularia auricula-judae, Tremella fuciformis* were obtained, the toxicity of the obtained extracts was evaluated, and the antiviral activity was researched. The influenza virus was grown in the allantois cavity of chicken embryos. The infectious titer of the influenza virus was determined by titration on chicken embryos. The presence of the virus was judged by the reaction of hemagglutinating activity. The virus infectivity titer was calculated using the Reed-Muench method. The hemagglutinating activity of viruses was determined by a standard method using 0.75 % suspension of chicken red blood cells. The main criterion for studying the specific antiviral effect of compounds was the CTI (chemical-therapeutic index), that is determined by the ratio of the average toxic concentration of the substance (TC50) to the average effective viral inhibitory concentration (EC50). The antiviral activity of the obtained extracts was studied on a model of human, animal and bird influenza viruses, in the dose range from 0.025 mcg/ml to 1.25 mcg/ml using the methodological recommendations of the “Guidelines for conducting Preclinical studies of medicines”. While studying the acute toxicity of 3 obtained fungi extracts, it was found that all studied fungi compounds with a single intragastric injection to white mongrel mice, did not show a toxic effect in the studied dose range. During the study of the ability to suppress the reproduction of various strains of the influenza virus, it was found that extracts of the fungi *Auricularia auricula-judae* and *Tremella fuciformis* have possessed antiviral properties, and extracts exceed in terms of CTI to commercial anti-influenza drugs.

Keywords: Pleurotus eryngii, Auricularia auricula-judae, Tremella fuciformis, mycelium, extraction, antiviral activity, influenza virus, toxicity.

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Характеристика полиморфизмов гена рецептора витамина D

В статье представлена характеристика основных полиморфизмов гена рецептора витамина D (VDR): rs2228570 (FokI), rs731236 (TaqI), rs1544410 (BsmI) и rs7975232 (ApaI). Описана роль гормонально-активной формы витамина D (1,25(OH)2D3, кальцитриол) как фактора транскрипции, регулирующего экспрессию генов в клетках-мишенях путем связывания с белком-рецептором витамина D. Отмечено иммуномодулирующее и опосредующее влияние рецепторов VDR на биологические функции организма человека. Дано описание гена рецептора витамина D, и указан его полиморфный характер. Проведен анализ четырех наиболее значимых однонуклеотидных полиморфизмов (SNP) гена VDR. Приведено подробное описание каждого полиморфизма, его геномной позиции, характера взаимодействия с другими полиморфизмами гена рецептора витамина D, а также его влияние на структуру и активность белка VDR. Представлен анализ аллельного состава указанных однонуклеотидных полиморфизмов по литературным источникам и специализированным базам данных SNP. Изучены частота встречаемости отдельных аллелей каждого полиморфизма, а также их влияние на предрасположенность и течение различных заболеваний. Показана необходимость проведения дальнейших исследований полиморфизмов гена VDR, их аллельного состава и распространенности, а также возможностей их потенциального использования в качестве генетических маркеров для таких актуальных, но мало изученных патологий, как COVID–19.

Ключевые слова: витамин D, рецептор витамина D (VDR), ген VDR, полиморфизмы гена VDR, rs2228570 (FokI), rs731236 (TaqI), rs1544410 (BsmI), rs7975232 (ApaI).

Введение

Витамин D был открыт и долгое время изучался как основной фактор фосфорно-кальциевого обмена, который участвует в формировании и нормальном функционировании костной ткани [1, 2]. Однако дальнейшие исследования показали, что в процессе метаболизма в печени и почках образуется гормонально-активная форма витамина D — 1,25-дигидроксивитамин D3 (1,25(OH)2D3, кальцитриол), роль и возможные эффекты которого гораздо шире [3].

1,25(OH)2D3 является плюрипотентным гормоном, обладающим иммуномодулирующими функциями [4, 5]. Свое эндокринное действие он реализует путем связывания с рецептором витамина D (vitamin D receptor, VDR), который принадлежит к суперсемейству факторов транскрипции, члены которого обладают уникальным свойством непосредственно активироваться небольшими липофильными соединениями [6–9]. Похожим образом функционируют стероидные рецепторы. Рецептор витамина D способен специфически взаимодействовать с 1,25-дигидроксивитамином D3, опосредовать его действие и продуцировать различные эффекты, влияющие на протекание биологических процессов в организме человека [4, 10, 11]. Также VDR функционирует как рецептор литохолевой и вторичной желчной кислоты [12].

Рецептор витамина D вместе 1a-гидроксилазой, которая катализирует последнюю и ключевую стадию синтеза активного 1,25-дигидроксивитамина D3, экспрессируется практически во всех тканях организма [10]. По данным L. Fagerberg и соавт. (2014), проводивших анализ тканеспецифической экспрессии человека методом РНК-секвенирования 27 видов тканей, наибольшая активность VDR была выявлена в тканях тонкой, двенадцатиперстной и толстой кишки, почках, коже, легких и желудка. При этом в тканях мозга, поджелудочной железы, яичников и печени уровень экспрессии гена был минимален [13].

Известны два уровня регуляции рецептора витамина D: генный и негенный. В первом случае рецепторы находятся и функционируют в ядрах клеток-мишеней, во втором — в цитоплазматических мембранах [7, 8]. Реализуясь на генном уровне, VDR проявляет себя как лиганд-индуцибельный фактор транскрипции [12]. При этом 1,25(OH)2D3 и VDR образуют комплекс, в состав которого входят специфические ДНК-связывающие домены, которые должны быть общими с сайтом начала тран-

скрипции первичных генов-мишеней рецептора. Основной функцией данных последовательностей ДНК является контроль транскрипции определенных генов. В результате изменяется последовательность синтезируемой матричной РНК и, как следствие, происходит образование новых форм соответствующих белков, участвующих в регуляции физиологических реакций [4, 9, 14, 15].

Характеристика гена рецептора витамина D

Структура рецептора витамина D закодирована в гене VDR (другие возможные названия: NR1I1; PPP1R163). Ген VDR находится в хромосоме 12, локус 12q13.11 [8, 12, 16]. Количество экзонов в данном гене, по данным разных источников, варьируется от 9 до 11 [6, 17–20]. Другие авторы, такие как Tuoresmaki et al. (2014) указывают, что ген VDR состоит из восьми экзонов и шести альтернативно сплайсированных областей, которые расположены в генетически активных частях, содержащих промоторную область [9]. Однако, по данным NCBI (National Center for Biotechnology Information, Национальный центр биотехнологической информации США), количество кодирующих областей ДНК гена VDR составляет 12 (идентификатор гена: 7421, сборка GRCh38.p13 от 28.02.2019) [12].

Полное секвенирование человеческого генома показало, что многие гены являются полиморфными, т.е. в их интронах и экзонах могут выявляться однонуклеотидные замены пар оснований (*single nucleotide polymorphisms, SNPs, снипы*). По своей сути SNP являются точковыми мутациями, однако различия в терминологии обусловливаются их частотой встречаемости. Таким образом, мутация считается однонуклеотидным полиморфизмом, если встречается более чем у 1 % населения [21–23].

SNP могут оказывать существенное влияние на скорость и эффективность транскрипции, стабильность матричной РНК, количество и активность синтезируемого белка, а также, в целом, на уровень экспрессии гена [3, 4, 22]. В настоящее время SNP различных генов используют в качестве биологических маркеров при изучении генетических признаков. Также имеется множество исследований, целью которых является выявление зависимости предрасположенности к какому-либо заболеванию и тяжести его течения от наличия или отсутствия конкретных аллелей в полиморфных генах. Количество аллелей одного SNP может варьировать от двух до четырех, а общая встречаемость и преобладание конкретной аллели во многом зависят от этнической принадлежности исследуемой популяции [5, 8, 11, 22].

Существует несколько баз данных SNP, находящихся в открытом доступе. Среди них dbSNP, SNPedia, MirSNP и др. База dbSNP была разработана и поддерживается Национальным центром биотехнологической информации США (NCBI), она содержит обширную информацию не только о структуре и позиции определенных SNP, но и описывает их клиническое значение, историю, а также встречаемость отдельных аллелей данных полиморфизмов среди различных этнических групп [24, 25].

Ген рецептора витамина D является полиморфным. В более ранних исследованиях были представлены данные о наличии в нем более 470 однонуклеотидных полиморфизмов [17, 18, 21]. Наиболее изученными среди полиморфизмов гена VDR являются rs2228570 (FokI), rs731236 (TaqI), rs1544410 (BsmI) и rs7975232 (ApaI). Второе название SNP обусловлено наличием или отсутствием в них сайтов рестрикции для соответствующих ферментов (FokI, TaqI, BsmI, ApaI) [4, 26, 27]. Существует множество исследований, посвященных выявлению связи данных полиморфизмов с такими заболеваниями, как бронхиальная астма, рак, ревматоидный артрит, туберкулез, сахарный диабет, денге, рассеянный склероз, болезнь Паркинсона и др. [1, 3–6, 17, 18, 28, 29].

Полиморфизм rs2228570 (FokI)

Полиморфизм rs2228570 (FokI) расположен в 5'-кодирующей области 2 экзона гена VDR [3, 11, 16]. Геномная позиция: chr12:47879112 [18, 30]. Данный SNP является единственным из четырех наиболее значимых SNP гена VDR, который изменяет структуру синтезируемого белка, т.е. является миссенс-мутацией. Кроме того, он не связан ни с одним из других полиморфизмов VDR [6, 18, 26].

В более ранних источниках можно встретить другое название данного полиморфизма — rs10735810 [18]. Однако, по данным NCBI (dbSNP), в период с 2006 по 2010 гг. в rs2228570 были объединены семь SNP, включая rs10735810 (рис. 1) [31].

Связанный ID	История обновлена (сборка)
rs117559231	16 августа 2010 г. (132)
rs17881966	11 марта 2006 г. (126)
rs8179174	23 мая 2008 г. (130)
rs10735810	23 мая 2008 г. (130)
rs57067622	23 мая 2008 г. (130)
rs56641119	27 мая 2008 г. (130)
rs52811041	21 сен.2007 г. (128)

Рисунок 1. Список полиморфизмов, объединенных в rs2228570 [31]

В литературных источниках полиморфизм rs2228570 преимущественно описывается как генетическая вариация замены нуклеотида T в стартовом кодоне ATG на аллель C. Таким образом, в гене VDR может находиться либо два стартовых кодона ATG, разделенных шестью нуклеотидами, либо один новый сайт инициации ACG. В результате экспрессии гена носителя аллели T (ATG) синтезируется белок, состоящий из 427 аминокислот, а в случае генотипа C (ACG) данный белок будет включать на три аминокислоты меньше, т.е. 424 [3, 6, 11, 20, 32, 33]. При этом исследования показали, что короткий вариант белка VDR более активен и обладает повышенной транскрипционной активностью по сравнению с полноразмерным белком [3, 16, 26, 27, 33].

По данным dbSNP (сборка 155 от 9 апреля 2021 г.), полиморфизм rs2228570 может иметь четыре варианта аллелей, т.е. A, C, G и T. При этом средняя частота встречаемости аллелей по агрегированным данным с выборкой 236272 образцов составляет G = 0,611257, A = 0,388743, T = 0,000000 (рис. 2) [34].

Показанное значение для аллели T и отсутствие информации по аллели C говорят об их крайне редкой встречаемости по сравнению с A и G.

Population	Group	Sample Size	Ref Allele	Alt Allele
Total	Global	236272	A=0.388743	G=0.611257, T=0.000000
European	Sub	200152	A=0.387441	G=0.612559, T=0.000000
African	Sub	3690	A=0.2759	G=0.7241, T=0.0000
African Others	Sub	118	A=0.288	G=0.712, T=0.000
African American	Sub	3572	A=0.2755	G=0.7245, T=0.0000
Asian	Sub	6580	A=0.4384	G=0.5616, T=0.0000
East Asian	Sub	4716	A=0.4315	G=0.5685, T=0.0000
Other Asian	Sub	1864	A=0.4560	G=0.5440, T=0.0000
Latin American 1	Sub	782	A=0.292	G=0.708, T=0.000
Latin American 2	Sub	4862	A=0.4881	G=0.5119, T=0.0000
South Asian	Sub	240	A=0.250	G=0.750, T=0.000
Other	Sub	19966	A=0.38756	G=0.61244, T=0.00000

Рисунок 2. Анализ частоты встречаемости аллелей полиморфизма rs2228570, по данным dbSNP [34]

Также среди ряда исследований, помимо описанного для rs2228570 генотипа C>T, встречаются аллельные комбинации A>G, A>T. В них рассматриваются либо общая распространенность аллелей данного SNP среди здорового населения, либо их связь с такими заболеваниями, как денге, бронхиальная астма, гепатит B, болезнь Паркинсона и туберкулез [4, 23, 29, 35–39]. Сводные данные приведены в таблице 1.

Таблица 1

Анализ изучения аллельных комбинаций rs2228570 в научных публикациях [4, 23, 29, 35–39]

Варианты аллелей rs2228570	Авторы, год издания публикации
CC / CT / TT	Kresfelder et al. (2011), Alagarasu et al. (2012), Grzegorzewska et al. (2014), Bahrami et al. (2020)
AA / AG / GG	Osman et al. (2015), Shih-Wei Lee et al. (2016), Hua et al. (2020)
AA /AT / TT	Wang et al. (2019)

Таким образом, ввиду высокой генетической вариабельности, полиморфизм rs2228570 требует дальнейшего изучения распространенности всех его аллелей среди различных этнических групп, а также расширения его роли в качестве генетического маркера заболеваний [22, 29, 35–38].

Полиморфизмы rs731236 (TaqI), rs1544410 (BsmI) и rs7975232 (ApaI)

Полиморфизмы rs731236 (TaqI), rs1544410 (BsmI) и rs7975232 (ApaI) находятся в сильном неравновесном сцеплении друг с другом в 3'-нетранслируемой области гена VDR. Поэтому довольно часто встречается их общее объединенное название: полиморфизм 3' UTR (3' untranslatedregion, 3'-нетранслируемая область) [4, 26, 28, 33]. Данные генетические изменения не влияют на количество аминокислот или их последовательность в белке VDR, но участвуют в регуляции уровня экспрессии гена VDR посредством уменьшения или увеличения стабильности мРНК [3, 11, 16, 27].

rs731236 находится в 9 экзоне гена VDR (геномная позиция chr12: 47844974) [40, 41]. По данным NCBI, в период с 2002 по 2014 гг. в rs731236 были объединены шесть полиморфизмов: rs2228571, rs17777794, rs17880019, rs59730659, rs118037316 и rs386609145 [42]. Согласно данным некоторых авторов [4, 11, 20, 37], этот полиморфизм представляет собой замену аллелей T>C и приводит к молчащим мутациям в соответствующих кодонах. При этом dbSNP (сборка 155 от 9 апреля 2021 г.) характеризует rs731236 как трехаллельный полиморфизм (A, G, T) с преимущественной встречаемостью аллели A=0,61282, меньшей распространенностью G=0,38718 и T=0,000000 (количество образцов в выборке составляет 193424) [43].

Исследования аллелей A и G полиморфизма rs731236 также проводили Osman et al. (2015), S.W. Lee et al. (2016) и Y. Wang et al. (2019). Представлены данные о распространенности данных генетических вариаций среди здорового населения ОАЭ, а также их связь с восприимчивостью к туберкулезу [21, 38, 39].

Полиморфизмы rs1544410 и rs7975232 расположены в интроне 8 [11, 27]. Геномные позиции: chr12: 47846052 и chr12: 47845054 соответственно (рис. 3, 4) [44–46].

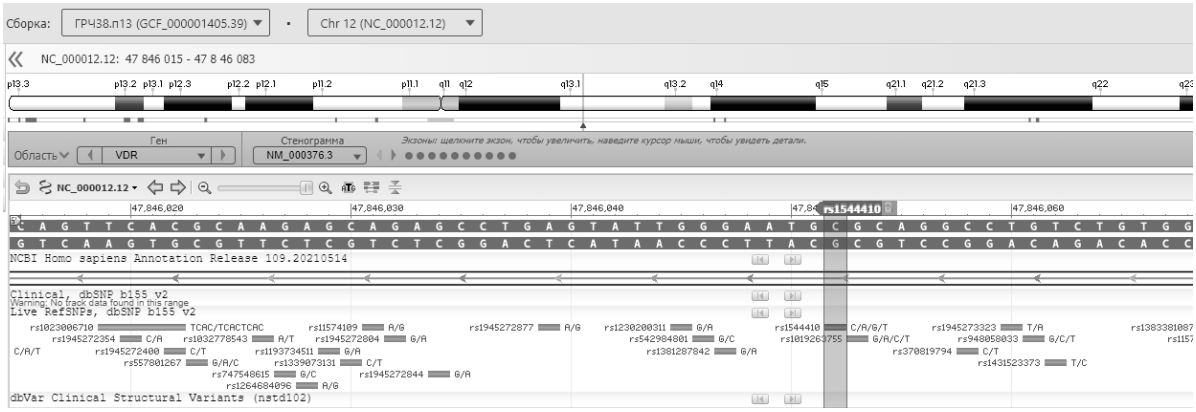

Рисунок 3. Положение rs1544410 в гене VDR [47]

В период с 2008 по 2014 гг. в rs1544410 были объединены три полиморфизма: rs56495123, rs56911380 и rs386536760 [48]. По данным dbSNP, rs1544410 включает в себя все четыре варианта аллелей (A, C, G и T) [45]. Общая частота встречаемости аллелей в выборке 220674 составила: C=0,611934, T=0,388066, A=0,000000, G=0,000000 [49]. Таким образом, преобладающими аллелями являются C и T, однако в литературных данных рассматриваются и другие генетические комбинации (табл. 2).

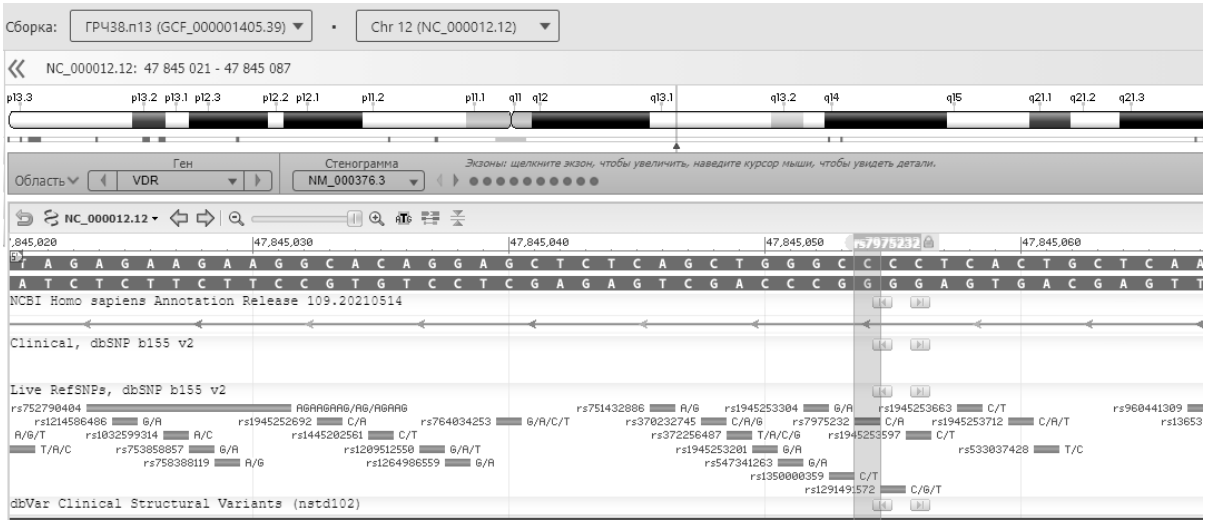

Рисунок 4. Положение rs7975232в гене VDR [50]

Таблица 2

Анализ изучения аллельных комбинаций rs1544410 в научных публикациях [4, 11, 20, 28, 36–39, 51]

Варианты аллелей rs1544410	Авторы, год издания публикации
GG / GA / AA	Alagarasu et al. (2012), Grzegorzewska et al. (2014), S.W. Lee et al. (2016), P. John et al. (2017) Silva-Ramírez et al. (2018), Yadav et al. (2021)
AA / AT / TT	Y. Wang et al. (2019)
GG / GT / TT	Bahrami et al. (2020)

rs7975232 был объединен с rs17879735 в 2006 г. [52]. Для данного полиморфизма характерно наличие двух вариантов аллелей: C и A [46]. При анализе общей распространенности среди 39134 образцов преобладающей аллелью является A=0,55448. Встречаемость альтернативной аллели C составляет 0,44552. Однако в различных этнических группах данные показатели могут меняться (рис. 5) [53].

Population	Group	Sample Size	Ref Allele	Alt Allele
Total	Global	39134	C=0.44552	A=0.55448
European	Sub	26550	C=0.46286	A=0.53714
African	Sub	7790	C=0.3693	A=0.6307
African Others	Sub	240	C=0.292	A=0.708
African American	Sub	7550	C=0.3718	A=0.6282
Asian	Sub	214	C=0.687	A=0.313
East Asian	Sub	156	C=0.686	A=0.314
Other Asian	Sub	58	C=0.69	A=0.31
Latin American 1	Sub	168	C=0.411	A=0.589
Latin American 2	Sub	670	C=0.582	A=0.418
South Asian	Sub	104	C=0.385	A=0.615
Other	Sub	3638	C=0.4461	A=0.5539

Рисунок 5. Анализ частоты встречаемости аллелей полиморфизма rs7975232, по данным dbSNP [53]

В литературных источниках изучение генотипов CC, CA и AA полиморфизма rs7975232 проводили Alagarasu et al. (2012), S.W. Lee et al. (2016), da Cunha Pereira et al. (2017), Y.Wang et al. (2019), преимущественно в связи с патогенезом туберкулеза [4, 38, 39, 54].

Однако имеется публикация Bahrami (2020) о связи полиморфизмов гена VDR с хроническим гепатитом B, где в качестве аллелей rs7975232 рассматриваются G и T [37].

Заключение

Таким образом, можно сделать вывод, что ген VDR является чрезвычайно полиморфным, и его SNP могут оказывать значительное влияние на протекание различных процессов в организме человека и на его показатели здоровья. Также имеются противоречивые данные об аллельном составе rs2228570 (FokI), rs731236 (TaqI), rs1544410 (BsmI) и rs7975232 (ApaI) среди литературных источников и базой данных dbSNP (NSBI). Одновременно все больше исследований направлено на изучение роли однонуклеотидных полиморфизмов гена VDR в патогенезе различных заболеваний, в числе которых значительное место занимает группа бронхолегочных заболеваний различной этиологии (туберкулез, бронхиальная астма, денге) [3, 4, 8, 12].

Все перечисленное выше делает полиморфизмы гена VDR потенциально значимыми объектами для изучения их влияния на предрасположенность и тяжесть течения других, менее изученных заболеваний. Одним из наиболее актуальных в настоящее время является COVID-19, вызванный коронавирусом SARS-CoV-2 [55].

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D дәрумені рецепторы генінің полиморфизмдеріне сипаттама

Мақалада D дәрумені рецепторы генінің (VDR) негізгі полиморфизмдерінің: rs2228570 (FokI), rs731236 (TaqI), rs1544410 (BsmI) және rs7975232 (ApaI) сипаттамасы берілген. D дәруменінің гормоналдық белсенді формасының (1,25(OH)2D3, кальцитриол) жасуша-нысаналардағы D дәрумені рецепторының ақуызы мен байланысу арқылы гендердің экспрессиясын реттейтін транскрипция факторы ретінде рөлі сипатталған. Адам ағзасының биологиялық функцияларына VDR рецепторларының иммуномодуляциялық және делдалдық әсері айтылған. D дәрумені рецепторының геніне сипаттама беріліп, оның полиморфты сипаты көрсетілген. VDR генінің ең маңызды төрт бір нуклеотидті полиморфизміне (SNP) талдау жасалды. Әрбір полиморфизм, оның геномдық позициясы, D дәрумені рецепторы генінің басқа полиморфизмдерімен әрекеттесу сипаты, сондай-ақ оның VDR ақуызының құрылымы мен белсенділігіне әсері туралы егжей-тегжейлі сипаттама берілген. Аталған бір нуклеотидті полиморфизмдердің аллельдік құрамына дереккөздермен арнайы мәліметтер базасы бойынша талдау жүргізілді. Әрбір полиморфизмнің жеке аллельдерінің кездесу жиілігі, сондай-ақ олардың әртүрлі аурулардың бейімділігі мен ағымына әсері зерттелді. VDR генінің полиморфизмі, олардың аллельдік құрамы мен таралуы, сондай-ақ, COVID-19 сияқты өзекті, бірақ аз зерттелген патологиялар үшін генетикалық маркер ретінде потенциалды қолдану мүмкіндіктері туралы қосымша зерттеулер жүргізу қажеттілігі көрсетілген.

Кілт сөздер: D дәрумені, D дәрумені рецепторы, VDR гені, VDR генінің полиморфизмдері, rs2228570 (FokI), rs731236 (TaqI), rs1544410 (BsmI), rs7975232 (ApaI).

V.V. Protas, G.P. Pogossyan, K.G. Li, M.P. Danilenko

Vitamin D receptor gene polymorphisms characteristic

The article presents the characteristics of the main vitamin D receptor (VDR) gene polymorphisms: rs2228570 (FokI), rs731236 (TaqI), rs1544410 (BsmI) and rs7975232 (ApaI). The role of the vitamin D hormonally active form (1,25(OH)2D3, calcitriol) as a transcription factor regulating gene expression in target cells by binding to the vitamin D receptor protein is described. The immunomodulatory and mediating effect of VDRs on the biological functions of the human body has been noted. A description of the vitamin D recep-

tor gene and its polymorphic character have been provided. The analysis of the four most significant single nucleotide polymorphisms (SNPs) of the VDR gene was carried out. A detailed description of each polymorphism, its genomic position, the nature of interaction with other polymorphisms of the vitamin D receptor gene, as well as its effect on the structure and activity of the VDR protein were given. The analysis of the indicated single-nucleotide polymorphisms allelic composition was conducted according to the literature and specialized SNP databases. The frequency of each polymorphism individual alleles occurrence, as well as their influence on the predisposition and course of various diseases, were studied. The need for further studies of VDR gene polymorphisms, their allelic composition and prevalence was designated. It is also necessary to study the possibilities of their potential use as genetic markers for such relevant but little-studied pathologies as COVID-19.

Keywords: vitamin D, vitamin D receptor (VDR), VDR gene, VDR gene polymorphisms, rs2228570 (FokI), rs731236 (TaqI), rs1544410 (BsmI), rs7975232 (ApaI).

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Characteristics of growth rates as a result of salt impact on seedlings of *Suaeda*

This article presents the experiment data on pre-sowing treatment of *Suaeda salsa* Pall. seeds by different concentrations of salts (Na_2SO_4 and NaCl) and soil extract solutions (0 %, 0.6 %, 1.2 %, 1.8 %, 2.8 %, and 3.6 %). The reaction of seedlings and young roots of *S. salsa* was observed, grown after treatment to salt solutions and soil extracts. In addition, based on the results of the growth of young roots and shoots which are exposed to salt, a comparative description of the growth rates of seedlings and young roots before and after salt stress was made. The results of the experiment showed that *S. salsa* seeds have a high germination capacity after the elimination of the high level of salt stress and soil extract solution. The significant changes in development rate of *S. salsa* juvenile root and shoot during and after the salt stress, as well as increasing the germination rate after influence of salt stress were noticed. It was discovered that the growth rates of young roots and shoots of *S. salsa* are different, salt solutions considerably inhibited the growth of roots of plants seedlings compared to soil extract solution. The salt concentration has a greater effect on roots development. It was found that after the removal of salt stress, the germination rate and regenerative capacity of *S. salsa* seedlings increased.

Keywords: saline soil, halophytes, salt concentration, soil extract solution, salt stress, seeds, seedlings, *Suaeda salsa.*

Introduction

Salinity is a significant abiotic factor that limits plant development and decreases agricultural capacity [1, 2]. More than eight hundred million hectares or approximately 6 % of the entire land area on the planet are impacted by salt [3]. Salt-affected soil reduces agricultural production by more than 12 billion US dollars per year, and this amount is still rising. Simultaneously, as more arable land is lost due to the urban expansion, agricultural production is being pushed into marginal areas [4]. Halophytic plants are one of the resources that can be effective in coping with salt-affected environments.

Halophytes are plants that are resistant to salt concentrations which lead to 99 % death of other plant species. Although halophytes have been known for hundreds years, their definitions have remained the same. They are plant species that are capable of continuing life process at concentration of a minimum of 200 mM NaCl with the circumstances that are comparable to those observed in nature [5]. Based on the definition of the life cycle, it was possible to distinguish halophytes from plants that cannot live in saline conditions.

There are 5000–6000 species of halophytes, which make up about 2 % of all angiosperms [6]. Only a few of the halophyte species (less than 500 species) are resistant to the salinity of seawater, and most halophytes can be tolerant only low salt concentrations. The agricultural system's salinity of saline soils can be equal to half of sea water, so some halophytes have the potential to be exploited as salt-tolerant crops. Understanding how halophytes endure saline soils can help for plant breeders and molecular biologists to improve the salt resistant of traditional agricultural crops [7].

Suaeda is a halophyte belonging to the family *Amaranthaceae*. Several species, such as *S. acuminata, S. aegyptiaca, S. arcuata, S. argentinensis, S. australis, S. baccifera,* are known as salt resistant plants. Many species of these plants grow well in saline or alkaline soils, such as coastal saline plains and sedimentary wetlands. They are adapted to grow in areas with high salt accumulation (halophytic plants). *Suaeda salsa* Pall. has been demonstrated to be resistant to salinity up to 500 mM [8]. At the same time, it is an important key in the restoration of deserts, solonetz and sea coasts.

S. salsa is commonly used for both edible and non-edible purposes. The shoots of the plant are used in salads or processed into salty drinks, vinegar. On the other hand, making soap from these plants and using it as a source of soda (sodium carbonate) has been a common practice for centuries [9].

Some species of *Suaeda* (*S. salsa*) are grown commercially for biofuel production, animal fattening, salt and fat production. Recent studies have shown that some species of *Suaeda* can be used as bio-indicators of

zinc and copper. In addition, the medicinal and nutritional properties of the plant *Suaeda* contributed to the growing interest in it [10].

Although the use of these plants is widespread, the use of halophytes as cultivated plants is still limited due to barriers including loosening the soil and uneven seed germination. In fact, some species of halophytes are salt-tolerant during the mature shrub, but undergo salinity — resistant ecotypic feedback during seed germination [11].

Seed germination is usually high in fresh water and germination decreases with increasing salinity, but in some species, low salt concentrations may stimulate seed germination [12]. Often, after the rainy season, when the salinity of the soil decreases, the germination of seeds is high and the risk of stress on the seeds of salt plants is reduced [13].

Halophytes are studied widely because of their importance in the development of saline arable lands. An example is the eugalophytic herb *Suaeda* (*S. salsa*). Eugalophytes can dilute salts in their leave sand stems, indicating that they have a high salt tolerance. This information will be useful in determining how dicotyledonous plants tolerate salt [14]. The possibility of using salt-tolerant, juicy halophytes (especially *Suaeda* and *Salicornia species*) in amaranth in saline fields is given in several articles [15]. *S. salsa* is highly salt-tolerant; for its growth, the ideal salt concentration is 200 mM NaCl, which germinates as well as in 400 mM NaCl solution in 10 mM NaCl solution [16]. A number of genes related to the salt resistance of *S. salsa* was cloned and their functions were studied before. That is, halophytic plant species are a promising model for understanding salt tolerance. In addition, the leaves of this species have been studied as vegetables, and its seeds are high in fatty acids that are edible and unsaturated, which can be used as crops. The value of *S. salsa* is considered from the economic and ecological point of view. The purpose of this study was to assess the growth and recovery of Aksora *(S. salsal)* seedlings under the influence of various salt stress.

Experimental

Test materials were obtained in late September, 2020 from the saline soils of Lake Maraldy, Pavlodar region. The seeds were obtained from a complete and mature European calf plant, the experiment was performed in the laboratory of the Department of Environmental Management and Engineering, L.N. Gumilyov Eurasian National University.

The light intensity was 12 h/day, the temperature was 25 ℃ (day time)/15 ℃ (night), the relative humidity was 75–80 %. Basic salts to be tested: NaCl, Na_2SO_4 and a soil extract solution (SES) soil sample obtained from Lake Maraldy, Pavlodar region. The proportion of basic elements in 10 grams: Cl — 0.679 %, K — 3.375 %, Ca — 2.326 %, Fe — 8.819 %, S — 0.039 %. Concentration of stress salts: 0 %, 0.6 %, 1.2 %, 1.8 %, 2.8 %, 3.6 %.

The plant seeds collected for the experiment are sterilized for 10 minutes with a 10 % hydrogen peroxide (H_2O_2) solution, then cleaned multiple times with distilled water. The cleaned seeds are dried on filter paper. This is done to prevent the seeds from rotting under the influence of bacteria and fungi [17]. Two layers of filter paper (10 cm in diameter) are placed on each Petri dish, and then 25 pieces of sterile plant seeds are placed on top of the filter paper. Distilled water is used to prepare different saline solutions, and each experiment is repeated 4 times. The number of seeds grown must be monitored and recorded daily (from the time the seedling grows 2 mm from the seed coat) [18]. The total duration of the experiment is 14 days.

Results and Discussion

Aksora *(S. salsa)* has young roots with different concentrations of salts (Na_2SO_4 and NaCl) and soil extract solutions (0 %, 0.6 %, 1.2 %, 1.8 %,2.8 %, 3.6 %). The results are demonstrated in Figure 1.

Figure 1 depicts the salt stress effect on development of the young roots of Aksora, depends on the type and concentration of salt, and the main trend in the growth of young roots is an increase in root growth retardation due to increased salt concentration.

It was found that low concentrations of salts are effective for the growth of young roots. At 0.6 % of salts and soil solutions, the root growth rate was 1.8–2.5 cm, which had a positive effect on their growth. When the salt concentration is more than 1.8 percent, it is demonstrated that the growth of young roots is inhibited, and inhibition grows with increasing salt concentration, and the degree of growth and inhibition depends on the type and concentration of salt, significantly inhibited.

Results of growth of Aksora seedlings at different concentrations of salts (Na_2SO_4 and NaCl) and soil extract solutions (0 %, 0.6 %, 1.2 %, 1.8 %, 2.8 %, 3.6 %) are illustrated in Figure 2.

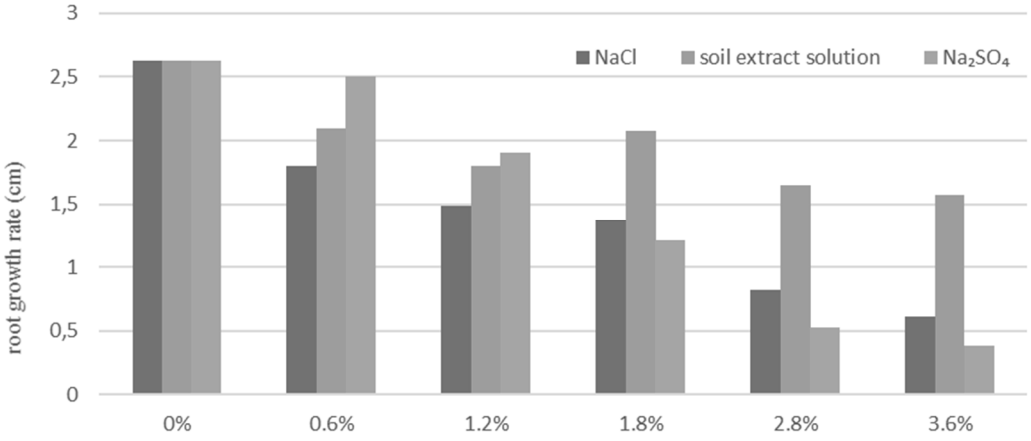

Figure 1. *Suaeda salsa* root growth rate (cm)

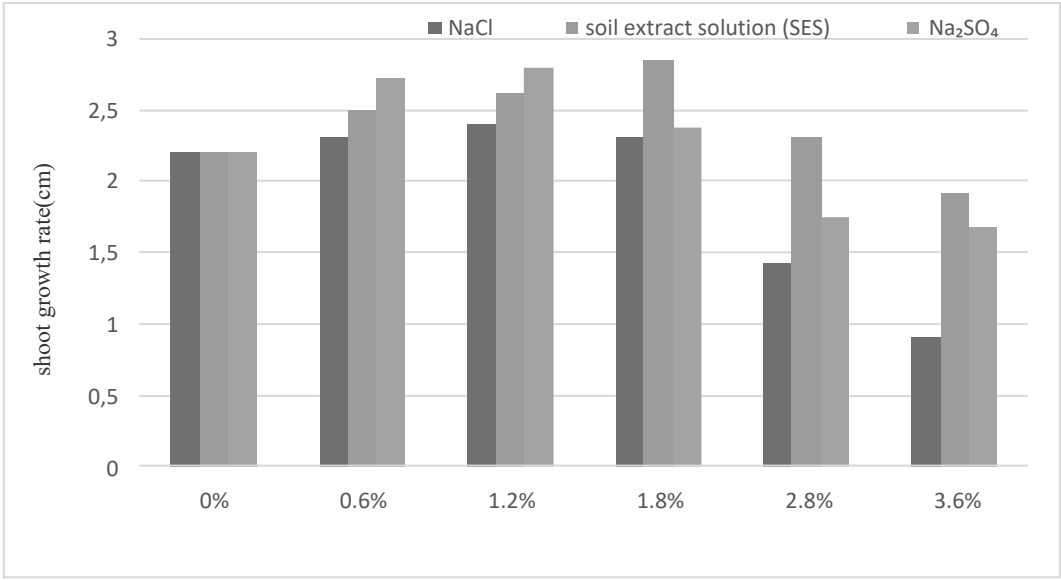

Figure 2. *Suaeda salsa* shoot growth rate (cm)

Figure 2 indicates that increasing the concentration of salts and soil extract solutions has a good effect on the development of *S. salsa* seedlings. At a concentration of 0.6 % of salts and soil solutions, the length of the growth was 2.31–2.73 cm, while at 1.2 % it was 2.40–2.80 cm. When the salt level exceeds 1.8 percent, the growth of the seedlings is inhibited; however, the effect of soil solution on seedling development is negligible.

It was established that the degree of inhibition of salinity in young shoots and young roots is different, the change in the parameters of young roots is clearly visible, and the change in young shoots is relatively slow. Only when the salt concentration exceeds 1.8 percent, there is a significant change in the growth rates of young roots and shoots. This indicates that the concentration of salts has an effect on the growth rate of *S. salsa* seedlings. In particular, these salts have been shown to have a greater effect on the growth of *Suaeda* roots.

There is an assessment of the growth of *S. salsa* seedlings after the elimination of salt stress. Figure 3 designates the normal growth rates of *Suaeda* seedlings after the elimination of high-concentration salt stress.

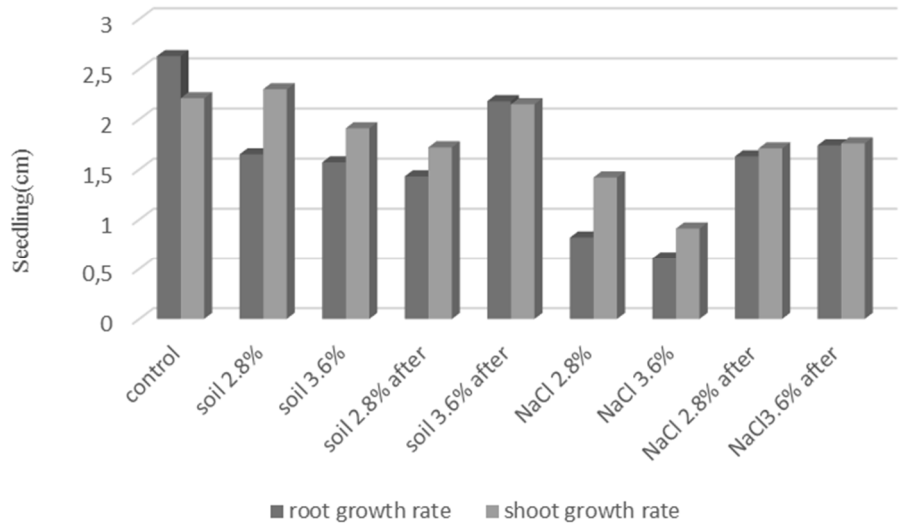

Figure 3. Comparison after re-cultivation of *Suaeda salsa* seedlings in distilled water, (cm)

Figure 3 demonstrates that after re-cultivation of *S. salsa* seedlings in distilled water, the growth of young roots exceeded the control data by more than 65 %, while the growth of young shoots exceeds that of the control by more than 80 percent. Before planting, the development of roots and shoots of *Suaeda salsa* seedlings was slowed down because of the increase in salt concentration, and after this process and treatment, the growth of roots and seedlings showed a tendency to increase concentration of saline solutions. As a result, it was found that the ability of *Suaeda* seedling store cover after the elimination of salt stress has improved. In addition, there were differences in the growth of seedlings and roots under stress and stress relief at different concentrations of salt, and at high concentrations of soil solution (3.6 %) there was a significant change in the growth of seedlings and roots before and after re-cultivation in water. It can be seen that the length of young roots and shoots increased by 1.57–2.18 (cm) and 1.91–2.15 (cm), respectively. However, before and after the stress of NaCl salt, there were paramount differences in the development of roots and branches, and high concentrations of NaCl significantly affected the growth of *Suaeda* seedlings.

Conclusions

It is illustrated that the growth of seedlings of Aksora *(S. salsa)* is directly related to the type and concentration of salt, and the degree of inhibition of seedling roots grows with increasing salt concentration under the stress of salt and soil solutions. Under stress of 0.6–1.8 %, the growth rates of young shoots increased to varying degrees, but the scale of change was negligible. It was found that the concentrations of salts and soil solutions have a greater effect on young roots than on shoots. *S. salsa* seeds not only germinate normally after high concentration of salt stress, but can grow normally in their seedlings, young roots and shoots can be used in 65 % and above 80 % salt-free conditions, and after exposure to salt, *S. salsa* improves the ability to restore the growth of seedlings.

Significant changes in the growth rate of white seedlings before and after treatment with NaCl salt were observed. Germination and germination of seeds in a saline environment will be a crucial and sensitive stage in the growth of halophytes [19]. Studies presented that Aksora has a strong ability to adapt to salt, so it is recommended to grow and use it extensively in saline-alkaline areas. The results of the experiment demonstrated that the *Suaeda* seeds still have a high germination capacity after the stressful effects of salts and soil extract solutions on the *Suaeda* seeds have been eliminated. Considerable changes in the growth rate of young roots and shoots of the plant *Suaeda* were observed during the salt stress. The improvement of seed germination rate after the removal of stress was identified. Consequently, the growth rates of young roots and shoots of *Suaeda* in different saline solutions were different, and the salt concentration had a greater effect on the roots. It was studied that after the elimination of salt stress, the germination rate and regenerative capacity of *Suaeda* seedlings increase.

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Ақсора көшеттеріне тұздардың әсер ету кезіндегі өсу көрсеткіштерінің сипаттамалары

Мақалада *Suaeda salsa* тұқымдарына тұздар (Na_2SO_4 және NaCl) мен топырақ сығындысы ерітінділерінің әртүрлі концентрациясында (0 %, 0.6 %, 1.2 %, 1.8 %, 2.8 %, 3.6 %) өңдеу жасалды. Өңделгеннен кейінгі өсіп шыққан Ақсора өсімдігінің өскіндерімен жас тамырларының тұздармен топырақ сығындысы ерітінділеріндегі реакциясы бақыланды. Сонымен бірге, тұз стресі жағдайында өсіп шыққан жас тамырлар мен өскіндердің өсу кезіндегі көрсеткіштерінің нәтижелеріне сүйене отырып, тұз стресінен бұрынғы және стрестен кейінгі кездегі өскіндер мен жастамырлардың өсу көрсеткіштерінің салыстырмалы сипаттамасы жасалынды. Эксперимент нәтижелері көрсеткендей, Ақсора тұқымына әсер етуші тұздар (Na_2SO_4 және NaCl) мен топырақ сығындысы ерітіндісінің стрестік әсері жойылғаннан кейін Ақсора тұқымдарының әліде жоғары өнгіштік қабілетке ие екендігі анықталды.

Тұз стресі кезінде және стресс жойылғаннан кейінгі кезде Ақсора өсімдігінің жас тамырлары мен өскіндерінің өсу көрсеткішінде айтарлықтай өзгерістер бар болғандығы, сонымен қатар стрестік әсерден кейін тұқымның өну жылдамдығының жақсарғандығы байқалды. Ақсораның жас тамырларымен өскіндерінің әртүрлі тұз ерітінділеріндегі өсу көрсеткіштерінің түрліше болғандығы, топырақ сығындысының ерітіндісімен салыстырғанда тұз ерітінділері Ақсора көшетінің тамырларының өсуін айтарлықтай тежейтіндігі, яғни тұз концентрациясының тамырларға көбірек әсер ететіндігі анықталды. Тұз стресі жойылғаннан кейін Ақсора көшеттерінің өну көрсеткішінің және қалпына келу қабілетінің жоғарылайтындығы анықталды.

Кілт сөздер: тұзды топырақ, галофиттер, тұз концентрациясы, топырақ сығындысының ерітіндісі, тұз стресі, тұқым, көшеттер, *Suaeda salsa.*

Ж. Рахымжан, Р.Р. Бейсенова, Ж.Б. Текебаева, А.Б. Абжалелов

Характеристики скорости роста при воздействии солей на проростки сведы солончаковой

В статье представлены результаты экспериментов по обработке семян *Suaeda salsa* Pall. различными концентрациями солей (Na_2SO_4 и NaCl) и почвенными экстрактами (0 %; 0,6; 1,2; 1,8; 2,8; 3,6 %). Наблюдали реакцию проростков и молодых корней растений *Suaeda salsa*, выращенных после обработки растворами солей и почвенными экстрактами. Кроме того, по результатам роста молодых корней и побегов, выращенных в условиях солевого стресса, было проведено сравнительное описание темпов роста проростков и молодых корней до и после солевого стресса. Результаты эксперимента показали, что семена сохраняют высокую всхожесть, несмотря на высокие стрессовые условия солей (Na_2SO_4 и NaCl) и растворов почвенных экстрактов, влияющих на семена *Suaeda salsa*. Наблюдались значительные изменения в скорости роста молодых корней и побегов растения *Suaeda salsa* во время и после солевого стресса, а также улучшение скорости прорастания семян после стресса. Выявлено, что темпы роста молодых корней и побегов *Suaeda salsa* в разных солевых растворах различаются, солевые растворы значительно подавляют рост корней проростков *Suaeda salsa* по сравнению с раствором почвенного экстракта, концентрация соли в большей степени оказывает влияние на корни растения. Установлено, что после снятия солевого стресса всхожесть и регенерационная способность проростков *Suaeda salsa* повышаются.

Ключевые слова: засоленная почва, галофит, концентрация соли, раствор, почвенная вытяжка, солевой стресс, семена, проростки, *Suaeda salsa.*

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Influence of zinc nanoparticles on the development of sprouts of *Avena sativa* and *Pisum sativum* plants

The research aim is to study the effect of zinc nanoparticles on morphological parameters of sprouts of monocotyledonous and dicotyledonous plants (*Avena sativa, Pisum sativum*) during its accumulation in the environment. In laboratorial conditions of the experiment, it was found peculiar features of various concentrations of nanoparticles. It was specified the multidirectional effect of zinc macro- and nanoparticles onto growth rate, green weight of both aboveground and underground parts, as well as species related effect. Authors of the article identified concentrations of macro- and nanoparticles trigger permanent biological response on the experimental plants. A stable stimulating effect of zinc nanoparticles on all indicators of growth and development of pea seedlings at the concentration of 20 mg per 100 ml was revealed. A similar effect was found in oat seedlings which were exposed to zinc nanoparticles at the concentration of 5 mg per 100 ml. The effects of zinc macro- and nano-particles on plants were manifested differently.

Keywords: nanoparticles, macroparticles, zinc, plants, *Avena sativa, Pisum sativum*, morphological parameters.

Introduction

There is a limited number of studies by the Kazakh authors related to the study of the physical and chemical properties of metal nanoparticles [1–3], while the physiological properties and the toxic effect of these xenobiotics on living organisms have not been studied to all intents and purposes.

In the Russian journals and overseas scientific publications, there are a number of works devoted to assessing the effect of metal nanoparticles on both plants and animal organisms. It is revealed that nanoparticles have both positive and negative effects on these organisms. The positive effect of nanoparticles (NPs) of zinc and its compounds is found in mammals and birds [4], which is associated with changes in the parameters of the intestinal barrier and antioxidant protection. By conducting a research on rodents and fish using in vitro and in vivo methods and, Rajput V.D. et al. (2018) [5] proves the importance of developing the metal nanoparticles' toxicity criteria. Similar conclusions are reached by Chen et al. (2016) [6], who emphasize the need to study the toxic effect of zinc NPs on terrestrial and aquatic animals, and to revise the levels of these pollutants in natural conditions, especially if a synergistic toxic effect is possible with a complex of pollutants.

A number of studies have shown both positive and negative effects of metal nanoparticles and their oxides on the growth, productivity and physiology of plants, including agricultural crops [7–10]. Some authors demonstrate how safe the environmental pollution by nanoparticles [11–12], while other researchers emphasize on some significant risks of contact of plant organisms with nanosized particles [13–16].

In this regard, the issues related to the effect of metal nanoparticles on biological objects remain an urgent and practically significant.

Experimental

For the experiments, the suspensions of Zn particles of various concentrations 5, 10, 20, 200 mg per 100 ml of distilled water were utilized. The particle sizes were 80–100 nm (nanoparticles) and 500–1,000 nm (macroparticles) [17–18].

Agricultural monocotyledonous crops — cultivated oat (*Pisum sativum*, "Irtysh 15" variety) and dicotyledonous plants — green pea (*Avena sativa*, "Sugary pod" variety) were selected as typical test organisms. The growth and weight parameters of seedlings were studied [19–21].

The suspensions of NPs in various concentrations and in a volume of 10 ml were applied to filter paper in Petri dishes. The plant seeds were sown there in an amount of 15 pieces per one dish. In 14 days, the roots of the seedlings were placed on filter paper ribbons, which were rolled up into a loose roll and immersed in

plastic cups with a volume of 150 ml distilled water (Fig. 1). The plant weight and their growth were measured in 28 days after the start of the experiment.

The work was carried out at the Research Center for Biotechnology and Eco-Monitoring. The nanoparticles of zinc were synthesized at the Research Center for Ion Plasma Technologies and Modern Instrumentation of Karagandy University of the name of academician E.A. Buketov.

A B

Figure 1. The test plants in plastic cups (A) and in Petri dishes (B)

Both plant species were cultivated in climatic chamber BINDER, temperature +24 ºC, lighting 14 hours.

Results and Discussion

Observations over biological development showed that macro- and nanoparticles of zinc had different effects on the seedlings of the cultures under the experiment.

The macroparticles of zinc had a depressing effect on oat seedlings in all experimental groups, which led to a decrease (Tab. 1) in the root length compared to the control values by 75.1 and 24.7 %, 7.6 %, 25.6 %, respectively.

Table 1

Growth and weight parameters of *Avena sativa* seedlings

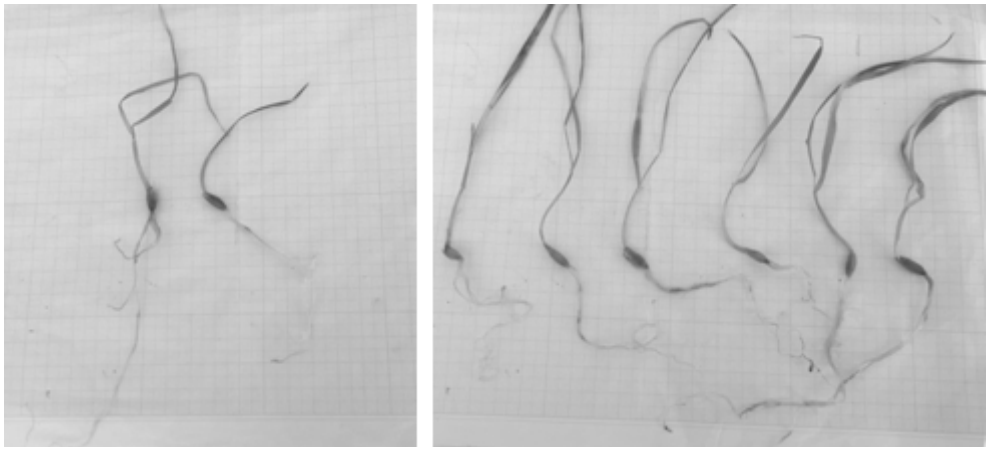
Concentration, mg/100 ml	Length of main root, cm	Aboveground part length, cm	Bio mass, g	
			Underground part	Aboveground part
Control	11.46 ± 2.96	10.6 ± 1.43	0.15 ± 0.06	0.07 ± 0.02
Macroparticles				
5	2.85 ± 1.56	4.5 ± 0.79	0.07± 0.01	0.03 ± 0.01
10	8.63 ± 2.64	11.0± 0.89	0.07± 0.03	0,06 ± 0.04
20	10.8 ± 2.4	9.2 ± 1.7	0.15± 0.06	0.07 ± 0.02
200	8.53 ± 2.34	10.72 ± 1.17	0.14± 0.03	0.06 ± 0.02
Nanoparticles				
5	15.2 ± 3.26	13.1 ± 1.9	0.14 ± 0.04	0.1 ± 0.02
10	13.0 ± 2.75	12.42 ± 2.78	0.16 ± 0.03	0.09 ± 0.02
20	8.13 ± 1.35	11.47 ± 2.21	0.16 ± 0.03	0.08 ± 0.02
200	12.28 ± 0.74	11.48 ± 1.76	0.15 ± 0.04	0.08 ± 0.01

When roots of seedlings treated with nanoparticles at the concentrations of 5, 10 and 200 mg, an increase in this indicator was noted by 32.6 %, 13.4 % and 7.1 %, respectively. At the same time, at the concentration of 20 mg/ml, the length of main root decreased by 29.1 % compared to the control values.

Measurement of the length of the aerial part of oat seedlings demonstrated that treatment with zinc macroparticles in some concentrations has a depressing effect on their growth parameters, and nanosized particles in all concentrations have a stimulating effect (Fig. 2). Compared with the control values, when treated with macroparticles at the concentrations of 5, 20 mg, the sizes of leaves and stems decreased by 57.6 % and 13.2,%, respectively. At the same time, at the concentration of metal particulates of 10 mg, an

increase in this indicator by 3.7 % was noted. The treatment of oat seeds with nanoparticles at all concentrations led to an increase in the length of the aerial part compared to the control values by 23.6 %, 17.2 %, 8.2 %, 8.3 %, respectively.

The wet weight of the underground oats organs, treated with zinc nanoparticles, had similar values for the experimental and control groups, while the weight of the roots of seedlings, treated with suspensions of macroparticles of 5 and 10 mg, was lower than the control values. A similar picture was observed by studying the parameters of the mass of the aerial part of seedlings.



A B

Figure 2. Appearance of seedlings of seed oats in the control (A) and against the background of zinc nanoparticles (B)

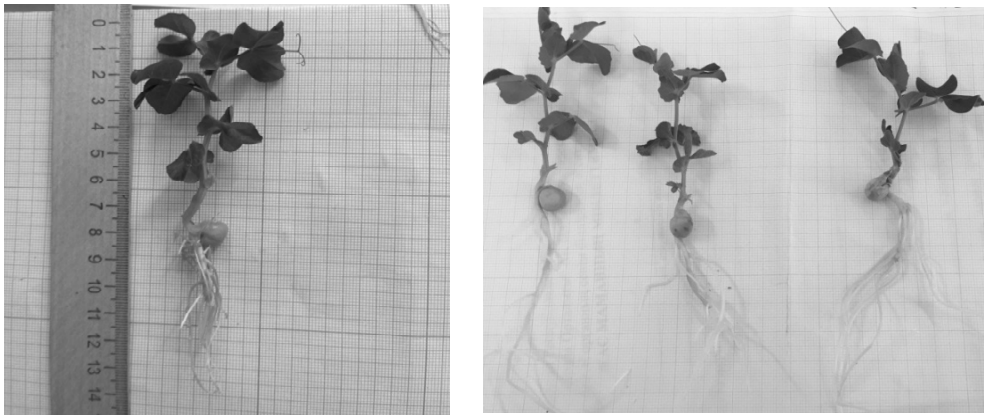
When studying the effect of zinc particles on the green pea, it was found that high values of all morphological parameters of the aboveground and underground parts of seedlings were recorded under exposure to zinc nanoparticles at the concentration of 20 mg (Tab. 2, Fig. 3). The nanoparticles at the concentration of 5 mg caused a significant increase in the mass of the aboveground part of the plants and the length of the underground part, with a decrease in its mass, compared with the control values.

Table 2

Growth and weight parameters of *Pisum sativum* seedlings

Concentration, mg / 100 ml	Length of main root, cm	Aboveground part length, cm	Bio mass, g	
			Underground part	Aboveground part
Control	7.17 ± 2.83	4.01 ± 1.71	0.53 ± 0.04	0.16 ± 0.09
Macroparticles				
5	8.05 ± 3.16	6.13 ± 2.52	0.39 ± 0.09	0.26 ± 0.12
10	5.42 ± 3.12	2.33 ± 1.13	0.55 ± 0.1	0.1 ± 0.06
20	4.94 ± 1.7	6.43 ± 2.34	0.5 ± 0.14	0.29 ± 0.11
200	4.44 ± 1.59	5.21 ± 3.87	0.52 ± 0.1	0.18 ± 0.07
Nanoparticles				
5	13.2 ± 2.42	4.69 ± 0.95	0.37 ± 0.07	0.22 ± 0.05
10	4.69 ± 1.38	3.61± 1.67	0.53 ± 0.13	0.12 ± 0.06
20	8.39 ± 3.25	5.13.± 2.96	0.59 ± 0.1	0.2 ± 0.11
200	7.92 ± 2.8	5.2 ± 1.13	0.49 ± 0.05	0.24 ± 0.06

An increase in the concentration of macroparticles led to a decrease in the length of the underground part. Thus, at the concentration of 5 mg, the root length increased by 10.9 %, while at a concentration of 10, 20, and 200 mg/ml, the root length significantly decreased in comparison with the control values by 32.2 %, 45.1 % and 61.5 %, accordingly.



A B

Figure 3. The internal view of pea seedlings after treatment with nanoparticles (A) and macroparticles (B)

In the experimental groups of those plants treated with nanoparticles, the root length exceeded the control values by 84.1 %, 17.0 %, and 10.5 % when treated at the concentration of 5, 20, and 200 mg, respectively. The shortest root length was observed in the variant with the concentration of 10 mg, where the length decreased by 34.6 %.

The study of the length of the aerial part of the green pea illustrated that the treatment with macroparticles and nanoparticles at the concentration of 10 mg has a depressing effect on the morphological parameters of both leaves and stems. Compared with the control values, the sizes of leaves and stems decreased by 41.9 % and 10.0 %, respectively. When treated with macroparticles at the concentrations of 5 and 20 mg, the leaf and stem length indicators were higher than the control indicators by 37.3 % and 38.7 %, respectively.

The treatment with nanoparticles at the concentration of 5, 20 and 200 mg has a beneficial effect on the plants. The lengths of the plants' sprouts were 16.9 %, 27.9 %, and 29.7 %, respectively.

A decrease in the weight of the root was observed upon treatment with macroparticles at the concentration of 5 and 20, 200 mg, which corresponds to 26.4 %, 5.7 %, and 1.9 %. At the same time, at the concentration of 10 mg of macroparticles, a slight increase in this indicator by 3.8 % was observed.

When treated with nanoparticles at the concentration of 10 mg, no change in the root wet weight was observed in comparison with the control values. At the same time, at the concentration of nanoparticles of 20 mg, an increase in this indicator by 11.3 % was noted. A decrease in the root weight was observed upon treatment with nanoparticles at the concentration of 5 and 200 mg by 30.2 % and 2.4 %, respectively.

The wet weight of the aerial part of the green pea treated with both macroparticles and zinc nanoparticles was higher than the control values, except for the case at the concentration of 10 mg, which caused a decrease in the indicator by 37.5 % when exposed to macroparticles and by 25 % when exposed to nanoparticles.

The study of the length of the underground part of Pisum sativum when treated with macroparticles showed that, in addition to those varieties treated at the concentration of 5 mg, an increase in the growth rate was observed. Whereas concentrations of 10, 20, 200 mg inhibited the root growth. When treated at the concentration of 5, 20 mg, an excess of the control values for the wet weight of aboveground organs was observed.

Conclusions

It can be concluded that the experiment with the treatment of oat and green pea by zinc water suspensions showed the dependence of the biological reaction of these plants on the particle size and the metal concentration.

In general, the suspensions of zinc nanoparticles caused a stimulating effect on oat seedlings, while the effect of macroparticles led to a decrease in a number of morphological parameters. The maximum values of the morphological parameters of oat seedlings were revealed when exposed to zinc nanoparticles at the concentration of 5 mg per 100 ml. The opposite effect manifested in the suppression of the growth of both

underground and aboveground parts of the plants was caused by the exposure to macroparticles at the concentration of 5 mg per 100 ml.

The treatment of green pea with zinc macroparticles mainly caused the stimulation of the length and mass of the plant sprouts, while most of the morphological parameters remained unchanged or decreased relative to the control values. The impact of suspensions of nanoparticles on the green pea caused an increase in the mass of the aerial part. Other morphological indicators showed a multidirectional nature of the reaction to the effect of nanoparticles. It should be noted that there is a stable stimulating effect of zinc nanoparticles on all indicators of growth and development of the green pea's seedlings at the concentration of 20 mg per 100 ml and the opposite effect of zinc macroparticles at the concentration of 10 mg per 100 ml.

To elucidate what mechanisms can be the basis for the reaction of the plants to such action of macro- and nanoparticles of zinc, an extensive study of the morphological structure of aboveground and underground organs, as well as changes in biochemical processes in them, is further required.

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Мырыш нанобөлшектерінің *Avena sativa* және *Pisum sativum* өсімдіктерінің өскіндерінің дамуына әсері

Зерттеудің мақсаты — қоршаған ортада мырыш нанобөлшектерінің жинақталуы кезінде дара және қосжарнақты өсімдіктердің (Avena sativa, Pisum sativum) өскіндерінің, олардың морфологиялық параметрлеріне әсерін зерттеу. Мырыштың әр түрлі макро- және нанобөлшектерінің өсімдіктердің өсу қарқынына, жоғарыдан да, төменнен де ылғалды салмаққа жан-жақты әсері ететіндігі анықталды. Авторлардың пайымдауынша эксперименттік жұмыстағы макро- және нанобөлшектердің концентрациясы өсімдіктерде тұрақты түрде биологиялық жауап тудыратыны байқалған. Бұршақ өскіндерінің өсуі мен дамуының барлық көрсеткіштеріне мырыш нанобөлшектерінің 100 мл 20 мг концентрациядағы әсері тұрақты түрде белсенді әсер ететіндігі анықталды. Осындай нәтижеде мырыш нанобөлшектерінің 100 мл-де 5 мг концентрацияда сұлы өскіндеріне әсер ететіндігі де зерттелді. Мырыштың макро- және нанобөлшектерінің өсімдіктерге әсері әр түрлі көрінген.

Кілт сөздер: нанобөлшектер, макробөлшектер, мырыш, өсімдіктер, *Avena sativa, Pisum sativum*, морфологиялық көрсеткіштер.

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Влияние наночастиц цинка на развитие проростков растений *Avena sativa* и *Pisum sativum*

Цель исследования — изучить влияние наночастиц цинка на морфологические параметры проростков одно- и двудольных растений (*Avena sativa, Pisum sativum*) при его накоплении в окружающей среде. Установлено разнонаправленное влияние макро- и наночастиц цинка на скорость роста, сырую массу как сверху, так и снизу, а также влияние видов. Авторами отмечено, что концентрации макро- и наночастиц вызывают постоянный биологический ответ у растений, участвующих в эксперименте. Выявлено стойкое стимулирующее действие наночастиц цинка на все показатели роста и развития проростков гороха в концентрации 20 мг на 100 мл. Аналогичный эффект был обнаружен у проростков овса, подвергнутых воздействию наночастиц цинка, в концентрации 5 мг на 100 мл. Влияние макро- и наночастиц цинка на растения проявлялось по-разному.

Ключевые слова: наночастицы, макрочастицы, цинк, растения, *Avena sativa, Pisum sativum*, морфологические показатели.

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The isolation of fungi from lichens of the Magadan region and biological activity of their extracts

The study aims to isolate fungi from lichens of the Magadan region (Russia) and evaluate their antibacterial and antifungal activity. Fourteen species of lichen from the Magadan region (Russia) were selected for the study. Antibacterial activity was determined based on gram-positive (*Staphylococcus aureus*) and gram-negative bacteria (*Escherichia coli*). Antifungal activity was identified by using strains of *Aspergillus terreus* and *Candida albicans*. According to the results of the study, fungi isolated from lichens *Peltigera leucophlebia* (CD), *Hypogymnia sachalinensis* (CD) showed antifungal activity, and fungi from *Peltigera leucophlebia* (CD), *Peltigera aphthosa* (CD), *Melanohalea olivacea* (PDA, CD), displayed antibacterial activity. As a result of studying the biological activity, the fungi isolated from the lichen *Peltigera leucophlebia* (CD) have both antibacterial and antifungal activity.

Keywords: lichens, Magadan region, fungi, antibacterial activity, antifungal activity.

Introduction

Lichens are complex symbiotic associations between a fungus (mycobiont) and an alga (photobiont) and used in traditional medicine for various diseases due to the presence of several bioactive compounds [1]. Lichen compounds can be arbitrarily divided into two groups: primary and secondary compounds. Primary lichen compounds have structural functions and are involved in cell metabolism.

Secondary lichen compounds are characterized by acid properties, such as lichen acids [2, 3]. Each lichen species has its own set of lichen acids, which generally gives qualitative reactions enabling the lichen species to be discriminated against. Many lichen species contain atranorin, usnic acid, lecanoric acid, salazinic acid, lobar acid, and other acids [4]. Lichen acids are essential to identify the lichens, and could be used as natural antibiotics [5, 6]. Therefore, the bioactive compounds from lichens have various biopharmaceutical applications as antimicrobial, antioxidant and cytotoxic agents, which can be the basis for the development of new antibiotics [7, 8].

Experimental

Lichen materials

Fourteen types of lichens: *Flavocetraria nivalis* (L.) Kärnefelt et A. Thell*, Cetraria laevigata* Rass.*, Umbilicaria hyperborea* (Ach.) Hoffm.*, Melanohalea olivacea* (L.) O. Blanco, A. Crespo, Divakar, Essl., D. Hawksw. et Lumbsch*, Cladonia ecmocyna* Leight*, Flavocetraria cucullata* (Bellardi) Kärnefelt et A. Thell*, Cetraria islandica* (L.) Ach.*, Cladonia uncialis* (L.) Wigg.*, Vulpicida pinastri* (Scop.) J.-E. Mattsson*, Peltigera aphthosa* (L.) Willd.*, Cladonia stellaris* (Opiz) Pouzar et Vězda*, Vulpicida juniperinus* (L.) J.-E. Mattsson et M.J. Lai*, Peltigera leucophlebia* (Nyl.) Gyeln.*, Hypogymnia sachalinensis* Tchabanenko et McCune, were collected in October, 2019, in the Magadan region (Russian Federation) and identified by Dr. E.V. Zheludeva (Institute of Biological Problems of the North, Far-Eastern Branch of the Russian Academy of Sciences) (Fig. 1).

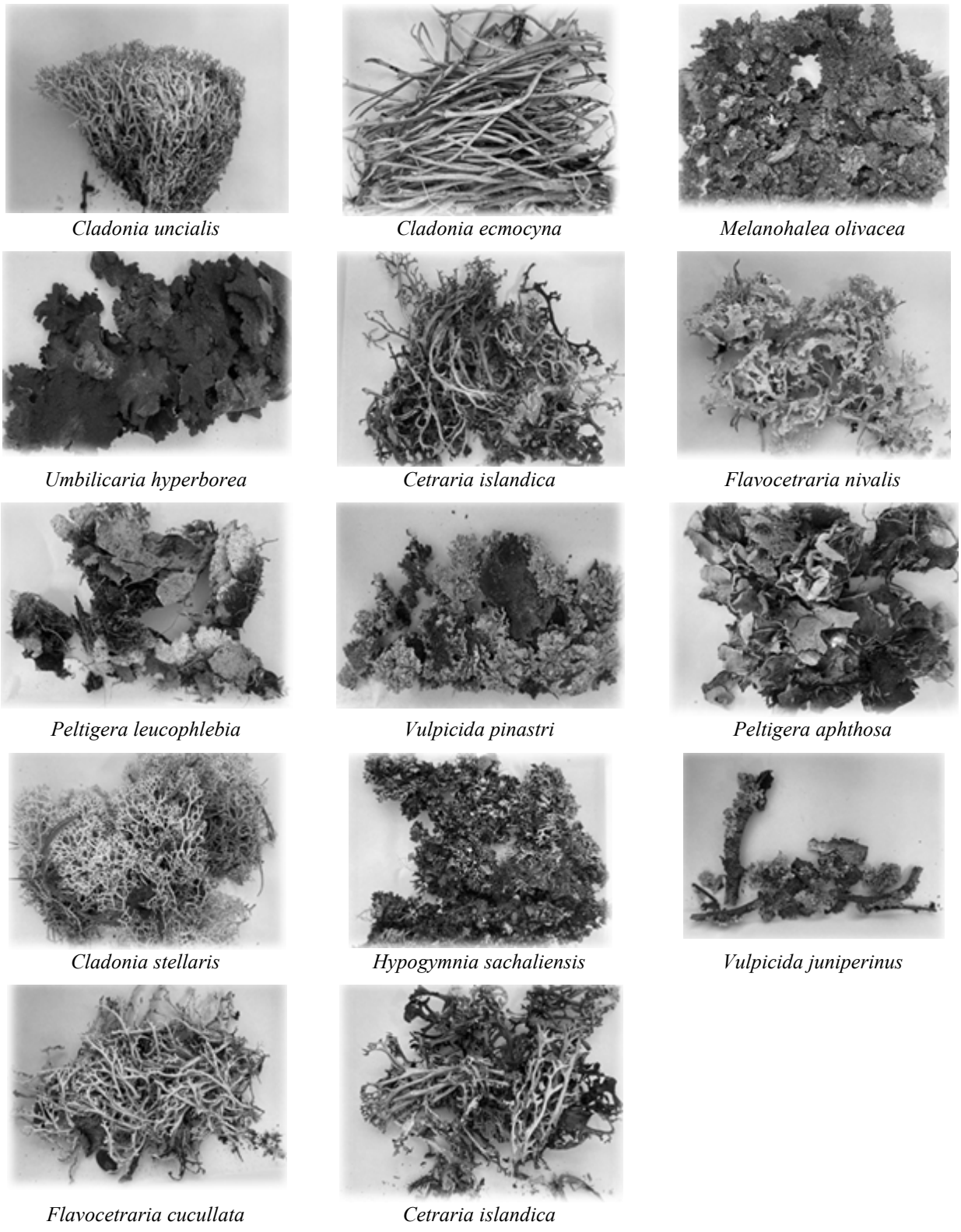

Figure 1. Lichens of the Magadan region (Russia)

Growth nutrient medium

Potato Dextrose Agar (PDA), Czapek DOX Agar (CD), Potato Dextrose Broth (PDB), and Czapek DOX Broth (CDB) were used.

Method of isolation of fungi from lichens

Lichen were cut into small pieces (about 0.5×0.5×0.5 cm), washed with a chemical solution (distilled water, 96 % EtOH, 70 % EtOH, 1 % NaClO). A Petri dish with an antibiotic (streptomycin) was divided into 4 sectors; one fragment of lichen was added to each sector. Samples were incubated in a darkened place at room temperature for 7–10 days. The process was repeated 3 times, after which a culture of pure fungi was obtained. A pure identified fungi culture, grown in a solid medium (PDA, CD), was placed in a flask with a liquid medium (PDB, CDB) to produce biomass. During cultivation at the room temperature in dark place for 7–10 days, it was used the Biosan PSU-20i Orbital Shaker at 110 rpm.

Antibacterial activity

The antagonistic activity of lichen-fungi was determined by diffusion into agar by the diameter of the zone of absence of the growth of opportunistic cultures: *Staphylococcus aureus* (B-RKM 0470) and *Escherichia coli* (B-RKM 0447), provided by the Central Museum of the Republican Collection of Microorganisms (Nur-Sultan, Kazakhstan). For this purpose, medium MPA (meat-peptone agar, Nutrient agar + Meat extract, 5 g/l) is used. The pathogenic cultures in the form of suspensions of cells in the amount of 1 bln/ml (for bacterial turbidity standard of 0.5) were applied on the surface of the Petri dish, rub thoroughly with a spatula over the surface of the medium, then cut out holes with a drill diameter of 10 mm and filled them with the investigated cultures (0.1 ml). The zones of inhibition were measured after 24 hours, and the results were presented without deducting the diameter of the whole zone. The antagonistic activity was considered zero at the width of the zone of absence of test strains up to 1.0 mm, low — at 1.1–4.9 mm, medium — at 5.0–8.9 mm, high — at 9.0 mm or more [9, 10].

Antifungal activity

Antifungal activity of fungi extract was identified using two test strains: *Aspergillus terreus* (B-RKM 0697), *Candida albicans* (B-RKM 0475) provided by the Central Museum of the Republican Collection of Microorganisms (Nur-Sultan, Kazakhstan). The Petri dishes with PDA and CD media were prepared and waited until solidification and suspension in the amount of 1 bln/ml (for bacterial turbidity standard of 0.5), were placed on Petri dishes and rub thoroughly with a spatula over the surface of the medium. Then, the holes with diameter of 10 mm were drilled and filled with the cultures organisms (0.1 ml). After 48 hours of incubation, the inhibition zones were measured.

Fermentation of fungi

Fermentation was carried out in conical flasks (250 ml), each containing 60 g of rice and wheat. Distilled water (60 ml) was added to each flask and autoclaved at 15 °C for 30 minutes. After cooling to room temperature, 50–100 ml of pure culture suspension isolated from lichen was poured into the flask. Cultivation was carried out at room temperature for 25 days, in a dark place.

Results and Discussions

Mycelial cultures

Fungi isolated from lichens *Cetraria islandica, Cladonia uncialis, Flavocetraria nivalis* did not grow after the first sowing on nutrient media (PDA, CD) with the antibiotic streptomycin, other fungi from the samples, such as *Peltigera aphthosa, Cladonia stellaris, Vulpicida juniperinus, Umbilicaria hyperborea, Flavocetraria cucullata* did not grow on PDA, but showed a good growth on CD (Fig. 2).

In the case of *Peltigera leucophlebia, Vulpicida pinastri Hypogymnia sachalinensis,* and *Melanohalea olivacea*, mycelium growth was observed on two nutrient media. The fungi were actively growing after the first sowing. After each seed incubation, the mycelium turned from light to dark. The growth of *Cladonia ecmocyna* is very slow in nutrient media, its color is light, and has acquired a convex shape. Fungi isolated from the lichen *Cetraria laevigata* showed excellent growth on the PDA medium; the shape is uniform, the color is white.

Mycelium growth was checked every week, and after one month, we received pure fungi. Each fungus demonstrated a different growth rate and pigmentation.

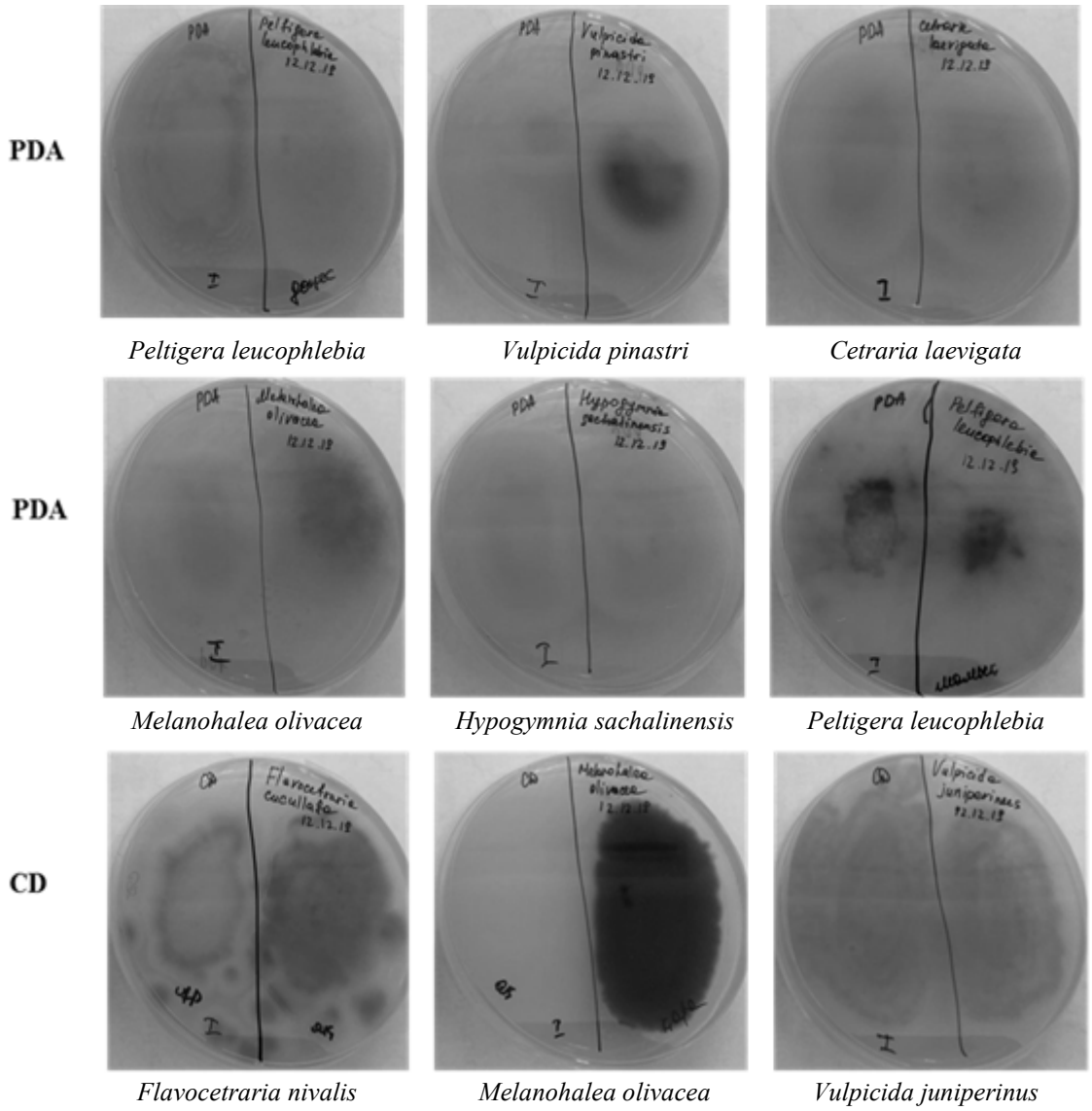

Figure 2. The process of fungi isolation from lichens of the Magadan region in two nutrient media PDA, CD

Antibacterial activity

The antibacterial activity of fungi isolated from lichens of the Magadan region was evaluated using agar diffusion method. The diffusion method in the agar provides information on the resistance of fungi material extracts to various microorganisms [11]. Fungi extracts were tested with gram-positive and gram-negative strains. *Vulpicida pinastri, Cladonia stellaris, Hypogymnia sachalinensis, Vulpicida juniperinus, Cetraria laevigata, Umbilicaria hyperborea, Flavocetraria cucullata* did not show antimicrobial activity on both test strains. Fungi from *Peltigera leucophlebia* (CD), *Peltigera aphthosa* (CD), *Melanohalea olivacea* (PDA, CD) showed an antimicrobial activity (average — 5.0–8.9 mm). According to experimental data, it is demonstrated that the activity of lichens is also affected by nutrient media.

Antifungal activity

Antifungal activity was determined on a solid medium based on a test strain of *Aspergillus terreus (B-RKM 0697), Candida albicans (B-RKM 0475).* This study illustrated relatively high activity of fungi from *Peltigera leucophlebia* (CD). Fungi isolated from lichens suppressed the growth of test strains, which indicates antifungal activity. At that time, only the growth of the test strain was observed in other samples.

Conclusions

It was found that fungi isolated from lichens of the Magadan region have a biological activity. Fungi isolated from *Peltigera leucophlebia* (CD), *Hypogymnia sachalinensis* (CD) showed antifungal activity on *Aspergillus terreus, Candida albicans*.

Fungi isolated from *Peltigera leucophlebia* (CD), *Peltigera aphthosa* (CD), *Melanohalea olivacea* (PDA, CD) have activity against gram-positive (*Staphylococcus aureus*), and gram-negative bacteria (*Escherichia coli*). These experiments make it possible to study further in-depth their other biological, physical, and chemical properties.

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Магадан облысы қыналарынан саңырауқұлақтардың алынуы және олардың ферментативті сығындыларының биологиялық белсенділігі

Зерттеу жұмысының мақсаты — Магадан облысының (Ресей) қыналарынан саңырауқұлақтарды бөліп алу және олардың микробқа, саңырауқұлаққақарсы белсенділігін анықтау. Зерттеу нысаны ретінде Магадан облысы қыналарының 14 түрі алынды. Микробқақарсы белсенділігі грамоң *(Staphylococcus aureus)* және грамтеріс бактериялар *(Escherichia coli)* негізінде анықталды. Саңырауқұлаққақарсы белсенділік *Aspergillus terreus* және *Candida albicans* штамдары арқылы табылды. Зерттеу нәтижелері бойынша *Peltigera leucophlebia* (CD), *Hypogymnia sachalinensis* (CD) қыналарынан бөлінген үлгілер саңырауқұлаққақарсы, ал *Peltigera leucophlebia* (CD), *Peltigera aphthosa* (CD), *Melanohalea olivacea* (PDA, СД) бөлініп алынған саңырауқұлақтар микробқақарсы белсенділік көрсетті. Биологиялық

белсенділікті зерттеу нәтижесінде *Peltigera leucophlebia* (CD) бөлініп алынған саңырауқұлақ микробқа және саңырауқұлаққақарсы белсенділікке ие болды.

Кілт сөздер: қыналар, Магадан облысы, саңырауқұлақтар, микробқақарсы белсенділік, фунгальғақарсы белсенділік.

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Выделение грибов из лишайников Магаданской области и биологическая активность их ферментативных экстрактов

Цель данного исследования — выделить грибы из лишайников Магаданской области (Россия) и оценить их антимикробную и противогрибковую активность. Для исследования были отобраны 14 видов лишайников. Противомикробную активность определяли на граммположительных (*Staphylococcus aureus*) и граммотрицательных (*Escherichia coli*) бактериях. Противогрибковую активность выявляли с использованием штаммов микроскопических грибов *Aspergillus terreus* и *Candida albicans*. Согласно результатам исследования, образцы, выделенные из лишайников *Peltigera leucophlebia* (CD), *Hypogymnia sachalinensis* (CD), показали противомикробную активность, а у образцов из *Peltigera leucophlebia* (CD), *Peltigera aphthosa* (CD), *Melanohalea olivacea* (PDA, CD) наблюдалась антимикробная активность. В результате изучения биологической активности установлено, что гриб, выделенный из лишайника *Peltigera leucophlebia* (CD), обладает антимикробной и противогрибковой активностью.

Ключевые слова: лишайники, Магаданская область, грибы, антимикробная активность, антифунгальная активность.

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Anti-inflammatory activity of a dental gel based on *Origanum vulgare* raw material

Inflammatory and destructive diseases of parodontosis are one of the most complex and common forms of the teeth diseases of human population. Search of the herbal preparation with anti-inflammatory activity is a prospect way for development of new drugs on the base of local raw material. A prerequisite for this study has been the presence of a high antimicrobial and anti-caries activity of the essential oil of medicinal plant *Origanum vulgare.* The article presents for the first time the results on the anti-inflammatory activity of dental anti-caries gel with essential oil and ethanol extract of oregano. A sample of dental gel at a dose of 25 mg / kg has anti-inflammatory activity, which was expressed in a significant decrease by 41.4 % in the amount of inflammatory lymph in the abdominal teeth in rats compared to controls. The anti-inflammatory activity of this sample is comparable to the reference drug diclofenac sodium.

Keywords: gel, essential oil, ethanol extract, *Origanum vulgare*, anti-inflammatory activity.

Introduction

Inflammatory and destructive diseases of parodontosis are one of the most complex and common forms of pathology and the prime cause of tooth loss among the adult population, therefore, the development and implementation of new dosage forms for the treatment of inflammatory periodontal diseases is an urgent task.

The use of herbal preparations is a promising direction today [1–5] due to the fact that the bioactive substances of medicinal plants are more related to the human body in nature, they are easier to enter into the life process, have a wider spectrum of action and are active against strains of microorganisms and viruses. Therefore, they are recommended for the prevention and treatment of many chronic diseases, including inflammatory periodontal diseases [6].

According to literature review, essential oils and extracts of many plants are used for various dental diseases [7–17]. For example, against gingivitis — *Larix sibirica, Acorus calamus, Origanum vulgare, Cedrus libani*, and etc.; against stomatitis — plants from genera *Rosa, Salvia, Chamomilla, Eucalyptus*, etc. Applications of bee wax with essential oils are actively used. Thus, for the treatment of stomatitis and ulcer were observed the beneficial effects of waxes with application of *Rose, Citrus, Salvia, Lavandula* on the mucous membranes of the mouth and prosthetic field tissue.

Essential oil of *Salvia* is effective in the treatment of root pulpits — the acute inflammatory process dies out in the pulp, its transition to the chronic stage stops. In the case of inflammation of gums, a chewing gums and preparations in the form of rinds of plants from genus *Juniper* is also used. Besides, the following essential oils are effective for the treatment of the parodontosis: *Citrus limon, Citrus x sinensis, Syzygium*

aromaticum, Monarda didyma, Myrtus communis, Citrus x bergamia, Lavandula officinalis, Thymus serpyllum, Mentha piperita, Pogostemon cablin, and etc.

The pharmaceutical market offers a wide range of drugs applied in the local treatment of inflammatory periodontal diseases [18]. However, there are a few combination of drugs. In addition, the presence of side effects, sensitivity reactions, and the phenomenon of antibiotic resistance make it paramount to search for new treatments. A prerequisite for this study was the presence of a high antimicrobial and anti-caries activity of the essential oil of medicinal plant *Origanum vulgare* [19–22].

Experimental

Raw material. As a plant material, we used the aboveground part of *Origanum vulgare* L. (family *Lamiaceae*), collected in the vicinity of the Ridder town (the Eastern — Kazakhstan region) during the flowering phase, July — August, 2020 (Fig. 1).

Figure 1. Internal view of flowering plants of *Origanum vulgare*

Before extraction, fresh leaves and flowers were dried at temperature +22 – 25 °C, avoiding exposure to direct sunlight, for 10 days. The humidity of the herb of *O. vulgare* after drying was not more than 6.38 %.

For the preparation of antimicrobial dental gel, essential oil was isolated from oregano (*Origanum vulgare L.),* which was carried out by the method of hydrodistillation. EM yield — 0.7 %. The content of cymophenol in the oil reaches up to 85 %. A thick ethanol extract of dark green color with a pleasant smell and a yield of 6.2 % was also obtained. To obtain the gel, Na-CMC was used as a gel base, glycerin, essential oil, and oregano extract as an active pharmaceutical ingredient, glycerin as a plasticizer, a sweetener — saccharin, water for dissolution.

In order to obtain 100.0 grams of gel, the calculated volume of Na-CMC was placed in a beaker with a capacity of 500 ml and poured with cold purified water, stirred and left to swell for 15–20 minutes. Then the solution was stirred with the mixer turned on 50–100 rpm until fully dissolved. Afterwards, in a separate container, the extract of oregano was dissolved in a measured amount of glycerin, and then the calculated amount of essential oil of oregano and other substances were added dropwise. The prepared solution was added to the gel base with the mixer turned on at 100 rpm and stirred until a homogeneous mass was obtained.

Statistical processing of the results was conducted using the “Statistica 6.0” software package. The results are presented as “mean ± standard error of the mean”. Intergroup differences were assessed by the nonparametric Mann-Whitney U test. Differences were considered significant at the achieved level of significance $p < 0.05$.

Discussion

Screening of a dental gel for anti-inflammatory activity

The studies were carried out on 48 white rats of both sexes with a mass 210–220 g, which were divided into 8 groups of 6 animals each: 1–6 experimental groups — animals receiving dental gel at a dose of

25 mg/kg; 7 comparison groups — animals receiving the comparison drug diclofenac sodium, 8 control groups — animals receiving the solvent.

Acute exudative reaction (peritonitis) was caused by intra peritoneal injection of 1 % acetic acid solution in a volume of 1 ml per 100 g of rat body weight. After 3 hours, the animals were sacrificed, the abdominal cavity was opened, the exudate was collected and its volume was estimated [23]. The objects under study were examined at a dose of 25 mg / kg when administered orally in the form of starch mucus. The sodium diclofenac comparison drug was administered to animals intragastrically once at an effective dose of 8 mg/kg (ED_{50}). Control animals received an equal volume of starch mucus. The test objects were injected once in 1 hour before the introduction of a 1 % solution of acetic acid.

Anti-inflammatory activity was expressed as a percentage of the decrease in inflammatory exudiation in the abdomen of experienced rats compared to control rats.

The results of an anti-inflammatory activity study of samples of test gel and sodium diclofenac are illustrated in Table 1.

Table 1

Anti-inflammatory activity of studied samples

Name samples	Dose, mg/kg	Exudate amount, ml	% to control	Anti-inflammatory activity
Control	–	7.0± 0.6	100	-
Diclofenac sodium	8	4.4 ± 0.8*	37.1	62.9
Dental gel	25	4.1 ± 0.5*	41.4	58.6

Note. * — p <0.05 compared to control.

As a result of the experiment, a sample of dental gel at a dose of 25 mg/kg was found to have anti-inflammatory activity, resulting in a reliable decrease of 41.4 % corresponding to the amount of inflammatory exudiation in the abdomen in rats compared to control.

The anti-inflammatory activity of stomatological gel with essential oil and ethanol extract of common cholera is comparable to that of sodium diclofenac.

Conclusions

It has been established that the sample of new dental gel based on common saline in vivo experiments has a high level of anti-inflammatory activity.

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Origanum vulgare өсімдік шикізатына негізделген тіс гелінің қабынуғақарсы белсенділігі

Парадонтоздың қабыну және деструктивті аурулары — адам популяциясындағы тіс ауруларының ең күрделі және жалпы түрлерінің бірі. Қабынуғақарсы белсенділігі бар өсімдіктерді іздеу жергілікті өсімдік шикізатына негізделген дәрі-дәрмектерді әзірлеудің перспективалы бағыты болып табылады. Бұл зерттеудің алғышарты *Origanum vulgare* дәрілік өсімдігінің эфир майының жоғары микробқақарсы және кариескеқарсы белсенділігінің болуы. Мақалада алғаш рет эфир майы мен этанол орегано сығындысы бар тіс кариескеқарсы гельдің қабынуғақарсы белсенділігін зерттеу нәтижелері келтірілген. 25 мг/кг дозадағы тіс гелінің үлгісі қабынуғақарсы белсенділікке ие, ол егеуқұйрықтардың іш тістеріндегі бақылауды салыстырғанда қабыну лимфасының мөлшерін 41,4 %-ға едәуір төмендеткен. Бұл үлгінің қабынуғақарсы белсенділігі диклофенак натрийінің анықтамалық препаратымен салыстырылды.

Кілт сөздер: гель, эфир майы, этанол сығындысы, *Origanum vulgare*, қабынуғақарсы белсенділік.

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Противовоспалительная активность зубного геля на основе растительного сырья *Origanum vulgare*

Воспалительные и деструктивные заболевания парадонтоза — одни из наиболее комплексных и общих форм зубных заболеваний человеческой популяции. Поиск растительных средств с антивоспалительной активностью является перспективным направлением для разработки лекарств на основе местного растительного сырья. Предпосылкой для данного исследования явилось наличие высокой антимикробной и противокариесной активности эфирного масла лекарственного растения *Origanum vulgare*. В статье впервые представлены результаты по изучению противовоспалительной активности зубного противокариесного геля с эфирным маслом и этанольным экстрактом душицы. Образец зубного геля в дозе 25 мг/кг обладает противовоспалительной активностью, которая выражалась в значительном снижении на 41,4 % количества воспалительной лимфы в брюшных зубах у крыс по сравнению с контролем. Противовоспалительная активность этого образца сопоставима с эталонным препаратом «Диклофенак натрия».

Ключевые слова: гель, эфирное масло, этанольный экстракт, *Origanum vulgare*, противовоспалительная активность.

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Investigation of the effect of agomelatine on cellular and humoral immunity in mice

Agomelatine has primarily been described as an antidepressant drug for laborartory animals. In the present study, agomelatine showed an overall stimulatory effect on the specific, as well as on non-specific immune functions of mice. Stimulatory effects were observed at 25 mg/kg. Administration of agomelatine in human beings is simple as it is available in the dosage form. The general immunomodulatory effects of agomelatine need further investigation for its use in the cases of clinical immunostimulation and in order to understand the precise mechanism of action for the stimulatory effect of the drug. The present result suggests that agomelatine may stimulate both the cellular and humoral immunity. Effects were evaluated at different doses of 1, 5 and 25 mg/kg using various parameters such as effect on hematological parameters. The results were further utilized to evaluate the activity on the cellular and humoral branches of immunity.

Keywords: agomelatine, cellular immunity, humoral immunity, immunostimulation, antidepressant, hematology, 5HT2 antagonist, neutrophil adhesion test.

Introduction

The search for new antidepressants has led to the discovery and development of the agomelatine (Valdoxan). In February, 2009, the agomelatine, a novel antidepressant with an innovative pharmacological profile, had received a marketing authorization by European Medicines Agency for the treatment of major depressive disorders [1–3]. The novel melatonergic agonist/5HT2 antagonist agomelatine displays robust antidepressant properties [4]. Agomelatine is a potent melatonin receptor agonist drug that strongly binds to and stimulates the activity of melatonin MT1 and MT2 receptors which are localized within the SCN [5]. Agomelatine has also been reported to resynchronize circadian rhythms and has anxiolytic properties in animal models. Besides its antidepressant efficacy, it may be helpful in sleep promotion. Agomelatine is an acetamide naphthalene analog of melatonin [2]. Melatonin plays a major role in the regulation of body temperature and consolidation of sleep. Melatonin is involved in the regulation of both cellular and humoral immune responses [6]. Immunological parameters included humoral and cell-mediated immune responses to sheep red blood cells (SRBC) and TLC, DLC.

Materials and Methods

Animals

Inbred Swiss albino mice (6–8 weeks) of either sex, weighing about 18–20 g, born and reared in the animal house of College of Pharmacy, IPS Academy, Indore, M.P. from a stock originally purchased from Govt. Veterinary College, MHOW, M.P., were used for the study. Animals were placed randomly in polypropylene cages (five/cage) with husk as bedding. Standard laboratory condition of temperature 25±2 °C, relative humidity 55±5 %, and 12h/12h light/dark cycle were maintained throughout the experiment. Animals were kept for 1 week to acclimatize to laboratory conditions before starting the experiment; they were given free access to water and standard mice food except during experimentation.

Drug Solution

Agomelatine — a melatonin receptor agonist, (Sigma Aldrich, USA) was dissolved in hydroxyethylcellulose 1 %, and melatonin, N-acetyl-5-methoxytryptamine, (Aristo Pharma, Daman, India) was dissolved in ethanol. The employed doses of agomelatine (1 mg/kg, 5 mg/kg, 25 mg/kg, i.p.) and melatonin (20 mg/kg, 40 mg/kg, 60 mg/kg, i.p.) were selected on the basis of our preliminary investigations and previous reports. Normal saline was applied as vehicle. All other chemicals were of analytical grade.

Experimental design

Grouping

Using Swiss albino mice of either sex, 7 groups were formed for the experiments (n = 5) fashioned as: Group I: control, normal saline; Group II: 20 mg/kg, MLT *i.p.*; Group III: 40 mg/kg, MLT, *i.p.*; Group IV: 60 mg/kg MLT, *i.p.*; Group V: 1 mg/kg, AGO, *i.p.*; Group VI: 5 mg/kg AGO, *i.p.*; Group VII: 25 mg/kg AGO, *i.p.*

Treatments

Determination of agomelatine effect on hematological parameters

Groups I–VII were pre-treated with saline and drug (Ago and Mlt) for 7 days, respectively. At the end of treatment, schedule blood was collected from retro-orbital puncture and parameters such as total RBC count, total WBC count, hemoglobin conten, and was counted with automatic blood cell counter. Differential count (Leishman's stain), were recorded [7, 8].

Assessment of cellular immune functions

Neutrophil adhesion test

Swiss albino mice in Groups I–VII were administered by Ago and Mlt and saline for 14 days in their respective groups. Adhesion of neutrophil to nylon fibers was determined using a modification of adherence assay. Briefly, 1cc tuberculin syringe was uniformly packed with 65 mg to a volume of 0.4 cc. This assemble was pre-warmed to 37 °C in an incubator. Blood samples were collected from mice (after 14 days of drug treatment) by retro-orbital puncture and 1 mL added to tuberculin syringe and allowed to flow through the fibers for 2 min with the effluent collected in a test tube. Percent of neutrophil adherence was calculated based on cell counts performed before and after blood sample was passed through the syringes. Cell count was determined applying automated blood cell counter. The neutrophil adherence was thus determined as a percentage using the formula

$$\% \text{ Neutrophil Adherence} = \frac{N_u - N_t}{N_u} \times 100,$$

where N_u is neutrophil count in untreated blood, N_t is neutrophil count of fiber treated blood [9, 18].

Determination of delayed-type hypersensitivity (DTH) response

The mice of group I–VII were sensitized to antigen by injecting SRBC (0.5×10^9 cells/mL/100 g suspended in saline solution, i.v.) and after 5 days they were antigenically challenged by injecting SRBC (10^8 cells/20 µl) into sub-planter region of hind paw. Increase in the thickness of paw was measured 24 h later with digital Vernier caliper and cell-mediated immunity expressed as difference in paw thickness [5, 9].

Assessment of humoral immune function

Serum antibody titre

After studying cell-mediated immune response, mice were lightly anesthetized with ether on 7th day and blood was withdrawn from the retro-orbital plexus. The serum was separated by centrifuging the blood at 3000 g. Serial two-fold dilution of serum was made in 25 µl of saline in 96-well microtitre plate and mixed with 1 % of SRBC (0.025×10^9 cells) in saline. After mixing, plate was kept at room temperature for 2 h. The value of antibody titre was assigned to the highest serum dilution showing visible hemagglutination [10–19].

Result

Determination of effect of agomelatine on neutrophil adhesion test

Incubation of blood with nylon fibres produced a decrease in the neutrophil counts due to adhesion of neutrophils to the fibers at a dose of 60 mg/kg of Melatonin and at a dose of 25 mg/kg of Agomelatine. There was also a rise in neutrophil count of untreated blood of all treated animals (Tab. 1).

Table 1

Effect of Agomelatine on Neutrophil Adhesion Test

No.	Groups	Neutrophil Index		% Neutrophil Adhesion
		UTB	FTB	
1	Control	1.6±0.21	1.3±0.16	17.98±1.19
2	MLT 60 mg/kg	7.4±0.95	2.8±0.08	57.97±8.45[a]
3	AGO 25 mg/kg	5.2±2.5	2.62±0.5	48.73±7.6[b]

Data represents mean±SEM; (n=5), values are compared with control animals, [a]p<0.01; Melatonin, [b]p<0.05; *Agomelatine*

Determination of effect of agomelatine on humoral immune function

In hemagglutination titre doses of Melatonin 20, 40, and 60 mg/kg showed titre values of 972.8±307.2, 1075±399.9 and 1638±250.8, and doses of agomelatine 1, 5, and 25 mg/kg showed titre values of 486.4±153.6, 512±140.2, and 1280±256, respectively, while the titre values of control (Group I) was 277.3±51.38, thus demonstrating increase in the titre values of all treated groups (Table 2).

Table 2

Effect of Agomelatine on Humoral Immune Function

No.	Groups	Titre Value
1	Control	277.3±51.38
2	MLT 60 mg/kg	1638±250.8[a]
3	AGO 25 mg/kg	1280±256.0[b]
Data represents mean±SEM; (n=5), values are compared with control animals, [a]p<0.01; Melatonin, [b]p<0.05; *agomelatine*		

Determination of agomelatine effect on hematological parameters

Differential leucocyte count

The percentage of peripheral blood neutrophils was significantly increased at doses of Mlt 20, 40, and 60 mg/kg and Ago 1, 5, and 25 mg/kg. On the other hand, the percentage of circulating peripheral blood lymphocytes was considerably increased at doses of Mlt 20, 40, and 60 mg/kg and decreased at doses of Ago 1, 5, and 25 mg/kg. No significant changes in other parameters were seen in all indicated doses (Table 3).

Table 3

Effect of agomelatine on DLC

No.	Groups	Parameters				
		Neutrophils (%)	Eosinophils (%)	Basophils (%)	Lymphocytes (%)	Monocytes (%)
1	Control	28.80±0.58	2.6±0.67	0.0	65.80±1.42	0.60±0.4
2	Mlt 20 mg/kg	30.40±0.51	2.6±0.40	0.0	66.40±1.36	0.20±0.20
3	Mlt 40 mg/kg	31.60±1.07	0.2±0.44	0.0	68.80±1.02	0.0±0.0
4	Mlt 60 mg/kg	32.80±0.86[a]	1.2±0.37	0.0	69.80±0.37	0.40±0.24
5	Ago 1 mg/kg	29.80±0.86	2.8±0.37	0.0	67.40±1.24	0.20±0.20
6	Ago 5 mg/kg	31.60±1.03	0.2±0.31	0.0	68.60±1.50	0.20±0.20
7	Ago 25 mg/kg	32.60±0.81[b]	1.2±0.60	0.0	69.20±0.58	0.20±0.20
Data represents mean ± SEM; (n=5), values are compared with control animals, [a]p<0.05; Melatonin, [b]p<0.05; *agomelatine*						

RBC Count, WBC Count and Haemoglobin content

Administration of agomelatine was found to increase the total RBC count (p<0.01) at a dose of 25 mg/kg, but the same was unaffected at lower doses of 1 and 5 mg/kg. There was no considerable change in the Hb content at all three doses, whereas total WBC count illustrated a rise (p<0.05) at 25 mg/kg dose (Table 4).

Table 4

Effect of agomelatine on RBC Count, WBC Count and Haemoglobin content

No.	Groups	Parameters		
		RBC Count (10^{12}/L)	WBC Count (10^{12}/L)	Hb (%)
1	Control	8.60±0.33	6.02±1.0	13.38±0.40
2	Mlt 20 mg/kg	9.20±0.17	8.20±8.5	15.76±0.71
3	Mlt 40 mg/kg	10.04±0.67	9.18±9.7	16.06±0.41
4	Mlt 60 mg/kg	11.15±0.64[a]	10.08±5.8[b]	17.70±0.60[a]
5	Ago 1 mg/kg	8.61±0.98	6.08±9.7	13.56±0.41
6	Ago 5 mg/kg	9.13±0.42	6.1±9.2	13.04±1.07
7	Ago 25 mg/kg	11.10±0.64[a]	9.8±5.6[b]	15.82±0.79[ns]
Values are mean±SEM; (n=6), [a]P<0.01, highly significant; [b]P<0.05, significant; [ns]P>0.05, non-significant (compared to respective control)				

Determination of agomelatine effect on delayed type hypersensitivity response

Melatonin (60 mg/kg) and agomelatine (25 mg/kg) produced a significant, dose-related increase in DTH reactivity of mice. The edema achieved a peak at 48 h comparing to control at 48 h (Table 5).

Table 5

Effect of agomelatine on delayed type hypersensitivity response

No.	Groups	Paw difference (mm)			
		0 hr	2 hr	24 hr	48 hr
1	Control	0.89±0.18	1.59±0.15	1.79±0.14	2.58±0.20
2	Mlt 20 mg/kg	0.96±0.24	1.80±0.22	2.00±0.19	2.78±0.33
3	Mlt 40 mg/kg	1.30±0.13	1.84±0.06	2.04±0.10	2.95±0.43[a]
4	Mlt 60 mg/kg	1.53±0.34	2.50±0.11	2.61±0.10	3.53±0.47[b]
5	Ago 1 mg/kg	0.89±0.18	1.59±0.15	1.79±0.14	2.85±0.19
6	Ago 5 mg/kg	1.30±0.28	2.00±0.26	2.21±0.22	3.03±0.19[c]
7	Ago 25 mg/kg	1.08±0.31	2.37±0.18	2.60±0.20	3.05±0.12[b]

Effect of Mlt (20, 40 and 60 mg/kg, i.p.) and Ago (1, 5 and 25 mg/kg, i.p.) on SRBC (0.5×10^9/ml/100 g) induced DTH at 0, 2, 24 and 48 h. Each value represents the mean±SEM of five observations. [a]$p<0.05$; [b]$p<0.0001$; Melatonin, [c]$p<0.01$; *agomelatine*

Discussion

Essentially, agomelatine has been determined as the antidepressant drug for laboratory animals. In this study, agomelatine showed an overall stimulatory effect on the specific and non-specific immune functions of mice. Stimulatory effects were observed at 25 mg/kg. Drug at this dose increased cell counts indicating its stimulatory effect on hematopoietic cells. Overall, it was concluded that 25 mg/kg is the optimum dose for mice. Thus, 25 mg/kg dose of Agomelatine seems to be pharmacologically effective dose for mouse as far as immunomodulatory effects are concerned. The response at lower dose i. e. 1 mg/kg, was either identical to control group animals or mildly stimulated comparing to control animals.

Immune activation is an effective and protective approach for treating infectious diseases. Among the leukocytes, only antigen specific lymphocytes possessed the diversity, specificity, memory, and self-recognition indicating an adaptive immune response. It was observed that agomelatine caused significant increase in TLC and lymphocyte population designating the presence of its immunological effects.

Boundary of neutrophil from the blood stream requires a firm adhesion which is mediated through the interaction of the β_2 integrins present on the neutrophil. The β_2 integrins stored in the cell granules and up-regulated for a firm adhesion. In this study, adherence of neutrophil to the nylon fiber was increased in the treated group comparing to the control.

DTH is a part of the process of immunity causing many intercellular infections, microorganisms, especially chronic diseases as tuberculosis. DTH requires the specific recognition of a given antigen by activated T lymphocytes, which subsequently proliferate and release cytokines. These, in turn, increase vascular permeability, induce vasodilation, macrophage accumulation and activation, promoting increased phagocytic activity and concentration of lytic enzymes for more effective killing. In the present study, SRBC was used to elicit hypersensitivity reaction of mice. It was found that agomelatine potentiated the DTH reaction induced by SRBC at 10^8 cells. Increase in DTH reaction of mice in response to thymus-dependent antigen revealed the stimulatory effect of agomelatine on T lymphocytes and accessory cell types for the expression of reaction.

The humoral immunity involves interaction of B cells with the antigen and their subsequent proliferation and differentiation into antibody-secreting plasma cells. Antibody functions as the effector of the humoral response by binding to antigen and neutralizing it or facilitating its elimination by cross-linking to form clusters that are ingested by phagocytic cells. To evaluate the effect of *Agomelatine* on humoral response, its influence was tested on sheep erythrocyte specific hemagglutination antibody titre in mice. It was found that agomelatine enhances the production of circulating antibody titre. This indicates the enhanced responsiveness of macrophages and T and B lymphocytes subsets involved in antibody synthesis.

Conclusions

Reviewing all the data presently available on agomelatine, a stimulatory effect was noted. This stimulatory effect is associated with increased cytokine production, enhanced phagocytosis and increased natural

killer cell activity. The results of this study propose that agomelatine may stimulate both the cellular and humoral immunity. Further investigation is suggested for the precise mechanism of action for the stimulatory effect of the drug. Effects were evaluated at different doses of 1, 5, and 25 mg/kg using various parameters as an effect on hematological parameters. The results were further utilized to evaluate the activity on the cellular and humoral branches of immunity. Its reported immunomodulatory effects deserve further investigation for its use in the cases of clinical immunostimulation. The drug can be evaluated for its consequence on stress induced immunomodulation.

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Вайшали Д. Нафаде, Гаураф Парихар, Д.К. Джаин, Атул Р. Бендале

Тышқандардағы агомелатиннің жасушалық және гуморальдық иммунитетке әсерін зерттеу

Агомелатин алғаш рет зертханалық жануарларда антидепрессант ретінде сипатталған. Осы зерттеуде агомелатин тышқандардағы нақты, сондай-ақ спецификалық емес иммундық функцияларға жалпы қоздырушы әсерін көрсетті. Агомелатинді адамға енгізу қарапайым, өйткені ол дәрілік түр түрінде оңай қолжетімді. Оның жалпы иммуномодуляциялық әсері клиникалық иммунокүшейту жағдайында қолдану үшін одан әрі зерттеуді қажет етеді. Алынған нәтижелерді агомелатин жасушалық және гуморальды иммунитетті қоздыруы мүмкін деп болжанған. Препараттың қоздырушы әсері үшін нақты әсер ету механизмін түсінуге қосымша эксперименттер қажет. Әсерлер гематологиялық параметрлерге әсер ету сияқты әртүрлі параметрлерді қолдана отырып, 1,5 және 25 мг/кг әртүрлі дозаларда бағаланды. Нәтижелер иммунитеттің жасушалық және гуморальды тармақтарындағы белсенділікті бағалау үшін қосымша қолданылды.

Кілт сөздер: агомелатин, жасушалық иммунитет, гуморальдық иммунитет, иммунокүшейту, антидепрессант, гематология, антагонист 5ht2, нейтрофилдердің адгезиясына тест.

Вайшали Д. Нафаде, Гаураф Парихар, Д.К. Джаин, Атул Р. Бендале

Исследование влияния агомелатина на клеточный и гуморальный иммунитет у мышей

Агомелатин впервые был описан как антидепрессант у лабораторных животных. В настоящем исследовании агомелатин показал общее стимулирующее действие на специфические и неспецифические иммунные функции у мышей. Стимулирующие эффекты наблюдались при дозе 25 мг/кг. Введение агомелатина человеку является простым, поскольку он доступен в виде лекарственной формы. Его общие иммуномодулирующие эффекты требуют дальнейшего изучения для использования в случаях клинической иммуностимуляции. Полученные результаты позволяют предположить, что агомелатин может стимулировать как клеточный, так и гуморальный иммунитет. Необходимы дальнейшие эксперименты, чтобы понять точный механизм действия для стимулирующего эффекта препарата. Эффекты оценивали при различных дозах 1, 5 и 25 мг/кг с использованием различных параметров, таких как влияние на гематологические параметры. Результаты были дополнительно применены при оценке активности на клеточных и гуморальных ветвях иммунитета.

Ключевые слова: агомелатин, клеточный иммунитет, гуморальный иммунитет, иммуностимуляция, антидепрессант, гематология, антагонист 5HT2, тест на адгезию нейтрофилов.

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Effects of *Rhodiola semenowii* extract on hematological parameters in experimental hypothyreosis

Thyroid pathology has a leading position in clinical endocrinology. Diseases of the thyroid gland in terms of prevalence are comparable with diabetes mellitus, and far ahead of other endocrine disorders. Current treatment approaches of hypothyroidism are rarely based on the pathogenesis, and are reduced to hormone replacement therapy. The purpose of this study is to determine the general hematological parameters after correction of experimental hypothyroidism with an extract of the root of the plant *R. semenowii* both alone and in combination with potassium iodide. As a result of the study, we found that in the experimental treatment of hypothyroidism, the extract of the root of *R. semenowii* B. with a predominant content of rhodioflavonoside has a pronounced therapeutic effect, expressed in the normalization of the level of pituitary and thyroid hormones. The obtained results indicate the absence of toxic and damaging effects such as activation and inhibition of hematopoiesis after enteral administration of the root extract of *R. semenowii*.

Keywords: hematology, hypothyroidism, thyroid, *Rhodiola semenowii*, extract, phytopreparation, medicinal plants, root.

Introduction

Thyroid pathology has a prime position in clinical endocrinology. Diseases of the thyroid gland in terms of prevalence share the priority with diabetes mellitus, far ahead of other endocrine disorders. Thyroid hormones (THs) that are synthesized and released by the thyroid are essential for normal growth, development, and metabolism of organisms, as well as energy homeostasis. Even small changes or an imbalance in thyroid homeostasis may adversely affect human health [1].

The methods of treatment are associated with the prescription of medications containing thyroid hormones; patients often do not adhere to treatment regimens. If the treatment is not adequate, then the patients might develop ischemic heart disease, disorders in reproductive system, and psychological disorders. With a high dose of hormones, myocardial dystrophy might develop and there might be changes in mineral composition of bone tissue [2]. Currently, the greatest prevalence and clinical significance are primary hypothyroidism caused by a defect in the biosynthesis of hormones T4 (and T3) due to disorders in the thyroid gland. Its frequency among the population is high: overt hypothyroidism — 0.2–2.0 %, subclinical — approximately 7–10 % among women and men 2–3 %. In the group of older women, the prevalence of all forms of hypothyroidism can reach 12 % or more (sporadic goiter). These data suggest that hypothyroidism is one of the most common endocrine diseases. Hypothyroidism might cause the development of complications from the cardiovascular, digestive, reproductive, and central nervous systems, and in case of decompensation, it might lead to death [3]. With a decrease in the function of the thyroid gland, changes in the hematopoietic system might occur [4]. Currently, it has been established that a deficiency of thyroid hormones leads to a qualitative and quantitative impairment of erythropoiesis [5]. It has been proven that low levels of thyroxine and thyroid teranine lead to impaired erythropoiesis, including a direct relationship between the erycitic index and the content of thyroid hormones in the blood [6]. Hypothyroidism has various effects on hematopoiesis, peripheral blood cells, and the coagulation system. 25–50 % of patients with hypothyroidism suffer from anemia and concomitant diseases that develop with dysfunction of the thyroid gland [7]. The protocol for the treatment of thyroid disorders has not changed over the past 15 years, and the new offered drugs are not effective enough [8].

Herbal medicines, acting systemically on the body, regulate the functions of various interconnected systems and organs. They have almost no side effects, and can be used both for treatment and the prevention of various diseases [9]. Research illustrates that *Rhodiola semenowii* Boriss. stimulates the body's immune response, enhances cell proliferation in the central and peripheral organs of the immune system and weakens

inflammatory damage in various diseases, regulating the differentiation of immune cells, activating inflammatory signaling pathways and releasing inflammatory factors [10]. Since stress factors with low immunity are the main causes of thyroid diseases, our main task is to conduct an experimental study by correcting (treating) primary hypothyroidism using an extract of the plant *R. semenowii*.

Experimental

The study material was the extract of the root of the plant *R. semenowii* both alone and in combination with potassium iodide. The experimental study was carried out in two stages on nonlinear white male rats (50 individuals) weighing 200–250 g. Animals were kept in cages in groups of 10 individuals. There were 4 groups of animals in total. Wood sawdust was used as a bedding. The air temperature in the premises of the vivarium was maintained in the range of 18–200 °C with a relative humidity of 60–70 %. The animals were kept under standard conditions on a vivarium diet. Animals were monitored daily applying an open field behavioral test and weighed. All experimental studies were conducted in accordance with the rules set out in the Guidelines for preclinical, biomedical, and clinical research in Kazakhstan (July 25, 2007, No. 442).

At the first stage, all animals were divided into 2 main groups: 1st group — control, 2nd group — experimental hypothyroidism. The first group of animals received oral water (placebo) daily for 15 days. To simulate experimental hypothyroidism in the second group, the pharmaceutical drug "Mercazolil Health" ("Health" pharmaceutical company, Ukraine) was used. Daily mercazolil was administered orally at the rate of 2.5 mg per 100 g of body weight for 15 days [11]. After creating an experimental model of hypothyroidism, a control study of the levels of TSH, free T4, free T3, and TG in the blood serum was carried out to confirm the development of the hypothyroidism state. At the second stage of the research, animals of the second group with confirmed hypothyroidism were divided into 3 subgroups: subgroup 2a — hypothyroidism model without treatment; subgroup 2b — correction of hypothyroidism with an extract of *R. semenowii* root by enteral administration of the extract at the rate of 2.5 mg per 100 g of body weight animal for 28 days; and subgroup 2c — correction of hypothyroidism with an extract of the root of *R. semenowii* by enteral administration of the extract at the rate of 2.5 mg per 100 g of animal body weight in combination with potassium iodide at the rate of 1 μg per 100 g of body weight for 28 days.

At the end of the experiment, peripheral blood was taken from all animals for hematological and immunochemical studies in vacutainers containing the K3-EDTA anticoagulant and a coagulation activator with a separating gel. Hematological tests were carried out on an automatic hematological analyzer Sysmex XS-550-i (Japan). Levels of TSH, free T4, free T3, and TG in blood serum to confirm the hypothyroid state were conducted on an automatic immunochemiluminescence analyzer "Immulite 2000XPi" Siemens (Germany). The obtained data were analyzed applying statistical methods in the Statistica-6.0 program. The significance of the arithmetic mean differences was assessed using the Student's t-test. P values ≤ 0.05 were considered statistically significant.

Results and Discussion

According to the available chemical composition data, in the root extract of plant *R. semenowii* substances such as flavonoids (74.8 %), coumarins (11.7 %), phenolic acids (6.1 %), and polysaccharides (7.4 %) were identified. The main biologically active component of flavonoids was rhodioflavonoside. In the course of this study, the purpose was to determine changes in the general hematological parameters after correction of experimental hypothyroidism with an extract of the root of the plant *R. semenowii* both alone and in combination with potassium iodide. The results of the study of the comparative assessment of the hematological parameters of the observed groups are presented in Table 1.

In the Table, there were statistically significant differences ($p<0.001$) between the hematological parameters of experimental animals, including the total number of leukocytes, the total number of erythrocytes, hemoglobin level, and the total number of platelets, but they were all within the physiological norm. Based on analysis of the hematological parameters of animals in groups 1, 2a, 2b, and 2c the following data was illustrated: the hemoglobin content in animals with experimental hypothyroidism was 160.60±4.47 g/l versus 146.00±4.06 g/l in the control. Here, small relative changes can be noticed. When counting the number of red blood cells $7.06\pm0.58\times10^{12}$/l, leukocytes $7.28\pm1.13\times10^{9}$/l, and platelets $475.41\pm49.47\times10^{3}$/l in animals of subgroup 2a with experimental hypothyroidism, it was found that the arithmetic mean values of the amount of the above elements are normal and do not differ significantly from those of clinically healthy animals of the 1st control group. The percentage of different types of leukocytes in animals of subgroup 2a did not change considerably in comparison with the leukogram of control animals.

Small relative changes were also observed only in the content of lymphocytes in animals of subgroup 2a with experimental hypothyroidism 48.48±2.76 % versus 40.40±2.30 % in the control group.

Table 1

Hematological parameters of the blood of rats of the intact group, with hypothyroidism and experimental treatment with the extract *R. semenowii* B. both alone and in combination with potassium iodide

Indicator name, unit of measurement	International abbreviation	Control group (group 1)	Experimental Hypothyroidism in no cure (group 2a)	Correction with extract *R. semenowii* (group 2b)	Correction with extract *R. semenowii* in combination with potassium iodide (group 2c)
Total number of Leukocytes, 10^9/l	WBC	6.22±0.44	7.28±1.13	7.64±1.19	6.73±1.04
Total Red Blood Cell Count, 10^{12}/l	RBC	6.29±0.52	7.08±0,58	7.81±0,65	8.28± 0.68
Hemoglobin level, g/l	HGB	146.00±4.06	160.60±4.47*	157.39±4.38	154.24±4.29
Total platelet count, 10^3/l	PLT	413.40±43.02	475.41±49.47	570.49±59.3	599.02±62.34
Absolute neutrophil count 10^9/l	Neut	3.06±0.41	3.03±0.54	3.46±0.86	2.55±0.80
Absolute lymphocyte count 10^9/l	Lymph	2.51±0.14	3.52±0.51	3.53±0.72	3.63±0.60
Absolute content of monocytes 10^9/l	Mono	0.47±0.12	0.52±0.23	0.49±0.13	0.26±0.04
Absolute eosinophil content 10^9/l	Eos	0.16±0.05	0.19±0.06	0.12±0.08	0,41±0.07***
The absolute content of basophils 10^9/l	Baso	0.3±0.01	0.20±0.02	0.04±0.01	0.10±0.05
The relative content of neutrophils %	Neut	49.00±3.60	41.58±4.66	45.17±7.44**	37.57±7.30***
The relative content of lymphocytes%	Lymph	40.40±2.30	48.48±2.76*	46.20±6.53**	54.20±6.57
The relative content of monocytes %	Mono	7.56±1.77	7.00±2.00	6.56±1.86	6.16±1.35
The relative content of eosinophils %	Eos	2.55±0.96	2.59±0.90	1.60±1.14	1.60±0.89
The relative content of basophils %	Baso	0.49±0.05	0.35±0.37	0.47±0.09	0.47±0.01

Note. * — statistically significant changes compared to hypothyroidism without treatment (p≤0.001); ** — statistically significant changes versus correction *R. semenowii* on my own (p≤0.001); *** statistically significant changes versus correction *R. semenowii* with the addition of potassium iodide

At the second stage of the study, after the application of the extract of *R. semenowii*, correcting hypothyroidism, alone and in combination with potassium iodide, the following picture was observed: the hemoglobin level in subgroups 2b and 2c did not demonstrate changes. The number of leukocytes showed insignificant changes in subgroup 2b (7.64±1.19×10^9/L) compared to subgroup 2a, while in subgroup 2c it did not show any considerable changes. The level of erythrocytes was considerably increased in subgroup 2c (8.31±0.68×10^9/L), which indicates the restoration of erythropoiesis. The number of platelets in subgroup 2b was 570.49±59.3×10^3/l, and in subgroup 2c — 599.02±62.34×10^3/l. There are no significant changes in this parameter.

According to the results of some researchers [11–13] on the study of blood parameters in pathologies of the thyroid gland, the number of erythrocytes in simulated hypothyroidism decreases. In addition, on this background, the hemoglobin content decreases by 4.65 % in hypothyroid animals which leads to the development of anemia [14]. In our study, evaluation of the hemoglobin content in animals with hypothyroidism, in comparison with healthy animals, did not detect any significant changes. When calculating the number of erythrocytes, leukocytes, and platelets in animals with hypothyroidism, a number of authors [11–14] designated that the average values of the named, shaped elements were within the norm range, not significantly differing from similar indicators of clinically healthy rats, which is consistent with the results of this study [12]. In studies of experimental hypothyroidism, when assessing the rate of erythropoiesis, it was found that mercazolil inhibits the maturation of erythrocytes [13]. However, with short-term modeling of the hypothyroid state, the function of erythropoiesis is preserved.

When assessing the biological effects of iodine-containing preparations in accordance with researchers [11], the number of erythrocytes in individuals receiving “iodovet” increased, in relation to the group with hypothyroidism, by 8 %, and the hemoglobin level — by 2.7 %, which indicates the restoration of erythropoiesis [14]. When assessing hematological parameters, the total number of leukocytes and platelets in the compared groups did not change significantly. The studied iodine-containing diets contributed to the restoration of the level of blood cells [12]. In hormone replacement therapy with thymazole, stimulation of

erythropoiesis takes place due to an increase in the production of erythropoietin, but the actual hematological changes after reaching euthyroidism are not eliminated [13]. The administration of levothyroxine in hypothyroidism contributes to the correction of hemogram parameters and the acceleration of iron metabolism in the body of animals. In addition, when using thyroid hormones in hypothyroidism therapies, it was shown that an increase in animal body weight reduced the effectiveness of treatment. Good therapy results were obtained in microcytosis, iron deficiency, hypochromic anemias [11].

Conclusions

As a result of the study, it was identified that in the experimental treatment of hypothyroidism, an extract of the root of *R. semenowii* with a predominant content of rhodioflavonoside (up to 70 %) has a pronounced therapeutic effect, expressed in the normalization of the level of pituitary and thyroid hormones. Furthemore, the obtained data indicate the absence of toxic and damaging effects such as activation and inhibition of hematopoiesis after enteral administration of the root extract of *R. semenowii B.* Based on this, an extract of the root of *R. semenowii* with a predominant content of rhodioflavonoside (up to 70 %) in combination with potassium iodide is recommended for further extended study as a means of correcting pathological conditions associated with a decrease in thyroid function.

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Rhodiola semenowii сығындысының эксперименттік гипертериоздағы гематологиялық көрсеткіштерге әсері

Қалқанша безінің патологиясы клиникалық эндокринологияда маңызды рөл атқарады. Қалқанша безінің аурулары таралуы бойынша басқа эндокриндік ауытқулардан гөрі қант диабетімен бірдей басымдықты көрсетеді. Қазіргі таңда қолданылатын гипотиреозды емдеу тәсілдері патогенезге тәуелді болмайды және гормонды алмастыру терапиясына әкеледі. Осы зерттеуді орындау барысында қойылған міндет — *R. semenowii* өсімдігінің тамырын жеке және калий йодидімен қосылған сығындысын гипотиреозды емдеуге қарсы қолдана отырып, оның жалпы гематологиялық көрсеткіштерін анықтау. Зерттеу материалы *R. semenowii* өсімдігінің тамырының сығындысы. Осылайша жүргізілген зерттеулердің нәтижесі көрсеткендей, *R. semenowii* өсімдігінің тамырынан жасалған сығынды тәжірибелі гипотиреозды өздігінен немесе калий йодид қосылған сығындысы болса да жақсы ықпал ететіндігі байқалды. *R. semenowii* өсімдігінің тамырының сығындысы қалқанша безі мен гипофиздің гормондар деңгейін қалыпқа келтіреді. Сонымен алынған нәтижелердің сараптамасына сүйенсек, *R. semenowii* өсімдігінің тамырының сығындысын ішке ауыз арқылы енгізгенде гемопоезға ешқандай зиянды ықпалының жоқтығы байқалды.

Кілт сөздер: гематология, гипертериоз, қалқанша без, *Rhodiola semenowii*, сығынды, фитопрепарат, дәрілік өсімдік, тамыр.

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Влияние экстракта *Rhodiola semenowii* на гематологические показатели при экспериментальном гипертериозе

Патология щитовидной железы занимает лидирующую позицию в клинической эндокринологии. По встречаемости нарушения щитовидной железы сравнимы с сахарным диабетом, таким образом, они намного опережают другие эндокринные заболевания. В настоящее время принципы, которых придерживаются при коррекции гипотиреоза, практически не учитывают патогенез заболевания и, в основном, включают заместительную гормональную терапию. В ходе выполнения данного исследования была поставлена задача — определить общие гематологические показатели после коррекции экспериментального гипотиреоза экстрактом корня растения *R. semenowii*, как самостоятельного, так и в сочетании с калием йодида. Материалом исследования послужил экстракт корня растения *R. semenowii*, как самостоятельно, так и в сочетании с калием йодида. В результате проведенных исследований было установлено, что в экспериментальном лечении гипотиреоза экстракт корня *R. semenowii* оказывает выраженный терапевтический эффект, проявляющийся в нормализации уровня гормонов гипофиза и щитовидной железы. Полученные данные свидетельствуют об отсутствии токсических и повреждающих эффектов в виде активации/угнетения гемопоэза при энтеральном введении экстракта корня *R. semenowii*.

Ключевые слова: гематология, гипертериоз, щитовидная железа, *Rhodiola semenowii*, экстракт, фитопрепарат, лекарственное растение, корень.

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Neurological symptoms and complications of COVID-19. Minireview

Since the first official case of COVID-19 in China in December 2019, researchers have been trying to uncover the mechanism of action of the severe acute respiratory syndrome Coronavirus 2 (SARS-CoV-2), which attacks several organs in addition to the lungs and causes circulatory changes that can lead to death not only because of lung failure but also failure of other organs. The aim of this study is to find out the neurological consequences of COVID-19. A systematic review of the literature was concretized by mobilizing the descriptors: "SARS-CoV-2", "coronavirus infections" and "Neurological Consequences". Although the effects of SARS-CoV-2 on the lung are exemplary and frightening, the long-term effects on the nervous system may be greater and even more overwhelming, as the regeneration of nerve tissue is difficult and can lead to general disability, as the nervous system coordinates the functions of the entire body. Considered studies point out the presence of various injuries (mild or severe) to central nervous system because of COVID-19 infection. It can be said that the studies all agree on the possibility of existing neurological sequelae and a majority emphasize on the need for further investigation.

Keywords: coronavirus, SARS-CoV-2, neurological consequences, coronavirus pathogenesis.

Introduction

Often, infectious diseases are the cause of local outbreaks. With the active spread, these infectious diseases develop into epidemics, pandemics. In December 2019, in the city of Wuhan, China, for the first time, cases of a previously unknown infection characterized by severe acute respiratory syndrome were recorded. As a result, it was found that the causative agent is RNA containing the SARS-CoV-2 (COVID-19) virus, according to WHO data [1]. Earlier SARS-CoV and MERS-CoV epidemics were registered as CoV. However, because of its virulence and pathogenicity the SARS-CoV-2 virus was declared as pandemic in December 2020. To date, more than 140 million cases have been registered worldwide, while in Kazakhstan this figure is 367 thousand.

Most often, coronavirus infection manifests itself with respiratory syndrome, and more attention is paid to studying these issues. Nonetheless, neurological manifestations were reported in 30–80 % of patients with COVID-19. Nervous system-related symptoms may include headache, dizziness, impaired consciousness, agitation, acute stroke, seizures, ataxia, and peripheral nervous system symptoms such as syndrome Guillain-Barre, changes in the sense of smell and taste, as well as painful neuropathy [2–7]. According to studies of previous respiratory pandemics, neurological symptoms can occur both in the acute period and in the long-term. Thus, after the Spanish Flu pandemic, the number of cases of Parkinson's disease, lethargic encephalitis increased. After SARS-CoV, MERS, the incidence of encephalitis, encephalopathies, neuromuscular, demyelinating diseases, Guillain-Barre grew [8–11].

To date, the literature contains data on the manifestation, features of the clinical course of coronavirus infection, including nervous system disorders. However, there is insufficient information about the long-term consequences that may develop 3–6 months or more after the infection. The study of the consequences will allow evaluating the effectiveness of the treatment, as well as improve the prevention of undesirable consequences.

Pathogenesis of coronavirus infection. In December 2019, hospitals in Wuhan began to receive patients with atypical pneumonia. During the examination of patients, their bronchopulmonary passage was studied. A virus, later named SARS-CoV-2, was detected in the passage of patients. Earlier, there were local outbreaks of coronavirus infection, but this mutation led to a pandemic. At the moment, the issue of the pathogenesis of the development of coronavirus infection remains one of the most relevant. There are several theories about the mechanisms of infection development.

ACE2 receptor. Currently, there are several hypotheses about the mechanisms that cause the signs and symptoms associated with SARS-CoV-2 infection. According to a number of studies, coronavirus infection interacts with ACE2 receptors, which are found in the cells of the nervous system, in muscles and respond to

the regulation of blood pressure in the RAS system. This type of receptor is also found in the brain, namely in the brain stem, in the medulla oblongata in the thalamus, which makes them a potential target for coronavirus infection [12, 13].

Direct damage to nerve cells. According to the literature, some of the symptoms of coronavirus infection are anosmia, aughesia. The olfactory nerve is the entrance gate of the virus to the central nervous system. The peculiarity of the olfactory nerves and the olfactory bulb is that this nerve is like a channel between the nasal epithelium and parts of the brain, especially the brain stem [14]. In the brain stem, there are centers that regulate the work of the heart and lungs, which can also cause a severe course of the disease, as well as the development of consequences against the background of a transferred coronavirus infection [15–17].

Immune response. One of the most relevant hypotheses is systemic inflammation. As a result of the immune response to the pathogen, there is an increase in the secretion of inflammatory mediators, cytokines, which leads to a cytokine storm and systemic damage. This phenomenon can lead to damage to endothelial cells and subsequent changes in the permeability of the blood-brain barrier. Infection can also cause autoimmune encephalitis due to the presence of autoantibodies attacking neurons and endothelial cells in blood vessels, thus, activating the hypothalamic-pituitary-adrenal axis, which causes stress and other physiological changes due to excessive activation of glucocorticoid effectors and their receptors [18].

Clinic for coronavirus infection. This viral disease is highly contagious and rapidly spreading. The main routes of transmission of coronavirus infection are airborne droplets and contact.

Initial symptoms of coronavirus infection include: fever, cough, shortness of breath, myalgia or fatigue, headache. In a number of patients, the manifestation occurs with neurological symptoms. Neurological manifestations were reported in 30–80 % of patients with COVID-19. The most common symptoms are headache, myalgia, dizziness, fatigue, and sleep disorders. Therefore, a study was conducted in which 214 patients were admitted with coronavirus infection to a hospital in Wuhan, 36.4 % had neurological manifestations, of which: CNS 24.8 %, peripheral NS 10.7 % and musculoskeletal 10.7 % [4].

In the literature, cases of manifestation of coronavirus infection with encephalitis in a 56-year-old patient from Wuhan were described [19, 20]. The patient was admitted to the intensive care unit and presented with a reduced level of consciousness, so, a CT scan of the brain was performed, which was normal. The diagnosis of encephalitis was confirmed by isolation of SARS-CoV-2 from the cerebrospinal fluid by genomic sequencing. There was also a case of acute hemorrhagic necrotizing encephalopathy in a patient with a coronavirus infection who developed symptoms of fever, cough, and changes in mental state. The diagnosis was made by detecting SARS-CoV-2 by PCR in a nasopharyngeal sample. CT scans of the brain revealed a symmetrical and bilateral area of hypodensity in the medial nucleus of the thalamus. MRI showed an increase in hemorrhagic lesions after contrast injection, multifocal and symmetrical, ring-shaped both in the thalami, insula and medial temporal lobe region. Acute necrotizing encephalopathy, although relatively rare, is a complication described in some viral infections, including the influenza virus. The authors suggest that its pathogenesis will be associated with the cytokine storm syndrome described by coronavirus infection [21].

Based on the course the following degrees of severity of coronavirus infection are distinguished: mild, moderate, severe, and critical. Patients with mild severity are characterized by an asymptomatic course, or a mild clinical manifestation without radiological changes. Patients with moderate severity are characterized by lung damage up to 25 %, saturation is not lower than 93 % moderate clinical manifestations. Patients with a severe degree are characterized by lung damage up to 75 %, saturation up to 90 %, as well as pronounced clinical manifestations. In the case of a critical degree, lung damage is more than 75 %, saturation is less than 90 %, and it includes multiple organ damage [22].

As with any infectious process, coronavirus infection is characterized by periods of development of the disease. The incubation period, which on average lasts from 2 to 14 days, is characterized by the replication of the virus in the body, usually without any clinical manifestations. The initial period, as a rule, is 1–7 days with characteristic clinical manifestations, as well as laboratory changes. The duration of the disease is divided into two main phases: early and late pulmonary phases. The early pulmonary phase lasts on average from 8–14 days, and the late pulmonary phase lasts 15–28 days. The main difference between the early and late pulmonary phases is the severity of the clinical course [23].

According to the studies, there are also 3 main stages, which are characterized by both clinical and laboratory changes. The first stage is the stage of early infection. It is characterized by the introduction of the virus into the lung parenchyma through the ACE2 receptor. The main marker of this stage is lymphocytopenia. The second stage is pulmonary. It is characterized by the development of viral pneumonia, lymphopenia,

and an increase in transaminases, such as CRP. As a rule, the patient is hospitalized at this stage. The third stage is hyperinflammation — the most severe stage of the disease. It is characterized by the development of a cytokine storm up to ARDS, MVS. At this stage, patients are admitted to the intensive care unit with an increase in all markers of inflammation in the blood. At the same time, other organs and systems of the body are damaged at this stage [24].

Consequences of coronavirus infection. According to the literature, coronavirus infection does not pass without a trace. So, in a study of the long-term consequences of infection, it was found that 63 % of the examined people developed general muscle weakness, 26 % had sleep disorders, and 23 % had anxiety. Also, most patients have respiratory system disorders. To a greater extent, patients who have suffered from a severe coronavirus infection are more susceptible to adverse consequences. At the stage of patient selection, cases of fatal outcome were registered as a result of insufficiency on the part of various organs and systems. At the same time, there were cases of repeated hospitalization of patients due to an increase in complaints and deterioration of the condition [25].

Since the outbreak of coronavirus infection began relatively recently, so far all estimates of long-term consequences are preliminary and hypothetical. Based on the experience of previous outbreaks from perspective of many researchers the most pronounced consequences will be from the respiratory system. Considering the results of the studies, it was found that among patients who had SARS-CoV (a history of SARS-CoV a year, two and fifteen years ago), persistent changes in the lungs, foci of fibrosis were revealed. These changes led to impaired breathing and quality of life, respectively [26, 27].

Coronavirus infection is characterized by a rapid course and multiple organ damage. According to a number of authors, the interaction of the virus with the ACE2 receptor contributes to damage to the kidneys, heart, blood vessels, nervous system, and other organs. As a result, patients after coronavirus infection develop diabetes mellitus, arterial hypertension, thrombosis, and diseases of the nervous system. However, it is not fully known whether coronavirus infection causes the development of somatic pathologies or only contributes to the manifestation of a disease that has already been latent [28].

Viruses, including respiratory viruses, can enter the central nervous system (CNS) (neuroinvasion), infect both neurons and glial cells (a property known as neurotropism), and cause various neurological pathologies. According to the scientists, coronavirus infection also has neuroinvasive properties. Such assumptions were made on the basis of the experience of previous coronavirus infections, clinical manifestations, and the creation of models of animal infection with coronavirus infection [29].

To date, the issue of the frequency of occurrence of neurological complications remains relevant. It is noted that patients who have suffered a coronavirus infection in severe form are more likely to develop neurological consequences. Besides the background of coronavirus infection, patients may develop brain edema, destruction of neurons.

Anosmia and taste disorders are common in people with coronavirus infection, and can occur suddenly [30]. The prevalence of olfactory and gustatory dysfunctions was analyzed in the case register of 12 European hospitals. The study involved 417 patients with mild to moderate coronavirus infection. Patients completed taste and smell disorder questionnaires based on the nutrition and health survey and a short version of the Olfactory Taste and Smell Disorder questionnaire. The most common symptoms were cough, myalgia, and loss of appetite. Olfactory and gustatory disorders were reported in 85.6 % and 88 % of patients, respectively, and olfactory dysfunction was the initial symptom in 12 % [31].

Patients with coronavirus infection suffer from severe hypoxia, which is a risk factor for encephalopathy. In a study by Mao et al., 15 % of patients with severe coronavirus infection had a disturbed level of consciousness, while only 2.4 % of patients with mild coronavirus infection had a disturbed level of consciousness [4]. Also, according to a number of authors, the immune-mediated mechanism of damage in coronavirus infection contributes to the development of acute cerebral circulatory disorders. Most often, patients with concomitant pathology, as well as patients who have suffered a severe coronavirus infection, are subject to impaired cerebral circulation.

The literature also describes cases of damage to the peripheral nervous system against the background of coronavirus infection. A case of the syndrome Guillain-Barre, associated with SARS-CoV-2 infection, was described in a 62-year-old female patient who had motor weakness in the lower extremities. The study of cerebrospinal fluid showed an increase in protein (124 mg /dl) and the absence of cells. Neurophysiological examination showed an increase in distal delays and the absence of F-waves, indicating a form of demyelinating GBS. The authors suggest that the patient was infected with SARS-CoV-2 at the beginning of HBS symptoms, as she had lymphopenia and thrombocytopenia [31].

Conclusions

To date, the literature describes multiple cases of damage to organs and systems, including the nervous system, during coronavirus infection. However, there is still insufficient data on the long-term effects of coronavirus infection on the nervous system. Overall, it is not fully known whether coronavirus infection is the root cause or a factor that stimulates the activation of latent processes. In this regard, this issue remains relevant and requires further study to prevent adverse consequences.

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COVID-19 неврологиялық симптомдары мен салдары

Қысқаша шолу

2019 жылдың желтоқсан айында Қытайдағы COVID-19 алғашқы ресми жағдайынан бастап, зерттеушілер бірнеше ішкі мүшелерге әсер ететін ауыр жедел респираторлық синдромның (SARS-CoV-2) әсер ету механизмін ашуға тырысты. Бұл синдром адамда өкпе және қан айналымының өзгеруіне әкеледі, бұл тек өкпе жеткіліксіздігімен ғана емес, сонымен қатар басқа органдардың зақымдалуымен бірге өлімге әкелуі мүмкін. SARS-CoV-2-нің өкпеге тигізетін әсері үлкен және қорқынышты болғанымен, жүйке жүйесіне ұзақ мерзімді әсері айтарлықтай және одан да ауыр болып саналады, өйткені жүйке тінінің қалпына келуі қиын және ол жалпы мүгедектікке әкелуі мүмкін, себебі жүйке жүйесі бүкіл дененің функцияларын үйлестіреді. Барлық зерттеулер орталық жүйке жүйесінің кез келген жарақатының (жеңіл немесе ауыр) болуын көрсетеді, бірақ кейбіреулері сенімділік үшін одан әрі зерттеу қажет деп санайды. Бұл синдром адамда барлық зерттеулерде неврологиялық асқынулардың мүмкіндігін жоққа шығармайды, сонымен қатар, қосымша зерттеулер жүргізуді талап етеді.

Кілт сөздер: коронавирус, SARS-CoV-2, неврологиялық зардаптар, коронавирустың патогенезі.

З.Д. Кульбаева, Д.А. Клюев, Ш.С. Калиева

Неврологические симптомы и последствия COVID–19

Миниобзор

С момента первого официального случая COVID–19 в Китае в декабре 2019 г. исследователи пытались раскрыть механизм действия тяжелого острого респираторного синдрома Coronavirus 2 (SARS-CoV-2), который поражает несколько органов в дополнение к легким и вызывает изменения кровооб-

ращения, способные привести к смерти не только из-за легочной недостаточности, но и поражения других органов. Хотя эффекты SARS-CoV-2 на легкие образцовые и пугающие, долгосрочные эффекты на нервную систему могут быть более значительными и даже серьезными, поскольку регенерация нервной ткани затруднена и может привести к общей инвалидности, так как нервная система координирует функции всего тела. Все исследования показывают наличие любого вида травмы (легкой или тяжелой) центральной нервной системы, но некоторые из них подчеркивают необходимость дальнейших исследований для большей уверенности. Авторы статьи приходят к выводу, что все исследования не исключают возможность существующих неврологических осложнений и, кроме того, требуют проведения дополнительных исследований.

Ключевые слова: коронавирус, SARS-CoV-2, неврологические последствия, патогенез коронавируса, поражение органов.

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Сахарный диабет и хронический пародонтит: двунаправленная связь

В настоящее время исследователями изучаются наиболее глубокие взаимосвязи между сахарным диабетом и хроническим пародонтитом, тем более они свидетельствуют о двунаправленной связи между двумя этими заболеваниями, каждое из которых отрицательно влияет на другое. По данным многих источников, есть сведения о связи между заболеваниями пародонта и гликемическим статусом, выражающимся через гликозилированный гемоглобин и показатель глюкозы. Вероятность возникновения и прогрессирование хронического пародонтита увеличиваются в 2–3 раза у пациентов с сахарным диабетом, по сравнению с людьми без указанной патологии. Ухудшение уровня гликозилированного гемоглобина прямо пропорционально состоянию полости рта. Люди с хроническим пародонтитом имеют более высокий уровень гликозилированного гемоглобина. Новые данные указывают на то, что лица с тяжелой степенью пародонтита имеют повышенный риск развития диабета 2-го типа. Также имеются работы, посвященные определению обратного влияния хронического пародонтита на течение сахарного диабета, в которых указывается, что после лечения воспалительных заболеваний пародонта, наблюдалась тенденция к коррекции гликимического показателя. Тем не менее точные механизмы, которые приводят к снижению гликемического гемоглобина и улучшению гликемического контроля после пародонтологического лечения у людей с сахарным диабетом 2-го типа, на сегодняшний день не совсем ясны и требуют дальнейшего изучения.

Ключевые слова: хронический пародонтит, гликозилированный гемоглобин, факторы риска, сахарный диабет 2-го типа, факторы риска, патогенез, осложнения, гликемический статус.

Введение

В современном мире практически во всех странах наблюдается стремительный скачок вверх эндокринных заболеваний, в частности, сахарного диабета (СД).

На 61-й Генеральной Ассамблее ООН была принята Резолюция, целью которой являлось объединение всех стран мира в борьбе с эпидемией сахарного диабета. По данным Всемирной организации здравоохранения (ВОЗ), на 9 декабря 2020 г. отмечалось, что за период с 2000 по 2019 гг. смертность от сахарного диабета во всем мире увеличилась на 70 %, из этого числа 80 % прироста приходится на долю мужчин [1].

Сравнивая данные с разницей почти 40 лет, можно выделить, что количество пациентов с патологией сахарного диабета увеличилось в 4 раза. В 1980-х гг. число людей с сахарным диабетом насчитывало 108 млн, то на 2014 г. количество людей уже составляло 422 млн [2]. Заболеваемость сахарным диабетом в Казахстане, как и во многих других странах, прогрессирует с каждым годом. В начале 90-х число выявленных больных на 100 тыс. населения находилось на уровне 35,2 чел., но на сегодняшний день этот показатель составил 115,8, что показывает прирост в 3 раза [3].

Организм человека — это единое целое, где каждая система связана и влияет друг на друга, этим же можно объяснить связь стоматологического здоровья с другими системами. Таким образом, воспалительные заболевания пародонта зачастую сопровождаются соматическими патологиями, тем самым приводя к ухудшению или прогрессированию первых.

В классификации заболеваний пародонта выделяют системные заболевания, связанные с потерей поддерживающих пародонтальных тканей, подчеркивается специфичность клинико-морфологических проявлений пародонтита у пациентов с системными заболеваниями, одним из которых является сахарный диабет [4, 5].

Несмотря на этот факт, на территории РК причинная связь сахарного диабета и воспалительных заболеваний пародонта не признана. Из чего вытекает отсутствие программ профилактики и систематически связанного подхода к комплексному лечению этих заболеваний.

В современной научной литературе активно разбираются причины развития и процессы протекания хронического пародонтита у пациентов с сахарным диабетом, однако до сих пор нет четких

ответов касательно того, каким образом происходит влияние эндокринной патологии на развитие и течение генерализованного пародонтита, как и протоколов ведения таких пациентов.

Цель работы — определить двунаправленную связь между сахарным диабетом 2-го типа и хроническим пародонтитом.

Материалы и методы

Проводился поиск публикаций по вопросам влияния двух патологий друг на друга в следующих базах данных: Medline/PubMed, Cochrane library, Web of Science, eLibrary. При проведении исследования использовался следующий критерий включения публикаций: выборка в исследовании представлена пациентами с подверженными диагнозами сахарного диабета и хронического пародонтита. Критерием исключения выступали недостаточность и неточность представленных данных.

Результаты и обсуждения

В начале 1990-х гг. впервые опубликованы работы, описывающие связи между СД и хроническим пародонтитом, в которых пародонтит был признан как «шестое осложнение» диабета (после классических диабетических осложнений: ретинопатии, нейропатии, нефропатии, макро- и микрососудистых заболеваний) [6, 7].

На сегодняшний день исследователями определяются более сложные связи между двумя этими заболеваниями, к тому же они свидетельствуют о двунаправленной связи СД и хронического пародонтита, каждый из которых отрицательно влияет на другого.

По данным многих источников, имеется подтверждение связи между заболеваниями пародонта и гликемическим статусом, выражающимся через гликозилированный гемоглобин и показателем глюкозы. Люди с хроническим пародонтитом имеют более высокий уровень гликозилированного гемоглобина (среднее значение 5,64 %; 95 % ДИ, 5,54–5,74 %), по сравнению с контрольной группой, у которых не диагностирован пародонтит (5,31 %; 95 % CI, 5,18–5,44 %), где разница средних значений по HbA1C составляет 0,29 % (95 % ДИ, 0,20–0,37 %, $p<0,01$) [4].

Риск развития хронического пародонтита увеличивается в 2–3 раза у людей с сахарным диабетом, по сравнению с людьми без данной патологии [8]. Как и другие осложнения сахарного диабета, риск развития и прогрессирование хронического пародонтита увеличиваются с ухудшением показателей гликемического профиля.

Патогенные процессы, связывающие эти две патологии, являются на сегодня основой многих исследований, и, вероятно, то, что ухудшение одного заболевания отрицательно сказывается на течении другого заболевания. Сахарный диабет увеличивает риск хронического пародонтита, тем самым способствуя усилению воспалительного процесса в тканях пародонта. К примеру, если у лица имеется сахарный диабет, то это приводит к повышенному отложению конечных продуктов гликирования (AGE) в тканях пародонта, т.е. происходит взаимодействие между AGE и их рецепторами (особенно на макрофагах), что, в свою очередь, приводит к активации местной иммунной и воспалительной реакций [6]. Это ведет к увеличению секреции цитокинов, таких как интерлейкин-1β (IL-1β), фактор некроза опухоли-α (TNF-α) и IL-6, имеет место повышенный окислительный стресс и, в конечном счете, это способствует резорбции костной ткани. Данные факторы приводят к локальному повреждению тканей и последующей резорбции альвеолярной кости и далее к более тяжелому течению хронического пародонтита.

Если рассматривать взаимодействие двух патологий в другом направлении и влияние хронического пародонтита на сахарный диабет, то реализуется следующий механизм: пародонтальные бактерии и продукты их жизнедеятельности вместе с воспалительными цитокинами, произведенными на местном уровне в воспаленные ткани пародонта, попадают в циркуляцию и тем самым способствуют усилению системного воспаления. Это приводит к нарушению передачи сигналов инсулина и инсулинорезистентности, таким образом, у пациента диагностируется обострение сахарного диабета.

В 2012 г. на совместном Международном семинаре Европейской Федерации пародонтологии (EFP) и Международной федерации диабета (IDF), в которую входят 15 экспертов из Европы, США и Южной Азии сделаны выводы, что имеется прямо пропорциональная зависимость между тяжестью пародонтита и сердечно-почечными осложнениями диабета [1]. Новые данные указывают на то, что лица с тяжелой степенью пародонтита имеют повышенный риск развития диабета 2-го типа [2, 9]. Ранее проведен систематический обзор, в котором изучали влияние лечения хронического пародонтита, на уровень гликозилированного гемоглобина (HbA1C). Через 3 месяца коррекции хронического

пародонтита в среднем наблюдалось снижение HbA1C на 0,36 % (95 % доверительный интервал [ДИ] р) времени (3–4 месяца) после коррекции хронического пародонтита.

Согласно проспективному клиническому исследованию сахарного диабета, проведенного в Великобритании, снижение HbA1c на 1 % приводит к снижению риска диабетической микроангиопатии на 35 %. Кроме того, исследование показало, что снижение гликозилированного гемоглобина приводит к снижению риска диабетической нефропатии, ретинопатии и невропатии.

На сегодняшний день нет никаких доказательств того, что наблюдается какой-то определенный уровень снижения HbA1c, после которого будут улучшения. Таким образом, предполагается, что любое снижение HbA1c сведет на нет риск диабетических осложнений. Эти результаты в проведенных исследованиях показывают, что даже небольшое снижение уровня HbA1c значительно улучшает самочувствие пациентов.

После лечения хронического пародонтита, куда входила процедура профессиональной чистки и полировки корня зуба (SRP) и оптимальная гигиена полости рта, все эти манипуляции снижали бактериальную нагрузку в поддесневой среде, это, в свою очередь, приводило к уменьшению степени воспаления в тканях пародонта. Уменьшение в поддесневой среде бактериальной нагрузки прямо пропорционально коррелировало с уровнем провоспалительных цитокинов и медиаторов воспаления (таких как TNF-α и CRP).

Точные механизмы, приводящие к снижению гликемического гемоглобина и улучшению гликемического контроля после пародонтологического лечения, у людей с сахарным диабетом не совсем ясны и требуют дальнейшего изучения. Так же будущие исследования должны быть направлены, на определение исходного уровня гликозилированного гемоглобина, после которого пародонтологического лечение даст наибольшую пользу здоровью пациента.

Как описано выше, специфическим биологическим проявлением длительной гипергликемии является образование продвинутых гликированных конечных продуктов (AGE), которые, в свою очередь, влияют на функцию нейтрофилов. Увеличение AGEs усиливает активность нейтрофилов и выступает ключевым фактором атипичного воспалительного процесса у лиц с СД. Также устойчивая гипергликемия вызывает увеличение внеклеточных нейтрофильных ловушек (ВНЛ), ответственных за сдерживание и уничтожение патогенов. ВНЛ состоят из деконденсированного хроматина и цитотоксических белков. Кроме того, они способны вызывать повреждение тканей и замедление репаративных процессов в ранах. Повышенный уровень глюкозы в крови и интенсивное высвобождение фактора некроза опухоли-альфа (TNF-альфа) характерны для СД и способствуют продукции и высвобождению ВНЛ. Липополисахариды также высвобождают ВНЛ, это приводит к более высокому уровню концентрации эластазы нейтрофилов, компонента ВНЛ, способного к разрушению каркаса раны и замедлению ее репарпации [10]. Это особенно важно при стафилококковом инфицировании ран, часто встречающемся у пациентов с СД, из-за неспособности ВНЛ эффективно уничтожать данный тип микроорганизмов. Как следствие, неспособность ВНЛ к защите от микроорганизмов и возможность дополнительной альтерации собственных тканей указывают на то, как СД может влиять на локальное повреждение тканей в пародонте.

Таким образом, остается открытым вопрос об интенсивности образования внеклеточных нейтрофильных ловушек и их роли в прогрессировании патологического процесса в пародонте у лиц, имеющих сахарный диабет 2 типа, и эти вопросы требуют детального и глубокого изучения.

Заключение

В заключение можно отметить, что в нынешнее время имеются более глубокие связи между двумя этими заболеваниями, тем более они свидетельствуют о двунаправленной связи между сахарным диабетом и хроническим пародонтитом, каждый из которых отрицательно влияет на другое заболевание. Исследования указывают на то, что лица с сахарным диабетом имеют повышенный риск развития и прогрессирования хронического пародонтита.

Кроме того, точные механизмы, которые приводят к снижению гликемического гемоглобина и улучшению гликемического контроля после пародонтологического лечения у людей с сахарным диабетом 2-го типа, на сегодняшний день не совсем ясны и требуют дальнейшего изучения.

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Қант диабеті және созылмалы пародонтит: екіжақтық байланыс

Бүгінгі күнге ғалымдар қант диабетімен созылмалы пародонтит арасындағы күрделі байланыстарды анықтап жатыр, сонымен қатар айтылған байланыстар осы екі аурудың екібағытты байланысын көрсетеді, олардың әрқайсысы басқаларына кері әсер береді. Көптеген дереккөздерге сәйкес, гликозилденген гемоглобин мен глюкоза арқылы көрсетілген гликемиялық статус пен пародонт аурулары арасындағы байланыстың растауы бар. Қант диабетімен ауыратын адамдарда созылмалы пародонтиттің даму қаупі осы патологиясы жоқ адамдармен салыстырғанда 2–3 есе артады. Қант диабетінің басқа асқынулары сияқты, созылмалы пародонтиттің пайда болу қаупі және дамуы гликемиялық профильдің нашарлауымен бірге артады. Созылмалы пародонтитпен ауыратын адамдарда гликозилденген гемоглобин деңгейі жоғары болады. Жаңа дәлелдемелер пародонтиттің ауыр формалары бар адамдарда 2-нші типті қант диабетінің даму қаупі жоғарылағанын көрсетеді. Созылмалы пародонтиттің қант диабетінің дамуына әсерін анықтау мақсатында зерттеулер жүргізілді, онда созылмалы пародонт ауруы түзетілгеннен кейін 2-нші типті қант диабеті бар науқастарда гликемиялық статустың төмендеу үрдісі байқалды. Одан басқа, гликемиялық гемоглобиннің төмендеуіне және периодонтальды емдеуден кейін гликемиялық бақылаудың жақсаруына әкелетін нақты механизмдер 2-нші типті қант диабетімен ауыратын адамдарда қазіргі уақытта толық анық емес және қосымша зерттеуді қажет етеді. Алайда, 2-нші типті қант диабетімен ауыратын адамдарда, гликемиялық гемоглобиннің төмендеуіне және пародонтитті емдеуден кейін гликемиялық бақылаудың жақсаруына әкелетін нақты механизмдерді зерттеу қажет.

Кілт сөздер: созылмалы пародонтит, гликозилденген гемоглобин, қауіп факторлары, 2-нші типті қант диабеті, патогенез, асқынулар, гликемиялық статус.

S.T. Tuleutayeva, Zh.Zh. Ashirbekova, O.A. Ponamareva, S.A. Granko

Diabetes mellitus and chronic periodontitis: bi-directional relationship

Today, scientists are identifying more complex links between diabetes mellitus and chronic periodontitis, and also indicate a bi-directional relationship between these two diseases, each of which negatively affects other. According to many sources, there is a confirmation of relationship between periodontal disease and glycemic status, expressed through glycosylated hemoglobin and glucose. The risk of developing chronic periodontitis increases 2–3 times in people with diabetes as compared to people without this pathology. In common with other complications of diabetes mellitus, the risk of developing and progression of chronic periodontitis increases with the deterioration of the glycemic profile. People with chronic periodontitis have higher levels of glycosylated hemoglobin. New evidence indicates that individuals with severe periodontitis have an increased risk of developing type 2 diabetes. Studie have been carried out to determine the effect of chronic periodontitis on the progression of diabetes mellitus, in which there has been a tendency to a decrease in glycemic status in patients with type 2 diabetes mellitus after correction of chronic periodontal disease. However, the exact mechanisms that lead to a decrease in glycemic hemoglobin and an improvement in glycemic control after periodontal treatment in people with type 2 diabetes mellitus are currently not entirely clear and require extensive study.

Keywords: chronic periodontitis, glycosylated hemoglobin, risk factors, diabetes mellitus type 2, pathogenesis, complications, glycemic status.

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Высотная организация равнинных ландшафтов (на примере Центрального Черноземья России)

Абсолютные и относительные высоты местности выступают важным фактором формирования механизмов организации геосистем не только в горах, но и на равнинах. Они предопределяют различия в показателях морфометрии земной поверхности, интенсивности и направленности ландшафтообразующих процессов, характере ландшафтных рисунков. Основная цель исследования состояла в выявлении зависимостей между высотами земной поверхности и ландшафтными метриками на четырех масштабных уровнях. В качестве исследуемой территории было выбрано хорошо изученное в ландшафтном плане Центральное Черноземье России. В ходе работ были подготовлены цифровые модели рельефа и ландшафтные карты, проведен их морфометрический, гидрологический, инсоляционный и текстурный анализы, результаты которых были сведены в базы данных оперативно-территориальных единиц разной размерности. Показатели ландшафтного устройства были разделены на три группы: условие, процесс, результат. В ходе проведенного исследования с помощью регрессионного анализа было установлено, что зависимость параметров расчлененности рельефа от абсолютных высот уменьшается с увеличением масштабного уровня исследования. В то время как зависимость показателей, характеризующих ландшафтообразующие процессы и ландшафтные текстуры от относительных высот, растут при уменьшении масштабного уровня исследования. Ранжирование оперативно-территориальных единиц разной размерности по показателям абсолютных и относительных высот позволило выделить единые в морфологическом и динамическом отношении высотно-ландшафтные системы. Также была разработана таксономическая схема высотно-ландшафтных систем, которая включает в себя следующие таксоны: отдел, класс, подкласс, тип, подтип, семейство, род, вид и подвид.

Ключевые слова: организация ландшафта, высотная дифференциация ландшафтов, высотно-ландшафтная система, регрессионный анализ.

Введение

Проблема организации ландшафта, как сложной парадинамической системы, в последние годы активно обсуждается в научной литературе, о чем свидетельствуют многочисленные работы, посвященные данной тематике. При этом термин «ландшафтная организация» понимается довольно широко, от ландшафтного устройства конкретной территории до процессов, формирующих ландшафт как систему. Приблизительно так же трактует термин «организация» Большая Советская энциклопедия, предлагающая рассматривать его, с одной стороны, как «внутреннюю упорядоченность, согласованность взаимодействия более или менее дифференцированных и автономных частей целого, обусловленных его строением», а с другой — как «совокупность процессов или действий, ведущих к образованию и совершенствованию взаимосвязей между частями целого» [1]. Такое широкое понимание термина вносит в ландшафтоведение некоторую путаницу, в результате чего под организацией ландшафта понимается практически все: внутреннее строение, пространственное устройство, динамические процессы и мн. др. По нашему мнению, организацию, в первую очередь, следует рассматривать

как процесс, имеющий множественные механизмы, в результате действия которых формируются определенные ландшафтные структуры.

Изучение механизмов организации ландшафтов находится еще в начальной стадии, что вызвано, с одной стороны, сложностью ландшафтного устройства, а с другой — трудностью получения объективных сведений о процессах, происходящих в геосистемах. Однако в последние годы совершенствование методов исследований и технических средств (геоинформационных технологий, аппарата математического моделирования, анализа данных дистанционного зондирования, приборной части) позволяет постепенно переходить от описательного уровня ландшафтного устройства к количественному анализу механизмов формирования ландшафта. Примером тому может служить целый ряд удачных исследований межкомпонентных и межландшафтных связей [2–7].

В механизмах организации ландшафта особая роль отводится факторам, влияющим на ландшафтообразующие процессы и структуры. В их числе важное значение имеют изменения абсолютных и относительных высот местности. В горах они способствуют образованию высотной поясности и ярусности горных стран. На равнинах проявляются в виде внутризональной вертикальной дифференциации ландшафтов [8], склоновой микрозональности [9], формирования звеньев ландшафтных катен [10], ландшафтных ярусов [11] и уровней [12] и др.

Научно-методические подходы к исследованию проблемы вертикальной дифференциации равнинных ландшафтов базируются на разработках отечественных и зарубежных ученых, которые по времени можно объединить в четыре этапа.

Появление первичных сведений о различиях природных компонентов возвышенных и низменных равнин. К этому периоду относятся работы середины XIX – начала XX века, посвященные преимущественно высотным отличиям почвенно-растительного покрова, в их числе труды Э.А. Эверсмана, А.Д. Нордмана, Ф.И. Рупрехта, М.Н. Богданова, П.А. Костычева, В.В. Докучаева, А.Н. Краснова, Г.И. Танфильева, Г.Ф. Морозова, Г.Н. Высоцкого [13].

Выявление закономерностей в вертикальной дифференциации компонентов природы и появление учения о вертикальной дифференциации ландшафтов. Включают в себя работы 20–40-х гг. XX века, среди которых следует отметить публикации А.А. Каминского, Е.Е. Федорова, С.А. Бастамова и Н.Н. Изюмова по высотным закономерностям изменения климата равнин; Б.А. Келлера, Г.Э. Гроссета, А.П. Ильинского, Е.М. Лавренко и А.В. Прозоровского, П.А. Смирнова по высотным отличиям растительного покрова; И.В. Тюрина, Л.И. Прасолова, С.С. Соболева по почвам; И.С. Щукина, Я.С. Эдельштейна по ярусности равнинного рельефа. В это время появился термин «вертикальная дифференциация ландшафтов», его предложил Ф.Н. Мильков в 1947 г. [14].

Установление внутрисистемных закономерностей в вертикальной дифференциации равнинных ландшафтов и их региональных особенностей. Этап объединяет работы по проблеме высотных различий равнинных ландшафтов 50–80-х гг. XX века. Среди них труды Ф.Н. Милькова [14, 15], Н.И. Дудника [16], М.А. Глазовской [10], Г.А. Белосельской [17], Н.И. Ахтырцевой [18], Г.Е. Гришанкова [19], З.П. Бердниковой [20], В.Б. Михно [21], А.А. Чибилёва [22], В.А. Николаева [11].

Математико-статистическое и геофизическое обоснование существования вертикальной дифференциации равнинных ландшафтов, геоинформационное моделирование высотно-ландшафтных систем. Работы современного этапа базируются на применении новых технологий в выявлении закономерностей в дифференциации ландшафтов равнин. В их числе можно отметить статьи В.Б. Михно [23], Б.Н. Нешатаева, А.А. Корнуса, А.Е. Шевченко [24], Г.И. Денисика, Л.М. Кирилюка [25], А.В. Бережного [26], А.С. Горбунова [27], И.П. Капитальчука [28], А.С. Табелиновой [29]. Проблема получила некоторое отражение и в англоязычной литературе, в частности, в работах Richard T.T. Forman [30], M.G. Turner, R.H. Gardner, R.V. O'Neill [31], Robert G. Baily [32], I.S. Zonneveld [33].

Методы и материалы

Общая методология исследования базировалась на следующих положениях:

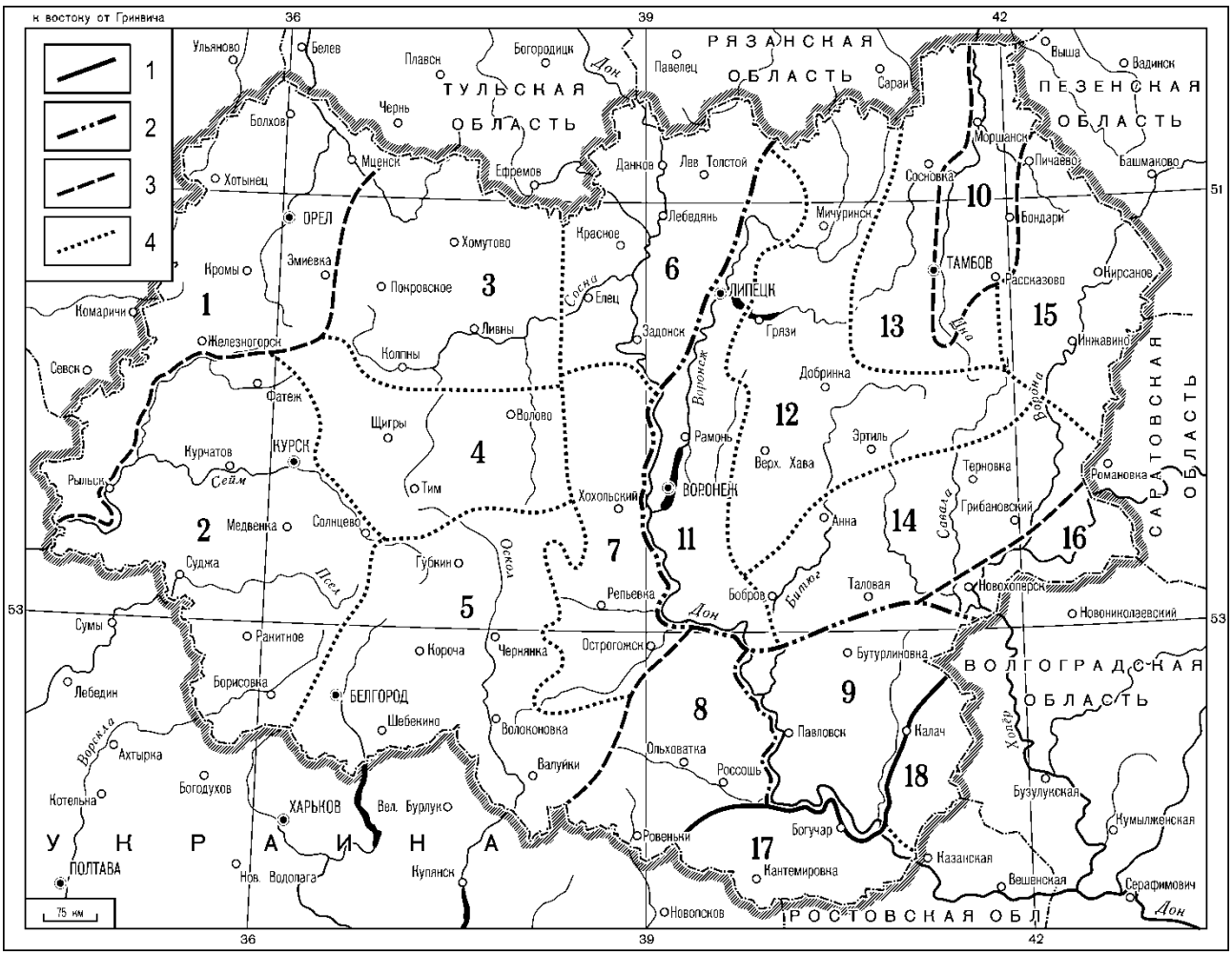
1) высотная дифференциация ландшафтов равнинных территорий — универсальное свойство качественного изменения геосистем в зависимости от различий рельефа и, прежде всего, его абсолютных и относительных высот. Несмотря на внутризональный характер, она находит достаточно яркое отражение в структуре и динамике геосистем и, таким образом, выступает в качестве индикатора трансформации зональных ландшафтов [26];

2) высотная дифференциация ландшафтов есть результат изменения интенсивности вертикальных потоков в ландшафтной сфере, и, в первую очередь, вызванных гравитационной энергией;

3) высота местности во многом предопределяет инвариантные свойства ландшафтов, скорость вещественно-энергетических потоков и направленность ландшафтообразующего процесса и, как следствие этого, на разных высотных срезах формируются разные ландшафтные рисунки (Викторов);

4) высотная дифференциация ландшафтов — полимасштабное явление, свойственное геосистемам различного таксономического ранга. В пределах Центрального Черноземья она проявляется в ландшафтах от уровня фации до физико-географической провинции;

5) в процессе вертикальной трансформации рельефа образуются высотно-ландшафтные системы, которые представляют собой динамически и морфологически единые группы ландшафтов различного таксономического ранга, имеющие общее высотное положение и сформировавшиеся вследствие совместного проявления двух основных направлений физико-географического процесса: горизонтального и вертикального.



Условные знаки: *Границы: 1* — природных зон; *2* — физико-географических провинций; *3* — природных подзон; *4* — физико-географических районов. Цифрами на карте обозначены физико-географические районы: *Лесостепная зона: провинция Среднерусской возвышенности:* Подзона северной лесостепи: *1* — Верхнеокский. Подзона типичной лесостепи: *2* — Суджанский; *3* — Соснинский; *4* — Тимский; *5* — Осколо-Донецкий; *6* — Придонской известняково-карстовый; *7* — Придонской меловой. Подзона южной лесостепи: *8* — Калитвинский волнисто-балочный; *9* — Калачский овражно-балочный. *Провинция Окско-Донской равнины:* Подзона северной лесостепи: *10* — Цнинский долинно-зандровый. Подзона типичной лесостепи: *11* — Левобережный придолинно-террасовый; *12* — Центральный плоскоместный; *13* — Северо-восточный Прицнинский; *14* — Южный Битюго-Хоперский; *15* — Восточный Вороно-Цнинский. Подзона южной лесостепи: *16* — Среднехоперский. *Степная зона: Провинция Среднерусской возвышенности: 17* — Богучарский правобережный; *18* — Южнокалачский левобережный.

Рисунок 1. Физико-географическое районирование Центрально-Черноземных областей [8]

В качестве территории исследования был выбран хорошо изученный в ландшафтном отношении регион России — Центральное Черноземье (Белгородская, Воронежская, Курская, Липецкая и Тамбовская области). Территория почти полностью располагается в пределах лесостепной зоны Русской равнины, провинциях Среднерусской, Приволжской возвышенностей и Окско-Донской равнины (лишь небольшая часть юга Воронежской области по схеме районирования Ф.Н. Милькова относится к северной степи) (рис. 1). Провинциальные различия в орографическом плане предопределили существование здесь внутризональной высотной дифференциации равнинных ландшафтов.

В числе основных задач исследования выступали:

– изучение степени влияния относительных и абсолютных высот на морфометрические параметры земной поверхности, показатели, характеризующие ландшафтообразующие процессы и текстуры типов местности;

– выявление зависимостей изменения характера связи перечисленных выше показателей на разных масштабных уровнях;

– выделение высотно-ландшафтных систем разной размерности и подготовка их классификации.

На первом этапе для проведения исследования на территорию Воронежской области в программе SagaGIS была подготовлена ЦМР с разрешением в 10 м. Для Центрального Черноземья использовалась гидрологически скорректированная модель рельефа с разрешением 30 м, созданная D. Yamazaki [34]. В дальнейшем по обеим моделям были рассчитаны показатели морфометрии рельефа (экспозиция, крутизна, общая, профильная, плановая, продольно-поперечная кривизна, позиционный индекс, индекс расчлененности рельефа, глубины долин, превышение водоразделов над тальвегами, водосборные площади, глубины замкнутых понижений), которые с определенной долей уверенности можно отнести к факторам, определяющим интенсивность ландшафтообразующих процессов. Для характеристики самих процессов на основе уже созданных моделей были рассчитаны следующие показатели: индекс развития плоскостного смыва, индекс линейной эрозии, индекс сноса и аккумуляции вещества, топографический индекс влажности, суммарная, прямая, рассеянная и фотосинтетически активная солнечная радиация, слой поверхностного стока и его работа.

На втором этапе на полученные модели были наложены сетки оперативно-территориальных единиц разной размерности: 25×25 км и 10×10 км — для Центрального Черноземья, 5×5 км и 1×1 км — для Воронежской области. Значения показателей из моделей (максимальные, минимальные, средние, дисперсия и разброс) были внесены в базу данных оперативно-территориальных единиц, после чего с помощью множественного регрессионного анализа были установлены зависимости между изменениями высот местности и значениями смоделированных показателей.

Для выявления текстурных особенностей ландшафтных рисунков использовались Ландшафтная карта вариантов типов местности Центрального Черноземья, масштаб 1:500 000, и Ландшафтная карта Воронежской области, масштаб 1:200 000 (рис. 2). В качестве показателя ландшафтной текстуры рассчитывалась энтропийная мера сложности ландшафтного рисунка [35].

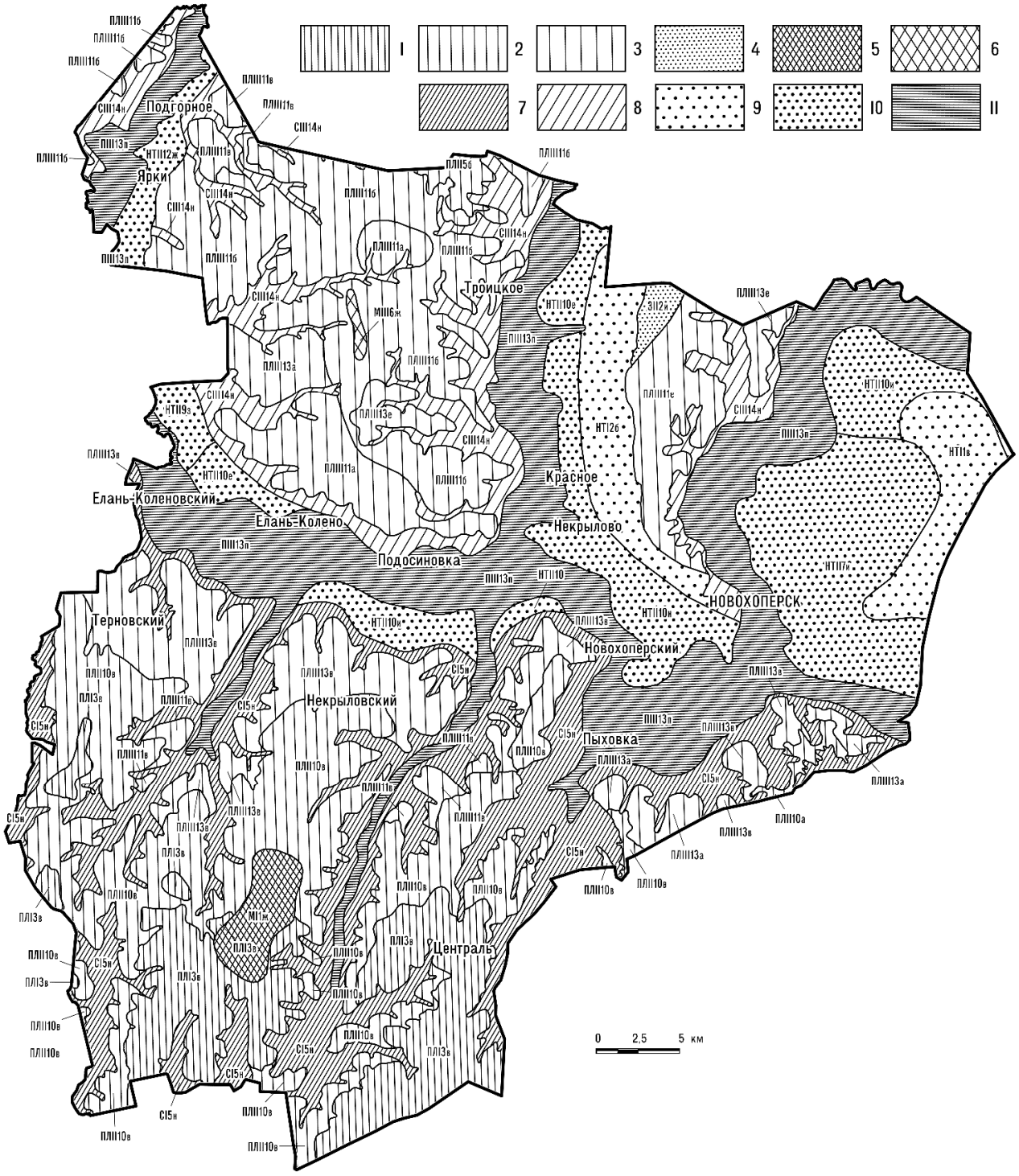
На третьем этапе была проведена кластеризация значимых для высотной дифференциации ландшафтов показателей, выделены высотно-ландшафтные системы разного таксономического ранга и подготовлена их классификация.

Результаты и их обсуждение

Формирование высотной дифференциации ландшафтов как глобального явления происходит благодаря разнонаправленным потокам вещества и энергии, которые складываются из восходящих, нисходящих и латеральных потоков. Как отмечал Ф.Н. Мильков: «Выполняя в круговоротах различные функции, они играют неодинаковую, но равно важную ландшафтообразующую роль» [8]. Среди всех потоков особое значение имеют восходящие антигравитационные перемещения, поскольку они выступают начальным звеном формирования географических круговоротов. Изменения интенсивности и характера вертикальных потоков лежат в основе высотной дифференциации ландшафтной сферы и образования *высотно-ландшафтных систем*. Его основными энергетическими источниками выступают солнечная радиация, внутренняя энергия Земли и гравитационная энергия.

Солнечная радиация определяет интенсивность восходящих потоков в атмосфере, которые, в свою очередь, формируют высотные различия климатических условий и определяют верхнюю границу природных зон. Это было убедительно доказано Г.Е. Гришанковым (1972) при обосновании трехмерности географической зональности [20]. В экваториальных широтах, характеризующихся мощными восходящими потоками в атмосфере, верхняя граница природной зоны располагается на высо-

тах 800–1000 м, в умеренном поясе — на высотах 350–400 м, в полярном — 200–250 м [20]. Именно поэтому даже высокие равнины в экваториальной Африке находятся в одной природной зоне и характеризуются внутризональной вертикальной дифференциацией ландшафтов, в то время как меньшие по высоте поднятия на Кольском полуострове могут насчитывать до 4 природных зон.



Условные знаки: *Плакорные местности:* 1 — возвышенные; 2 — пониженные; 3 — низменные. *Водораздельно-зандровые:* 4 — пониженные. *Междуречно-недренированные местности:* 5 — возвышенные; 6 — пониженные. *Склоновые местности:* 7 — с глубоковрезанной эрозионной сетью; 8 — со слабоврезанной эрозионной сетью. *Надпойменно-террасовые местности:* 9 — высокие; 10 — низкие. *Пойменные местности:* 11 — пониженные. Индексами на карте обозначены виды местностей: *Плакорные:* ПЛІ3в — пологоволнистые суглинисто-меловые возвышенные полевые с черноземами обыкновенными; ПЛІІ10а — пологоволнистые суглинисто-меловые пониженные полевые с черноземами выщелоченными; ПЛІІ10в — пологоволнистые суглинисто-меловые пониженные полевые с черноземами обыкновенными; ПЛІІІ11а — плоские суглинистые

низменные полевые с черноземами выщелоченными; ПЛIII11б — плоские суглинистые низменные полевые с черноземами типичными; ПЛIII11в — плоские суглинистые низменные полевые с черноземами обыкновенными; ПЛIII11е — плоские суглинистые низменные полевые с серыми лесными почвами; ПЛIII13а — плоские песчано-суглинистые низменные полевые с черноземами выщелоченными; ПЛIII13в — плоские песчано-суглинистые низменные полевые с черноземами обыкновенными; ПЛIII13е — плоские песчано-суглинистые низменные полевые с серыми лесными почвами. *Междуречно-недренированные:* МI1ж — пологоволнистые суглинистые возвышенные полевые с лугово-черноземными почвами; МIII6ж — плоские суглинистые низменные полевые с лугово-черноземными почвами. *Водораздельно-зандровые:* ЗII2и — волнисто-бугристые пониженные лесо-полево-степные с черноземовидными песчаными почвами. Склоновые: СI5н — суглинисто-меловые с глубоковрезанной эрозионной сетью лесо-полево-степные с почвами овражно-балочных склонов; СIII14н — суглинистые со слабоврезанной эрозионной сетью лесо-полево-степные с почвами овражно-балочных склонов. *Надпойменно-террасовые:* НТI1в — песчано-суглинистые ложбинно-лощинные высокие полевые с черноземами обыкновенными; НТI2б — песчано-суглинистые ложбинно-лощинные высокие лесо-полево-степные с черноземами типичными; НТII9з — песчаные ложбинно-западинные низкие лесные с дерново-лесными почвами; НТII7и — песчаные бугристо-котловинные низкие лесные с черноземовидными песчаными почвами; НТII10и — песчаные ложбинно-западинные низкие лесо-полевые с черноземовидными песчаными почвами; НТII10е — песчаные ложбинно-западинные низкие лесо-полевые с серыми лесными почвами. *Пойменные:* ПIII13п — сегментные иловато-торфяные низкие лугово-болотные с иловато-болотными почвами.

Рисунок 2. Фрагмент ландшафтной карты Воронежской области (территория Новохоперского района) [36]

На Русской равнине, в связи с ее орографическим планом, возвышенности не достигают верхней границы природной зоны, в которой они расположены, поэтому повсеместно преобладает внутризональная вертикальная дифференциация, исключение составляют Волыно-Подольская возвышенность, Молдавские Кодры и отчасти Донецкий кряж, где наблюдаются зачатки высотной поясности.

Внутренняя энергия Земли предопределяет скорость и направленность вертикальных движений земной коры, вносящих существенный вклад в высотную дифференциацию рельефа. На высоко приподнятых территориях (1000 м и более) наблюдается существенная трансформация климатических условий, сопровождающаяся глубокими изменениями зональных ландшафтов и формированием высотной поясности. Наряду с этим образовавшиеся перепады высот усиливают нисходящие потоки вещества и энергии, вызванные гравитационными силами.

Гравитационная энергия оказывает влияние на интенсивность большинства экзогенных ландшафтообразующих процессов, формирующих морфоскульптурный облик рельефа и рисунок ландшафта. Она не только компенсирует воздействие восходящих потоков за счет активизации денудационно-аккумулятивных процессов, но и определяет тесноту связей между геосистемами, регулируя объемы поверхностного стока, перенос твердого вещества, воздушные потоки. В этом отношении справедливо утверждение В.Н. Солнцева (2002) о том, что «гравитация выступает одним из двух равноважных факторов формирования и функционирования ландшафтного пространства» [37].

Механизм формирования внутризональной высотной дифференциации ландшафтов и образование высотно-ландшафтных систем выглядит следующим образом: 1) изменение интенсивности вертикальных движений земной коры (тектоническое поднятие) вызывает высотное разобщение территории, увеличивается перепад высот между вершинной и базисной поверхностями; 2) возрастает потенциальная энергия поверхностного стока и уклоны между водоразделами и тальвегами; 3) увеличивается скорость водных потоков, растут их кинетическая энергия и работа; 4) увеличивается глубина и густота эрозионного расчленения, продолжается рост кинетической энергии и работы поверхностного стока; 5) формируется рисунок ландшафтного устройства, экспозиционные различия наклонных поверхностей; 6) трансформируется инсоляционный режим склонов разных экспозиций, появляются локальные различия в поступлении солнечной радиации и микроклиматических условий; 7) образуются морфологически и динамически схожие высотно-ландшафтные системы.

При опускании территории наблюдается обратный процесс: происходит накопление осадочных горных пород, выравнивание территории, уменьшается потенциальная и кинетическая энергия поверхностного стока, сглаживаются экспозиционные различия в инсоляции и микроклиматических условиях.

В связи с этим в качестве основной задачи высотно-ландшафтного анализа ставится выявление влияния абсолютных и относительных высот местности на совокупность показателей морфометрии рельефа, ландшафтообразующих процессов и итоговых свойств ландшафтного рисунка.

В первую очередь, необходимо установить, как связаны между собой абсолютные высоты местности и вертикальная расчлененность рельефа, поскольку последняя выступает ключевым фактором формирования высотно-ландшафтных систем (вертикальная расчленённость рельефа рассматрива-

лась как перепад высот в пределах оперативно-территориальных единиц разных размеров). Очевидно, что зависимость здесь должна присутствовать на всех исследуемых масштабных уровнях. Однако проведенный линейный регрессионный анализ показал, что значения коэффициента детерминации (R^2) по мере увеличения масштаба исследования уменьшались. Для ячеек размером 25×25 км R^2=76,34; 10×10 км — R^2=59,00; 5×5 км — R^2=46,10 и 1×1 км — R^2=28,60. Это говорит о том, что с увеличением масштаба исследования роль абсолютных высот в формировании вертикальной расчленённости рельефа уменьшается.

Иная ситуация наблюдается при установлении связи между относительным перепадом высот и показателями морфометрии рельефа. Так, проведенные расчеты показали, что зависимость между вертикальной расчлененностью и максимальной крутизной склонов по мере уменьшения масштаба исследования увеличивается, соответственно R^2 меняется от 22,84 для ячеек размером 25×25 км до 75,53 для ячеек 1×1 км. Аналогичная ситуация отмечается и для многих других показателей, в том числе для текстурных различий рисунка типов местности.

Поскольку по каждому масштабному уровню было рассчитано более 350 зависимостей, привести их все в рамках данной статьи не представляется возможным, по этой причине сделаем некоторые обобщения. Все реакции трех групп показателей (факторов, процессов и текстур) на изменения абсолютных и относительных высот можно объединить в пять групп: 1) показатели, реагирующие на изменения высот, при этом с увеличением масштабного уровня исследования зависимость растет. К таковым относятся большинство показателей морфометрии рельефа и ландшафтообразующих процессов, реагирующих на изменения абсолютных высот; 2) показатели, реагирующие на изменения высот, при этом с увеличением масштабного уровня исследования зависимость падает. В их число входят все основные показатели, связанные с изменением относительных высот; 3) показатели, реагирующие на изменение высот вне зависимости от масштабного уровня. К ним принадлежат взаимообусловленные или близкие по содержанию показатели, такие как глубины долин, превышение водоразделов над тальвегами, потенциальная энергия поверхностного стока, позиционный индекс и др. Зависимости их от относительных высот на всех масштабных уровнях остаются высокими; 4) показатели, не реагирующие на изменения высот на всех масштабных уровнях. Они включают в себя в основном средние значения показателей, как правило, связанных с инсоляцией. Также отмечено, что средние значения в пределах какой-либо оперативно-территориальной единицы имеют меньшую зависимость от высоты местности, нежели его максимальные величины или дисперсия, связано это с известными недостатками расчетов среднего арифметического; 5) показатели, хаотично реагирующие на изменения высот. Их не так много, в качестве примера можно привести показатель дневной освещенности, который в значительной мере предопределен расчленённостью рельефа в масштабе ячеек 1×1 км (R^2=76.82), а на остальных масштабных уровнях зависимость отсутствует.

В целом установлено, что абсолютные высоты влияют на морфометрию рельефа, показатели процессов и текстуру ландшафтов при низкой детализации матриц (25×25 км и 10×10 км), а перепад высот предопределяет изменчивость большей части показателей при высокой детализации матриц (1×1 км). Исходя из этого, возникает возможность провести ранжирование оперативно территориальных единиц по показателям абсолютных и относительных высот с целью выявления однотипных в морфометрическом, динамическом и текстурном отношении высотно-ландшафтных систем разного таксономического ранга. Перед проведением группировки ячеек по высотным показателям, экспертным путем устанавливалось количество диапазонов, в качестве метода объединения значений был выбран подход естественных групп. В результате ранжирования ячеек размером 25×25 км в пределах Центрального Черноземья было обособлено три наиболее крупные высотно-ландшафтные системы уровня группы физико-географических районов: верхняя среднерасчлененная, средняя сильнорасчлененная и нижняя слаборасчлененная, которые находят некоторое соответствие с высотно-ландшафтными ступенями Ф.Н. Милькова.

Последующее ранжирование оперативно-территориальных единиц проводилось отдельно для каждой выделенной на предыдущем этапе высотно-ландшафтной системы. Группировка ячеек размером 10×10 км позволила по значениям абсолютных высот обособить высотно-ландшафтные системы уровня группы подрайонов. Их внутренняя структура довольно хорошо раскрывается матрицей размером 5×5 км, которая помогла выявить две внутридолинные высотные системы ландшафтной размерности и три междуречные. Ранжирование ячеек 1×1 км обособило высотно-ландшафтные системы уровня групп местностей.

Логичным завершающим итогом анализа высотной организации ландшафтов является подготовка классификации высотно-ландшафтных систем. Но основании высотных различий рельефа, предопределивших дифференциацию литолого-геоморфологического строения, характера динамических взаимосвязей, направленности развития и общности структуры геосистем, была разработана *таксономическая схема высотно-ландшафтных систем,* включающая в себя: *отдел, класс, подкласс, тип, подтип, семейство, род, вид* и *подвид. Отделы* выделяются по типу контакта контрастных сред (литосфера–атмосфера, литосфера–гидросфера), в результате чего формируется высотная дифференциация ландшафтов суши и глубинная дифференциация аквальных геосистем. *Классы* обособливаются по перепаду высот морфоструктур первого порядка (горы–равнины), итогом деления являются высотная дифференциация равнинных ландшафтов и высотная поясность горных стран. *Подклассы* выделяются с учетом различий радиационного баланса, определяющего последующую высотную биоклиматическую дифференциацию геосистем. Результатом выделения является высотная дифференциация равнинных ландшафтов полярного, умеренного, субтропического и тропического поясов. *Типы* обособливаются на основании ступенчатости рельефа, формирующего ландшафты низменных, возвышенных и высоких равнин. *Подтипы* обособливаются с учетом преобладающих ландшафтообразующих процессов (аккумуляции и денудации) и предусматривают деление геосистем на долинные и междуречные. *Семейства* выделяются на основе зонального положения геосистем и биоклиматических особенностей высотной дифференциации равнинных ландшафтов. В основе выделения *родов* лежат различия вершинной поверхности водоразделов, определяющие местный перепад высот. Результатом деления выступает формирование на междуречьях низких, пониженных, возвышенных и высоких участков. *Виды* обособливаются внутри родов по особенностям водно-геохимического режима, сноса и аккумуляции вещества. На основании этого выделяются водораздельные автономные геосистемы, склоновые денудационно-транзитные, надпойменно-террасовые транзитно-аккумулятивные и пойменные аккумулятивные геосистемы. С учетом относительного высотного положения, морфологии и динамики локальных геосистем внутри видов обособляются *подвиды.* Примером их могут служить ландшафты центральных, привершинных, прибровочных водоразделов, высоких, пониженных и низких пойм, верхних, средних и нижних частей склонов. В предложенной схеме поясное и зональное деление ландшафтов суши поставлено на более низкие таксономические уровни по сравнению с известными классификациями Ф.Н. Милькова (1981), А.Г. Исаченко (1995), Д.Л. Арманда (1975), В.А. Николаева (1979) и других в связи с тем, что критерии их обособления представляются менее значимыми для процесса высотной трансформации ландшафтов суши.

Заключение

Таким образом в ходе проведенного исследования было установлено:

1. На механизмы организации геосистем существенное влияние оказывают высоты местности, которые предопределяют изменение интенсивности вертикальных потоков в ландшафтной сфере и, в первую очередь, процессов, инициированных гравитационной энергией Земли.

2. Зависимость показателей расчлененности рельефа, перепада высот, глубины вреза от абсолютных высот местности проявляется на уровне оперативно-территориальных единиц ландшафтной размерности (25×25 км и 10×10 км). При увеличении масштаба исследования зависимость пропадает.

3. Зависимость морфометрических показателей рельефа, характеризующих особенности строения земной поверхности, индексов ландшафтообразующих процессов и ландшафтных рисунков, отмечается на уровне оперативно-территориальных единиц, соответствующих размерности ландшафтного урочища и местности (1×1 км, 5×5 км). При уменьшении масштаба исследования зависимость пропадает.

4. Итогом высотной дифференциации показателей структуры геосистем, ландшафтообразующих процессов и ландшафтных рисунков выступают высотно-ландшафтные системы, которые представляют динамически и морфологически единые группы ландшафтов различного таксономического ранга, имеющих общее высотное положение.

5. Таксономическая схема высотно-ландшафтных систем имеет следующее соподчинение: отдел, класс, подкласс, тип, подтип, семейство, род, вид и подвид.

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А.С. Горбунов, О.П. Быковская

Жазық ландшафттардың биіктігін ұйымдастыру (Ресейдің Орталық Черноземье мысалында)

Рельефтің абсолютті және салыстырмалы биіктігі тек тауларда ғана емес, жазықтарда да геожүйелерді ұйымдастырудың маңызды факторы болып табылады. Олар жер бетіндегі морфометрия, ландшафт процестерінің қарқындылығы мен бағытын, ландшафт сызбаларының табиғатындағы айырмашылықтарды анықтайды. Зерттеудің негізгі мақсаты жер бетінің биіктіктері мен ландшафт өлшемдері арасындағы тәуелділікті төрт ауқымды деңгейде анықтау. Ландшафт тұрғысынан жақсы зерттелген Ресейдің Орталық Черноземье зерттеу аумағы ретінде таңдалды. Жұмыс барысында рельефтің цифрлық модельдері мен ландшафттық карталар дайындалды, олардың морфометриялық, гидрологиялық, инсоляциялық және текстуралық талдаулары жүргізілді, нәтижелері әртүрлі өлшемдегі жедел-аумақтық бірліктердің деректер базасында жинақталды. Ландшафт құрылғысының көрсеткіштері үш топқа бөлінді: шарт, процесс, нәтиже. Жүргізілген зерттеу барысында регрессиялық талдау көмегімен рельефтің бөліну параметрлерінің абсолюттік биіктіктерге тәуелділігі зерттеудің масштабтық деңгейінің ұлғаюымен азаятыны анықталды. Ландшафты құрайтын процестер мен ландшафт құрылымын сипаттайтын индикаторлардың салыстырмалы биіктіктерге тәуелділігі зерттеудің масштабты деңгейінің төмендеуімен артады. Абсолюттік және салыстырмалы биіктіктер көрсеткіштері бойынша әртүрлі өлшемдегі жедел-аумақтық бірліктерді саралау біртұтас морфологиялық және динамикалық биіктік-ландшафт жүйелерін бөлуге мүмкіндік берді. Сондай-ақ биіктік-ландшафтық жүйелердің таксономиялық схемасы әзірленді, оған мынадай таксондар кіреді: бөлім, сынып, төменгі сынып, типі, тип тармағы, тұқымдас, туыстас, түр, түр тармағы.

Кілт сөздер: ландшафтты ұйымдастыру, ландшафтардың биіктік дифференциациясы, биіктік-ландшафт жүйесі, регрессиялық талдау.

A.S. Gorbunov, O.P. Bykovskaya

Altitudinal organization of plain landscapes (on the example of the Central Black Earth Region of Russia)

Absolute and relative terrain altitudes are an important factor in the genesis of geosystems. They determine differences in morphometry indicators, intensity and direction of landscape-forming processes, and landscape patterns. The study objective is to identify the relationships between altitudes and landscape metrics at four scale levels. The forest-steppe zone of the Central Black Earth Region of Russia was chosen as a study area. Authors of the article created a digital elevation model and a landscape map for the area, then conducted morphometric, hydrological, insolation, and textural analyses. Applying grids with different cell-sizes, the analyses results were obtained and stored into a spatial database. Authors divided the obtained indicators into three groups: condition, process, result. The regression analysis showed that the dependence of the relief dissection parameters on the absolute altitudes decreases with the increase of the study scale. The dependence of the indicators of landscape-forming processes and landscape textures on the relative heights increase when the study scale decreases. Ranking of the greed cells by indicators of absolute and relative heights made it possible to identify morphologically and dynamically unified altitudinal landscape systems. As one of the research results, the authors of the article devised a taxonomic scheme of altitudinal landscape systems, which included the division, class, subclass, type, subtype, family, genus, species, and subspecies categories.

Keywords: landscape organization, altitudinal differentiation of landscapes, altitudinal landscape system, regression analysis.

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Functioning of steppe landscapes in the autumn season by the example of the Karadag Nature Reserve

The results of the functioning of low-mountain sub-Mediterranean steppe landscapes in the autumn period (from 2014 to 2019) are obtained on the example of the Karadag Nature Reserve. The results of the processes of "development", "destruction" of both prerequisites and results of landscape functioning and "accumulation" of prerequisites for landscape development, as well as mixed categories in the autumn season are distinguished. Relatively alternating with each other, in the autumn season, the process of accumulation of prerequisites (in 2015, 2016, and 2019) and the process of development (in 2014 and 2017, respectively) have minimum values. In 2018, the processes of accumulation and development are at the same level, and each account for 2.6 % of the total number of the processes observations, which occurred in the steppe landscapes this year. The autumn season is absolutely dominated by the process of destruction of prerequisites and results of functioning in landscapes. This process varies from 93.9 % in 2014 to 98.8 % in 2016.

Keywords: functioning of steppe landscapes, types of states, weather types, meteorological parameters, autumn season, Karadag Nature Reserve, Crimean Peninsula.

Introduction

Landscape dynamics are inextricably linked to its functioning and are seen as a sequence or more complex structure of landscape transition from one state to another. Changes of states and maintenance of landscape in one state are provided by different functional processes [1]. Therefore, the study of the dynamics of any landscape system is based precisely on the study of functional processes which take place in them.

The processes that manifest themselves in the landscape and the study of its dynamics, are characterized by a rhythmic manifestation. They can be active at relatively equal intervals of time and lead to changes in the state of individual components of the landscape throughout the year [2].

Our article deals with intraday states of landscapes associated with measurements of system parameters every hour. Intraday dynamic is determined by such external environmental factors, which are caused by the influence of the sun, and have a rapid change (within a few minutes), as they differ only in parameters associated with the transformation of solar energy [1].

The stable sequence of changing landscape states is defined as the temporal structure of the landscape [3]. In many studies, as in ours, landscape dynamics is studied precisely through the change of its states [4–9].

In the study of landscape dynamics, stationary studies are of great importance. For example, Beruchashvili N.L. has developed a functional model of the landscape at the Martkop stationary on the basis of the substance and energy flows in the landscape system [7]. The Roztocze landscapes also quantify indicators of substance and energy flows by determining the main parameters of radiation, water, and heat balances [10]. Geochemical and geophysical features of landscapes are studied at the Chernogorsk station, in their strategies, synergetic and spatial, and temporal organization, as well as regime landscape-monitoring observations (meteorological, hydrological and phenological) [11–13]. Krauklis A.A. had been carrying out studies in the Priangar taiga facies since 1963. He conducted long-term observations of the natural regimes of typical southern taiga facies in the Chunoyarsk station. He paid special attention to the study of seasonal cycles and regeneration-age dynamics of dark taiga [14–16].

Also phenological research methods are now actively used as an approach to the study of landscape dynamics. In central Russia, phenological data is collected by the Moscow branch of the Russian Geographical Society (RGS). In the northwestern region, this has been carried out for a long time by the staff of the Botanical Institute of the Russian Academy of Sciences. In the Far East, long-term phenological monitoring is conducted at the Orotuk stationary of the IBPS FEB RAS (Kolyma River headwater). In addition, phenologi-

cal studies are carried out in the phenological section of the Sverdlovsk Branch of the Russian Geographical Society at the Ural Pedagogical University by a group of students and followers of Batmanov V.A.: Yantser O.V., Terentyeva E.Yu., Skok N.V., and others [17].

At present, the study of years-long states of landscapes that characterize their functioning remains as an urgent task. Knowledge of the mechanisms of interaction between landscapes and their environmental conditions makes it possible to solve problems of predicting their dynamic patterns and trends [18].

The methodology, taken as the basis of our study of the landscape dynamics' states, was developed by Mamay I.I. [4] when studying the functioning of landscapes at the Lesunovo landscape stationary [19–22].

Experimental

The approach used in this paper is the landscape functional assessment approach according to the methodology [4]. Based on the completeness of the primary data for assessing the dynamics of landscape states, a specific approach to the assessment was chosen:

1) The rank of the territorial complex is selected: at the facies, natural landmark (tract) or landscape level;

2) The rank of periodic states observations of the territorial complex is selected: intraday, diurnal, intraseasonal, seasonal, intra-annual, and multi-annual states.

In this work, the functioning of the natural system is given at the landscape level. Intraday meteorological indicators of the Karadag station of baseline environmental monitoring (fixing meteorological data every hour), as well as materials of the "Annals of Nature" [23–28], where indicators were applied for some of the diagnostic attributes of landscape functioning, were used as source data.

The diagnostic signs for assessing the functioning of steppe landscapes in the autumn season are those processes, which manifest themselves within steppe landscapes and which can be assessed over the time period. For over 6 years (2014–2019) we assessed the following diagnostic attributes, which are proposed in the methodology [4]. The diagnostic signs include:

– Heat transfer;
– Moisture transfer;
– Wind speed;
– Precipitation;
– Phytomass growth, vegetation;
– Increase of moisture in soil;
– Freezing and thawing of soil;
– Surface sediments transfer;
– Change of soils of one type by another while preserving the type of soil formation;
– The emergence of new morphological parts of the landscape or the disappearance of old ones;
– State of vegetation, phenology;
– Soil formation;
– Evaporation and transpiration;
– Surface runoff;
– Change of ground water level.

Each of these diagnostic signs refers to a particular category of functioning results, which influence the development of steppe landscapes as a whole. The results of landscape functioning include "development", "accumulation" of prerequisites and "destruction" of prerequisites and results of landscape functioning.

A certain type of weather conditions establishes the result of steppe landscape functioning: development, accumulation and destruction of different degrees of intensity (weak, medium, strong). In one type of weather conditions all named results or only some of them can be realized simultaneously. When assessing each process, among the results of the functioning of landscapes are defined:

– Strong development (3 scores);
– Medium development (2 scores);
– Weak development (1 score);
– Strong accumulation (3 scores);
– Medium accumulation (2 scores);
– Weak accumulation (1 score);
– Stabilization (0 score);

– Weak destruction (1 score);
– Medium destruction (2 scores);
– Strong destruction (3 scores).

Scores can reflect both positive "+" and negative "–", as well as the contribution of each diagnostic signs to the overall result of landscape functioning. Correspondingly, scores with a "+" and "–" signs reflect the strengthening or weakening of these functional signs in the landscape.

The autumn season is characterized by different categories of results of steppe landscape functioning with different degrees of intensity of their manifestation. The final results of steppe landscape functioning in the autumn season include development, destruction of both prerequisites and results of steppe landscape functioning, and accumulation of prerequisites for landscape development, as well as mixed categories.

Study Area

The Karadag Nature Reserve is located on the shore of the Black Sea, between the Otuzka River valley and the Koktebel hollow. The climate of this area is characterized as hot, arid, with mild winters, and the area is classified as the south-eastern climatic region of Crimea. In general, the territory of the reserve is insufficiently wetted. 87 % of annual precipitation evaporates and only 13 % (53 mm) forms surface runoff [29].

Results

The duration of the autumn season in 2014–2019 varies greatly from 60 to 108 days. Autumn occurs between 24 September (2014) and 23 October (2018). The end of autumn is marked between 13 December (2016) and 13 January (2017). The longest autumn was recorded in 2017 with 108 days, while the shortest autumn season was in 2016 with 60 days.

In the autumn period of 2019, it was impossible to assess the situation under which the functioning of steppe landscapes took place. As for technical reasons there were difficulties in obtaining meteorological data from the Karadag station of baseline environmental monitoring in the period from 13 November to 27 November (on these days there is no data on the amount of precipitation, so it was not possible to identify weather types. Therefore, this period was not taken for the functioning assessment).

The autumn season from 2014 to 2019 is characterized by 48 types of weather in the study area. In 2014, 35 types occur, in 2015 — 27 types, in 2016 — 34 types, in 2017 and 2018 — 30 types, and in 2019 26 types were identified (given the lack of weather data for some period of the autumn season in 2019). Some weather types recur during each year and some occur only in certain years of the studied time period.

One of the results of the steppe landscapes functioning in autumn is the landscape "development" process. This was observed throughout the entire six-year time period. A weak development process was present in all the listed years, however, also in the period from 2014 to 2017, weather types were noted in which the development process was classified as a medium category, and strong development was noted in all years except 2015.

During the autumn period, based on methodology [4], such diagnostic signs as surface sediments transfer, change of soils of one type by another while preserving the type of soil formation, the emergence of new morphological parts of the landscape or the disappearance of old ones, state of vegetation, phenology, soil formation are classified as developmental.

The result of steppe landscape functioning, such as the "accumulation" of prerequisites for landscape functioning was noted in the autumn periods of 2014, 2016, 2017, and 2018. Moreover, it was pointed out that the category of strong accumulation is completely absent in the autumn season. The processes of prerequisites accumulation in the autumn season according to the methodology [4] include diagnostic signs: heat transfer, moisture transfer, wind regime, precipitation, phytomass growth and vegetation, increase of moisture in soil.

The process of "destruction" of both prerequisites and results of landscape functioning is characteristic for the whole period under consideration, with all categories of intensity (weak, medium and strong result of functioning) occurring in each year. Among the signs influencing the overall destruction result in the autumn season according to the methodology [4], the following are highlighted: heat transfer, moisture transfer, wind regime, evaporation and transpiration, and surface runoff.

The following categories of outcomes are related to the manifestation of two, three or more parallel steppe landscape processes or combinations thereof. In this case, the intensity of the manifestation of the result is zero and it is characterized by the definition "in the absence of result". This suggests that the parallel processes in the type of weather under consideration have levelled each other, resulting in the same level of their functioning, i.e. the intensity of the processes does not stand out.

Discussion

During the autumn season each of the diagnostic signs contributed to the overall picture of steppe landscape functioning.

Development of steppe landscapes. The process of development in different years was caused by different diagnostic signs, but it was mainly dominated by the surface sediments transfer, which is inseparably linked with the intensity of precipitation in this season. Besides, such signs as the emergence of new morphological parts of the landscape or the disappearance of old ones in the period under consideration and the change of soils of one type by another were not manifested, while preserving the type of soil formation.

The percentage of cases (of the total number of observations) of the result with weak development varies from 0.1 % to 3.4 %. Generally, this category of landscape functioning is a fraction of a percent and does not exceed 0.6 % of the total number of process observations. In 2019, however, this category accounted for 3.4 %. This category is mainly characterized by diagnostic signs such as the surface sediments transfer and soil formation.

In 2016, 2018, and 2019, such a diagnostic sign as "state of vegetation and phenology" affected the overall picture of steppe landscape functioning and levelled out the overall positive result of the functioning of weak development. This sign makes the most of its negative contribution in 2019. In 2014 and 2015, it had no influence at all on the overall steppe landscape functioning result.

Medium landscape's development in the autumn season is supported by the surface sediments transfer and soil formation. The other diagnostic signs do not have the intensity for which the current category of steppe landscape functioning results. It is important to note that in 2018 and 2019 no weather types with a landscape functioning result such as medium development were identified. This category of functioning result is poorly represented among the others and amounts to no more than 0.5 % of the total number of observations. Overall, average development as a result of steppe landscape functioning occurs in fractions of a percentage of the total number of observations: 0.1 % in 2014 and 2015, 0.3 % in 2016, and 0.5 % in 2017.

The functioning result characterized as a strong development was considered in all years except for 2015. The dominant diagnostic sign is the surface sediments transfer, which makes the main contribution to the category of strong development. Parallel to this, soil formation makes a positive contribution to this category too. There is also a negative impact of the diagnostic attribute "state of vegetation and phenology" on the final result of this category in 2019. During the autumn season, this diagnostic sign actively influences the reduction of the category result through the weakening and complete termination of flowering processes.

The percentage of the total number of observations with a strong development result varies from 0.1 % in 2014, 2017, and 2018 to no more than 0.4 % in 2016. The development process itself accounts for small fractions of a percentage of the autumn season compared to other processes.

Accumulation of prerequisites for the steppe landscapes functioning. The accumulation of prerequisites for the steppe landscapes functioning is weak and not all diagnostic signs are presented in this category. Such sign as wind regime does not appear at all in this category of results. Also, it is presented the negative impact of "phytomass growth and vegetation" on the general process of accumulation, indicating that this sign increasing the weakness of overall result of weak accumulation functioning in autumn 2016 and 2018. Observations (of the total number) with weak accumulation of prerequisites for steppe landscape functioning constitute a very small percentage: 0.1 % in 2016 and 1.2 % in 2018.

The next category of the result intensity of steppe landscapes functioning is the medium accumulation. It occured only in 2014 and 2017 and was realized through wind activity, precipitation, phytomass growth and vegetation, moisture transfer, and increase of moisture in the soil. In addition, wind speed affected this category of functioning only in 2014 and moisture transfer only in 2017. A negative contribution in 2014 and 2017 to the overall steppe landscape functioning result in this category is brought by the sign "phytomass growth and vegetation", as the autumn season tends to depress phytomass growth in plant communities. The percentage of the average accumulation result from the total number of observations is 0.1 % in 2014 and 0.7 % in 2017.

Destruction of prerequisites and results for steppe landscape functioning. Weak destruction of results is not implemented by all diagnostic signs in this category of landscape functioning. For example, surface runoff is not a diagnostic sign in none of the years under consideration, the activity of which would influence the overall result of weak destruction. Individual attributes do not reflect their contribution in the autumn season functioning of some years (for example, the wind regime does not have such activity in 2015 to influence the total result of the considered category of steppe landscapes functioning).

Autumn 2017 was characterized by the smallest number of diagnostic signs actively acting on the described result; only three diagnostic signs standed out in this year: heat transfer, wind speed, change of groundwater level.

It should be noted that changes in the groundwater level in 2014 and 2015 contributed positively to the overall process of destruction of the results, while in 2017 and 2018 it contributed negatively, with a strong intensity. Due to this, the destruction of the steppe landscape in the autumn of 2017 and 2018 was weakened.

The percentage of cases (of the total number of observations) with weak destruction of steppe landscape results varies from 0.4 % to 8.4 %. The lowest values are characteristic of 2014, 2015, and 2019 (1.51 %, 0.4 % and 2.1 %, respectively). In 2016 it is 8.4 %, in 2017 — 6.9 % and in 2018 — 4.6 % of the total number of observations.

In the medium destruction of result of steppe landscapes functioning, all diagnostic signs were active, except for surface runoff. This diagnostic signs did not manifest itself at all in those types of weather, when the category of medium destruction of results operated. There was a negative impact of the sign “change of groundwater level” on the total contribution to the result of this category of functioning in 2014–2019.

This category of steppe landscape functioning varies between 0.8–28.2 % of the total number of observations. Between 2014 and 2018, this percentage ranged from 0.8 % to 6.9 %, and increased sharply in 2019 (28.2 %).

The result of the landscape functioning as a strong destruction of the results is manifested under more types of weather. Thus, heat transfer in the air, moisture transfer, wind regime, evaporation and transpiration and change of groundwater level are active in the autumn season in all years under consideration. Little activity of surface runoff was recognized in autumn 2016, where it made a small positive contribution to the overall result of functioning of steppe landscapes.

As in the other categories of intensity of result, destruction in the last three years (2017–2019) had a negative contribution of the diagnostic sign “change of groundwater level”. In these years, there was a frequent increase in the groundwater level during the autumn season. This category of performance result varies between 57.6 % and 89.6 % of the total number of observations. The minimum percentage of observations that characterize the functioning result of this category is noted in 2019 (57.6 %). Between 2014 and 2018, this percentage remained approximately at the same level, ranging from 82.5 % to 89.6 % (the maximum was noted in 2015).

The result of steppe landscape functioning as a destruction of prerequisites was only noted in 2015 and 2018.

The medium destruction of prerequisites is typical for some weather types only in 2018. The more intense category of strong destruction of preconditions was found in 2015. These functioning processes add up to different diagnostic signs. Only three diagnostic signs contributed in both 2015 and 2018. Such signs include: wind regime, evaporation and transpiration, and change of groundwater level. Moreover, the negative impact of the signs on the general result was made by different processes: in 2018, with medium destruction of the prerequisites the negative contribution to the overall result of landscape functioning was made by change of groundwater level, while in 2015, with a strong destruction of the prerequisites the negative contribution to the total result was made by evaporation and transpiration.

The percentage of cases (of the total number of observations) with medium destruction of steppe landscape prerequisites in the autumn season 2018 is 3.8 %, and with strong destruction of prerequisites in 2015 is 0.8 %.

An interesting category of performance is the one in which both prerequisites and results destruction processes occur together. Such categories of different intensities were observed throughout the whole period under consideration, except for 2016. It must be said that evaporation and transpiration are presented in almost all years and at all intensity categories of the functioning results, except for 2019, in which the medium intensity category is absent. However, in the autumn of 2015 with weak intensity of this result category evaporation and transpiration made a negative contribution to the total functioning result of steppe landscapes. This diagnostic sign is joined by others. Each year a particular range of diagnostic signs dominated. There is an absolute lack of activity of diagnostic signs in 2019 with a weak category of intensity of the process. This suggests that within each diagnostic sign that manifested itself in a particular weather type in 2019, there was a mutual balancing of positive and negative scores affecting the overall result with zero process manifestation result. It is noted that in the autumn season of 2019 with the category of strong intensity of the considered result of functioning only one diagnostic sign was manifested — it is wind speed.

The category of steppe landscape functioning, such as weak destruction of preconditions and results has the following percentage distribution of the total number of observations: 0.2 % in 2015, 1.3 % in 2018 and 0.3 % in 2019. The medium category has the following distribution: 1 % in 2014, 0.6 % in 2015 and 1.9 % in 2016. In 2016 and 2019, this result at a strong level is 1.3 % and 7.1 %, respectively.

Co-dominant categories of steppe landscape functioning. When assessing the joint accumulation and development category of steppe landscape functioning, it is noted that it occured in all years except autumn 2018. Among the fundamental diagnostic signs there are: wind regime, precipitation, phytomass growth and vegetation, increase of moisture in soil, surface sediments transfer, state of vegetation and phenology, soil formation. Additionally, considering all years, two diagnostic signs contributed negatively to the overall results of this category during the autumn season. These are phytomass growth and vegetation, and also vegetation condition and phenology, which are due to the fact that in the autumn season active processes of vegetation flowering and growth cease and are inhibited, so a stronger negative impact of these attributes is found in deep autumn near winter.

The accumulation and development category accounts for small fractions of a percentage of the total number of observations. The years 2014, 2016, 2017, and 2019 accounted for just 0.1 % and 2016 for 0.2 % of the results in this category.

The next result with parallel processes of landscape functioning is the development and destruction of the result. This result category occurs in the autumn season in all years. It should be noted that the diagnostic signs influencing the overall result in each year is soil formation. It is joined by other diagnostic signs with different levels of contribution in different years. There is a negative contribution of some signs in 2014, 2015, 2017 and 2018. These include: state of vegetation and phenology, as well as change of groundwater level (only in autumn 2018).

In general, the occurrence of this category varies between 0.1–1.9 % of the total number of observations. In 2014, 2016 and 2017, there is the lowest percentage of occurrence of this steppe landscape result among all observations, 0.3 %, 0.3 % and 0.1 % respectively, while in 2015, 2018 and 2019 the occurrence increases to 1.9 %, 1.1 % and 0.9 %, respectively.

A significant contribution to the functioning of the steppe landscapes of individual years in the autumn season is made by the category of accumulation and destruction of prerequisites. This category of steppe landscape functioning is evident in autumn in 2014 and 2017. In these years, almost all characteristic diagnostic signs are observed, with a high level of negative contribution of phytomass and vegetation growth, as well as change of groundwater level (only in 2017). The occurrence of this category result does not at all exhibit heat transfer as a process of destruction. The occurrence of this category of steppe landscape functioning result is 9.6 % in 2014 and 2.4 % in 2019 (% of total observations per season).

The last category of the result of the steppe landscapes functioning in autumn is the category which includes all the processes: accumulation, development and destruction, running in parallel. However, only some of the diagnostic attributes appear in this category and influence its result. Among them: heat transfer (as accumulation), moisture transfer (as accumulation), wind regime (as accumulation), precipitation, phytomass growth and vegetation, increase of moisture in soil, surface sediments transfer, state of vegetation and phenology, soil formation, moisture transpofer (as destruction), evaporation and transpiration, surface runoff, change of groundwater level.

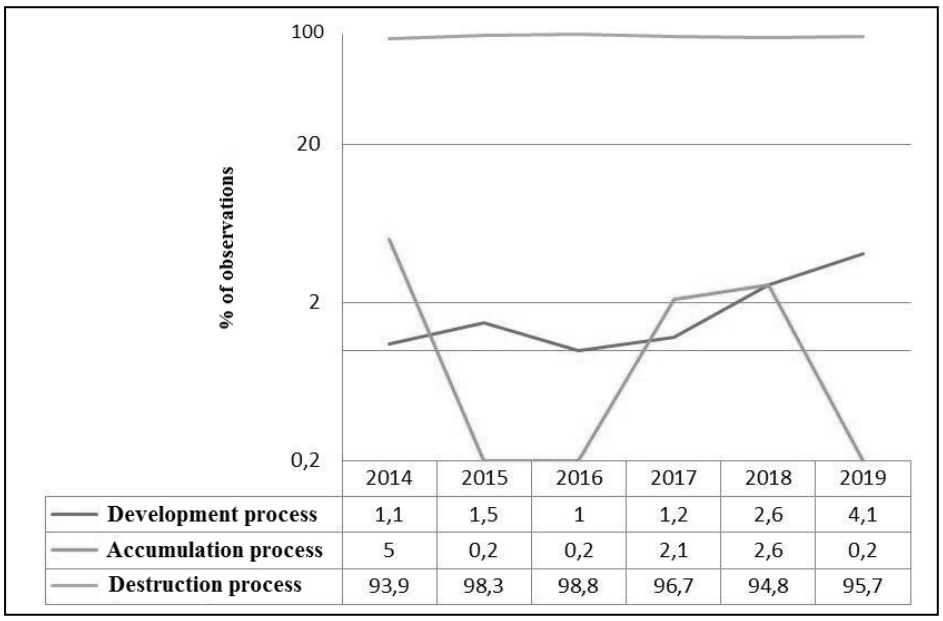
This mixed category of steppe landscape results is found in all years of the time period, except for the autumn season of 2016. It is noted that in 2018, the intensity of such diagnostic signs as phytomass growth and vegetation, as well as state of vegetation and phenology contribute more negatively to this category of functioning than in other years. On the contrary, such diagnostic signs as moisture transfer, accumulation make the largest positive contribution compared to other years.

Comprehensively, various signs have a negative impact on the overall steppe landscape functioning in individual years, including: phytomass growth and vegetation, state of vegetation and phenology, evaporation and transpiration, precipitation and change of groundwater level. This category of steppe landscape functioning accounts for small percentages of occurrence: in 2014, 2015, 2017, and 2019, it is only up to 0.2 %, and in 2018 — 4 % of the total number of observations.

Conclusions

In general, the autumn season in the period of 2014–2019 is characterized by the presence of both accumulation and development and destruction processes, together with the parallel processes of various steppe landscape functioning.

By grouping and summarizing the main categories of steppe landscape functioning processes in the autumn season, a graph of their correlation and dynamics in the time period under consideration was obtained. The graph (Fig. 1) illustrates that in the autumn season, the process of destruction in steppe landscapes absolutely dominates. It ranges from 93.9 % in 2014 to 98.8 % in 2016 (of the total number of functioning processes within the study area). In turn, the processes of development and accumulation are weak and do not exceed a total of 5 %, in some years they characterized by fractions of percentages of the total picture of functioning of steppe landscapes.



	2014	2015	2016	2017	2018	2019
Development process	1,1	1,5	1	1,2	2,6	4,1
Accumulation process	5	0,2	0,2	2,1	2,6	0,2
Destruction process	93,9	98,3	98,8	96,7	94,8	95,7

Figure 1. Processes functioning in steppe landscapes in the autumn season, their correlation and dynamics in the period 2014–2019

Figure 1 shows that relatively alternating with each other, in the autumn season in different years, the accumulation process of prerequisites for functioning and the development process in steppe landscapes are characterized by minimal values. The accumulation process makes the minimum contribution among the other processes in 2015, 2016, and 2019, and the development process is in 2014 and 2017, respectively. In 2018 the processes of accumulation and development are at the same level and make up 2.6 % from the processes occurring in the steppe landscapes in the autumn season of this year.

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Карадаг табиғи қорығының мысалында күзгі маусымда дала ландшафттарының жұмыс істеуі

Карадаг табиғи қорығының мысалында күзгі кезеңдегі (2014 жылдан 2019 жылға дейін) төментаулы Жерорта теңізінің дала ландшафттарының жұмыс істеу нәтижелері алынды. Осындай нәтижелер негізінде күзгі маусымда мынадай процестер анықталды: ландшафттардың жұмыс істеу нәтижелерінің алғышарттарының «дамуы», «жойылуы» және ландшафттардың дамуы үшін алғышарттардың «жинақталуы», сондай-ақ аралас санаттар. Бір-бірімен салыстырмалы түрде ауысып, күзгі маусымда жұмыс істеу алғышарттарын жинақтау процесі (2015, 2016 және 2019 жылдары), содан кейін даму процесі (сәйкесінше 2014 және 2017 жылдары) ең аз мәнге ие. 2018 жылы жинақтау және даму процестері бір деңгейде болып табылады және биылғы жылы дала ландшафттарында болып жатқан процестерді бақылаудың жалпы санының 2,6 %-ын құрайды. Күзгі маусымда ландшафттардың жұмыс істеуінің алғышарттары мен нәтижелерін жою процесі мүлдем басым болған. Ол 2014 жылдан 93,9 %-дан 2016 жылға дейін 98,8 %-ға дейін ауытқыған.

Кілт сөздер: дала ландшафттарының жұмыс істеуі, түрлердің жағдайы, ауа-райының түрлері, метеорологиялық параметрлер, күз мезгілі, Карадаг табиғи қорығы, Қырым түбегі.

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Функционирование степных ландшафтов в осенний сезон на примере Карадагского природного заповедника

На примере Карадагского заповедника получены результаты функционирования низкогорных субсредиземноморских степных ландшафтов в осенний период (с 2014 по 2019 гг.). В качестве таких результатов в осенний сезон выделяются процессы: «развитие», «уничтожение» как предпосылок, так и результатов функционирования ландшафтов и «накопление» предпосылок для развития ландшафтов, а также смешанные категории. Относительно чередуясь между собой, в осенний сезон минимальными значениями обладает то процесс накопления предпосылок функционирования (в 2015, 2016 и 2019 гг.), то процесс развития (соответственно в 2014 и 2017 гг.). В 2018 г. процессы накопления и развития находятся на одном уровне и составляют по 2,6 % от общего количества наблюдений за процессами, происходящими в степных ландшафтах в этом году. В осенний сезон абсолютно преобладает процесс уничтожения предпосылок и результатов функционирования ландшафтов. Он варьирует в пределах от 93,9 % в 2014 г. до 98,8 % в 2016 г.

Ключевые слова: функционирование степных ландшафтов, типы состояний, типы погоды, метеорологические параметры, осенний сезон, Карадагский природный заповедник, Крымский полуостров.

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Informal roads as social-ecological-technological systems (SETS): sustainability challenges and impact on landscape transformations

Following the call to mobilize studies of social-ecological systems and sociotechnical systems, the paper presents the case for studying integrated social-ecological-technological systems (SETS), and dynamic systems that include social, natural and technological (engineering) elements. Using the case study of informal roads in the Baikal region, authors of the article argue that re-focusing on SETS creates additional synergies and convergence options to improve the understanding of coupled systems and infrastructure in particular. Historically, transportation infrastructure has contributed to changes in natural and social systems of Northern Eurasia: Trans-Siberian and Baikal-Amur railroads and Eastern Siberia–Pacific Ocean and Power of Siberia pipelines have been the main drivers of social-ecological transitions. At the local scale, informal roads serve as one of the most illustrative and characteristic examples of SETS. The examination of development and transformation of the informal roads allows exploring the interactions between socioeconomic processes, ecological dynamics and technological advances. The variety of informal roads reflects the importance of specific social, natural or technological factors in the SETS transformation largely unconditioned by policy and regulations thus providing a unique opportunity to better understand sustainability challenges facing infrastructure-based SETS. Relying on interviews and in-situ observations conducted in 2019 in the Baikal region, the following factors affecting sustainability of informal road SETS were identified: social (identification of actors involved in location, construction, maintenance, use and abandonment of informal roads), technological (road cover, width, frequency and nature of use by different kinds of vehicles), environmental (geomorphology and landscape sensitivity and vulnerability). The sustainability challenges of SETS development and transformations are found in changing mobility practices, social structure and economies of local communities, increased occurrences of forest fires and development of erosion and permafrost degradation in local environment and push for development of new technologies of transportation and communication.

Keywords: informal roads, benefit-sharing, extractive industries, transportation infrastructure, indigenous people, transformation of geosystems.

Introduction

Development of transportation infrastructure has been in the focus of attention of researchers for a long time. Researchers recognize both positive and negative effects that transportation infrastructure brings. The issues of 'infrastructure violence', 'tunnel effects of infrastructure' have been discussed in the southern context, contagious development has been in the center of attention of studies in Amazonia, and the changing geopolitical map under the influence of pipeline networks has been a point of concerns in Europe. The Arctic and Subarctic environmental impact of infrastructure is rarely considered in terms of power relations. Moreover, prevailing assumption that the infrastructural development has a network character, which means connections between different nodes are more or less similar. In our study, we emphasize the access to some links is restricted or negotiated, which means it involves some power relations and subsequent hierarchies of infrastructure. Such phenomenon is evident in the resource extractive regions, such as the North of Irkutsk Region or the South of the Republic of Sakha (Yakutia) where new boom of infrastructural development was caused by construction of the Eastern Siberia–Pacific Ocean (ESPO) oil pipeline in 2008 and current construction of Power of Siberia gas pipeline.

During the fieldwork in Vershina Khandy, we travelled by roads of common use, forest roads, former geophysical line clearings, inter-settlement informal road and subsistence tracks.

In the process of the fieldwork in Tokma, we used roads of common use, federal and municipal winter roads, forest roads, former geophysical line clearings, and subsistence tracks.

These roads have distinguishable physical properties that in some cases are regulated and have to be conformed to certain requirements by low, and in some cases — used and maintained by local traditions and capacities. However, the officially existing requirements differ from real practices of maintenance and use.

The federal winter road can be narrow and the municipal winter road can easily be blocked by a road accident.

Roads for special use, in our case, are mostly forest haul and logging roads with the former being larger than latter. They are often created along the former geophysical line clearings which explain their straight lines.

Roads with restricted use usually have a gated access point, which is sometimes enforced by security cameras, as in the case of oil service road. Their roads are patrolled, and unwelcome intruders are quickly expelled. Or the access restrictions can be formal, when there is just a local hired guard as in case of forest road near Vershina Khandy. The main purpose of the guard in this case is to make sure no illegal loggers will get on the rented forest area.

Roads with customary use are the least visible; they have fewer imprints both in summer and winter and easily destroyed by ice heave, rain, snow, or heavy vehicles. Therefore, we put them in the lowest place in our hierarchy of infrastructure. In addition, the outsiders either do not know, or do not care about rules of use and maintenance of these roads, while local communities cannot enforce their low in any form.

Road construction negatively affects the state of the landscape, damaging or destroying its natural elements, and therefore, disturbs the balance in nature [1]. Thus, road landscapes belong to direct anthropogenic complexes formed as a result of purposeful human activity in nature [2].

Addressing the need to deal with complex issues humanity faces today, researchers look for convergence of different sources of knowledge. One of such approaches is studies of social-ecological-technological systems (SETS).

Theoretical considerations

We understand SETS as integrated and dynamic systems that include social-cultural, environmental, and technological-infrastructural domains. Environmental domain provides ecosystem services to the social-cultural domain, while humans apply anthropogenic impact on the environment. Chester et al. [3] estimate the environmental impacts of transportation systems, and the ways to cost-effectively minimize these impacts, by including vehicle, infrastructure, and energy production life-cycle components, in addition to operation. The technological-infrastructural domain affects the social-cultural domain by the use of technologies and infrastructure, as well as impacting on local mobility, while social perception and values are embedded in the creation and maintenance of infrastructure and technologies. Bearing capacity of infrastructure is significantly determined by environmental conditions while transformations in technologies and infrastructure cause changes in ecological flows [4] (Fig. 1).

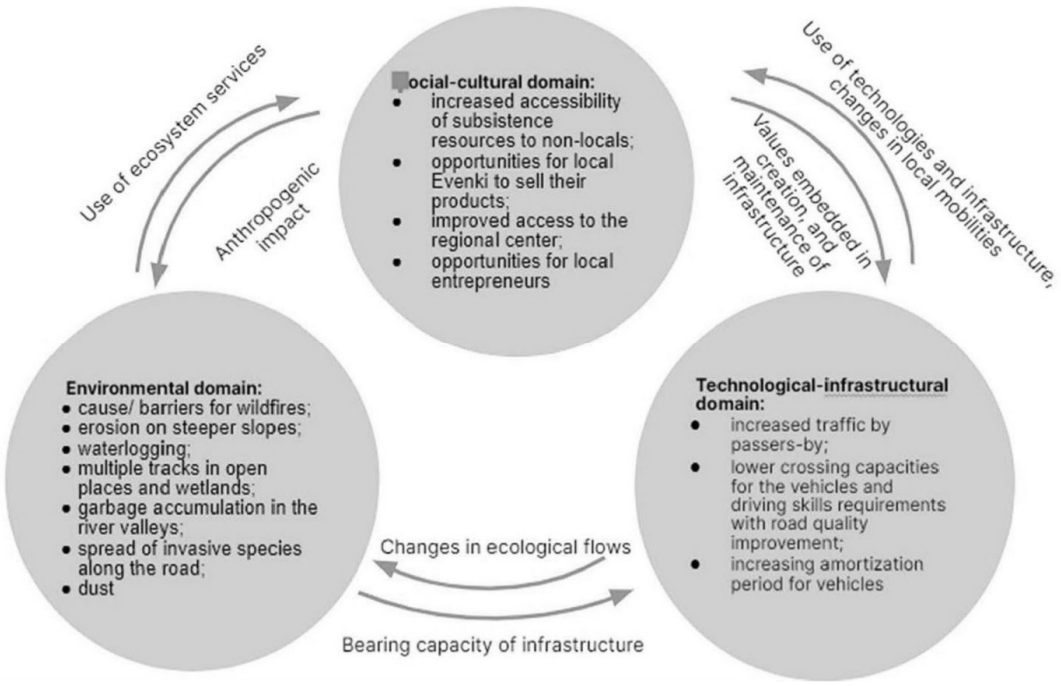

Figure 1. Study area SETS components

Transportation networks have already been explored as the networks developing in a hierarchical pattern [5]. The same is true about electricity grid networks [6]. To analyze the structure and operations of infrastructure systems, Janssen et al. [7] use the couple infrastructure systems (CIS) framework. “Poor road quality is not just a consequence of biophysical processes, but also a consequence of choices for funding, planning, construction, use, and maintenance” [7]. As many other unbuilt and unfinished projects [8], strength of Siberia pipeline construction has not been finished yet, but has already had significant impact on local expectations, mobilities, economies, and even environment.

To study SETS, we use a panarchy metaphor for describing multi-scale social-ecological-technological interactions with patterns of stability and change within and across scales. They have specific adaptive cycles that instead of traditional within social-ecological systems phases of growth, conservation, release, and reorganization [9], they rather include growth and exploitation when the system expands, maintenance, when the system is stable, collapse — decline of a system in the current form, and reorganization — transformation of one type of SETS into another. Processes in an adaptive cycle at one scale affect adaptive cycles at other scales.

Resilience in this view is “the amount of disturbance that can be sustained before a change in system control and structure occurs — ecosystem resilience” [10].

Among the slow variables we can list growth of cedar and lichens. Among the fast variables: growth of thicket, wildfire.

Study Area

In this paper, we discuss the preliminary results of the studies of informal roads as an example of SETS. Under informal roads we understand all the transportation pathways that the remote, mostly indigenous communities use in absence of public roads [11]. The study area is located in North-Eastern Siberian taiga having similarities in taiga and bears with many other Arctic and Subarctic regions. It has harsh climatic conditions, presence of permafrost, traditional indigenous cultures, high dependency on extractive industries, and nascent elements of tourism. The dynamics of economic development are closely linked to the large infrastructure projects Baikal-Amur Mainline, Eastern Siberia–Pacific Ocean and Power of Siberia pipelines. Forestry and geological exploration companies are also active in the study sites. These activities take place on the territories of traditional land use of indigenous people of Evenki. Traditional subsistence activities of Evenki include hunting, fishing and pine nuts, berries and herbs gathering [12].

The study communities are rather small, with 54 people in Tokma and from 6 to 20 in Vershina Khandy depending on the season [13]. However, both settlements are home for Evenki, indigenous people of the North whose traditional culture depends on hunting, fishing, and gathering activities. So, the territories of traditional land use occupy significant territories, in case of Khandinskaya obshchina almost comparable with the territory of the Road Island state. The study areas are crossed by major pipelines, developed by oil and gas companies, logged by forest companies and explored by geological parties (Fig. 2).

Methods

This research is based on data from field studies in Vershina Khandy, Kazachinsko-Lenskiy district in August 2019 and in Tokma Katangskiy district of Irkutsk region in March 2020 which includes 14 in-depth interviews, both on the move, and in settlements with local residents, and participated in daily activities. The residents shared their personal stories, concerns and emotions related to the existence and use of informal roads. Travelling together by these roads using different modes of transportation gave us a glance on sensory experiences of local mobility. Also, we utilize data from previous studies in the region where we have worked since 2006.

To make an inventory map of the study area, we used medium- and high-resolution satellite data such as Landsat and Digital Globe, multi-temporal topographic maps, infrastructure development planning documents, interviews with local residents, and drone imagery. To study dynamics of the road network development in the study areas since 1980s, students of George Washington University mapped informal roads from using Landsat imageries.

We categorized existing transportation infrastructure according to the regulations and distinguished formal, semi-formal and informal ones (Fig. 3). Then we identified different forms of ownership for understanding maintenance and use of these roads and differentiated public and private roads, rented and owned by different state agencies. In regard to accessibility, we distinguish public roads of common use, private and rented roads with limited access. The roads with special use have been created for specific purposes, but the

access is not controlled. Subsistence and informal inter-settlement roads form specific kind of roads for traditional use that are maintained, used, and regulated according to local traditions.

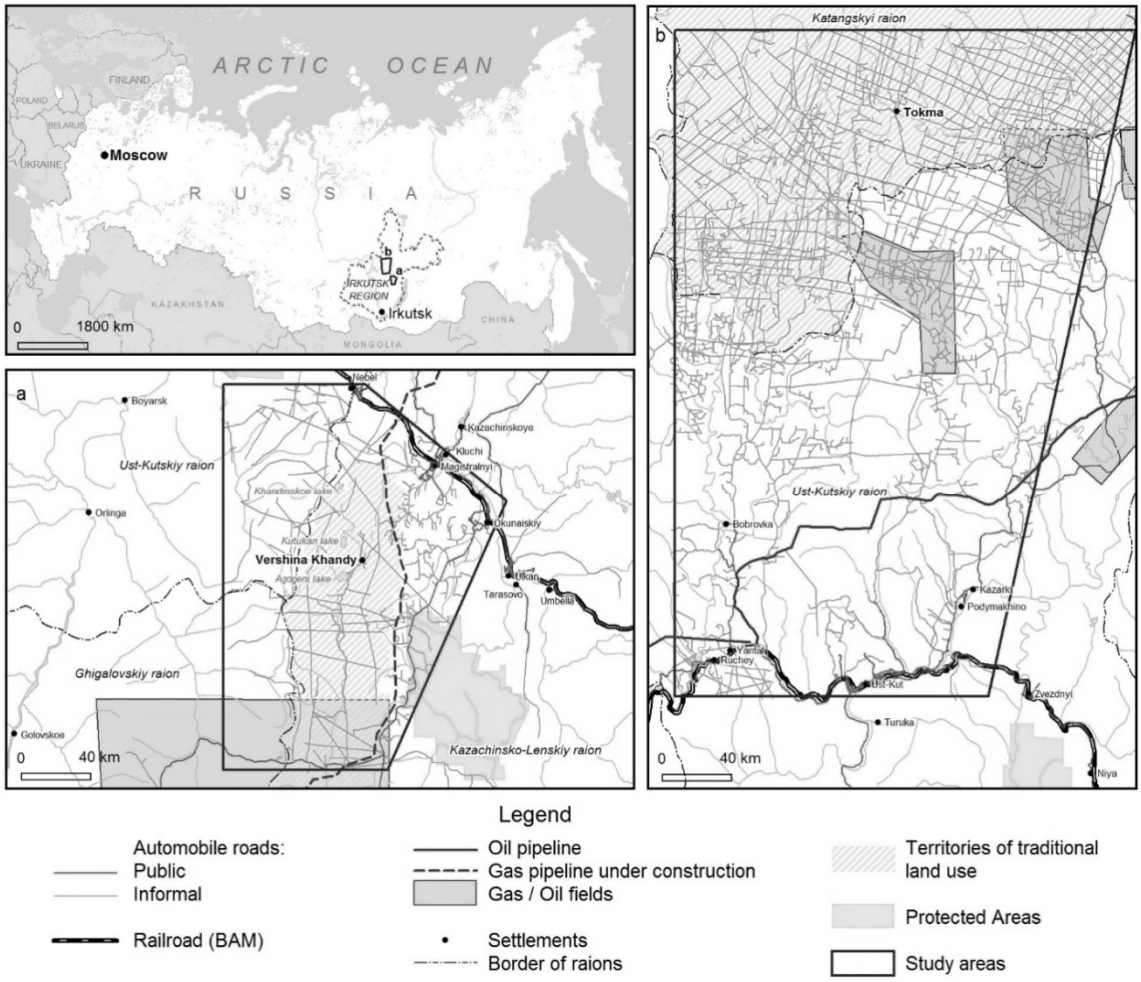

Figure 2. Study area

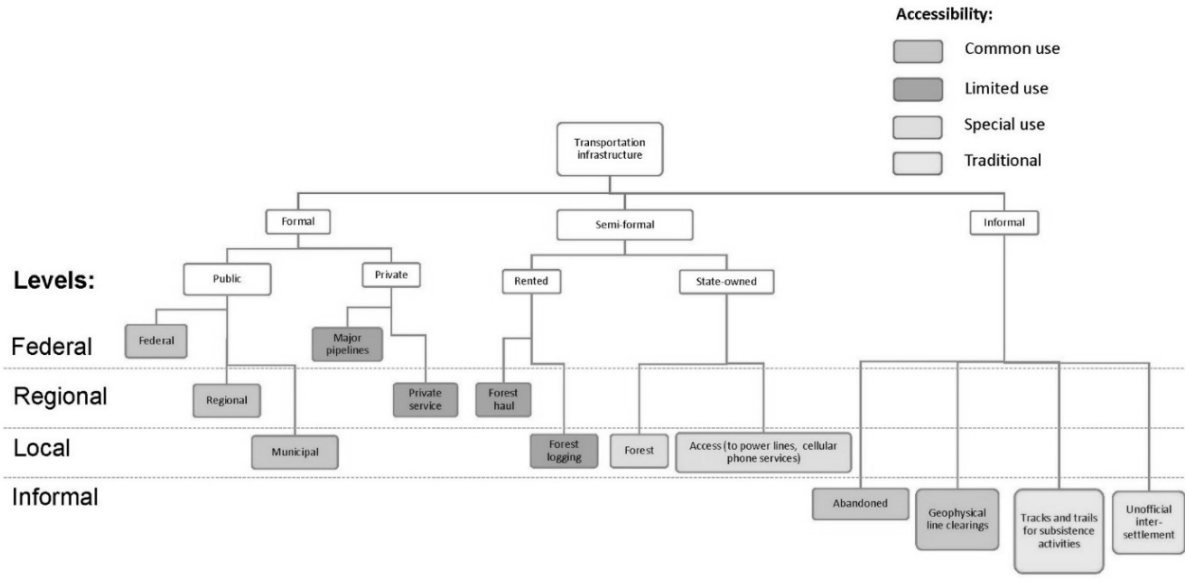

Figure 3. Informal roads classification

Finally, we tried to identify existing hierarchies that are materialized in the forms of pavings, right-of-way and regime of access. Partially, they conform to the Russian regulations on automobile roads and their environmental impact assessment. At the federal level, we distinguish federal roads and major infrastructure objects, at the regional: roads of regional significance, private service roads and the forest haul roads. At the local level, there are municipal roads and roads for forest logging. Informal roads represent an additional level where we list not only traditional roads, but also former official roads that have been abandoned and geophysical line clearings since specific regulations concerning roads and transportation infrastructure do not apply to them.

The landscape studies included measurements of soil erosion, permafrost degradation, vegetation condition. For this analysis, we verified data from remote sensing applying a variety of cartographic material, field studies, and data from engineering geological drilling.

Results

SETS at federal, regional and local levels of spatial hierarchy have similarities with existing regulations on automobile roads and their environmental impact, including categories of roads, ecological classes, zones of impact and protection, reserve technological strip, work project and specific recommendations for measures to mitigate the negative impact. Among techno-infrastructural characteristics, there are distance, traffic volume, specifications of infrastructure objects, and availability of engineering project. The socio-cultural aspects are limited by an investment plan and specific recommendations to mitigate negative social impact (Fig. 4).

Legend
Function
roads of common use
informal roads
oil and gas roads
forest haul roads
other
Railroad
Settlements
Border of raions
0 10 km

Roads		Total length	Affected area (km2)
Federal	railroad	65	97.5
Regional	roads of common use	317	317
Local	service roads	13	7.8
	municipal	23	13.8
	forestry	469	281.4
Traditional	geophysical line clearings	1146	114.6
	subsistence	111	11.1
Total		2144	843.2

Figure 4. Informal roads level

In the study area, the infrastructure of the federal level is represented by the Baikal-Amur Mainline (Fig. 5), Eastern Siberia–Pacific Ocean oil pipeline, and Power of Siberia gas pipeline under construction.

Decisions about construction are made at the highest state or international level and take a long time to implement. For example, discussions about BAM construction started in the end of 19th century, the call to build BAM was announced by the former Soviet Secretary Leonid Brezhnev in 1974 [14], and the project was fully completed only in 2013. The BAM includes over 4300 km of railroad, multiple side tracks and 200 stations, linking over 60 cities and towns and crossing over 2000 bridges across the territories of six federal subjects of East Siberia and the Russian Far East. It served as an impetus for local and regional economic development, changed transportation accessibility, and led to significant environmental problems in the region [15, 16].

However, even before the completion of the construction, the project was heavily criticized during the 1990s, and only state subsidies secured it from collapse.

Because construction of the major infrastructure has such profound impact across large territories, even anticipation of construction plays an important role in social dynamics [16, 17].

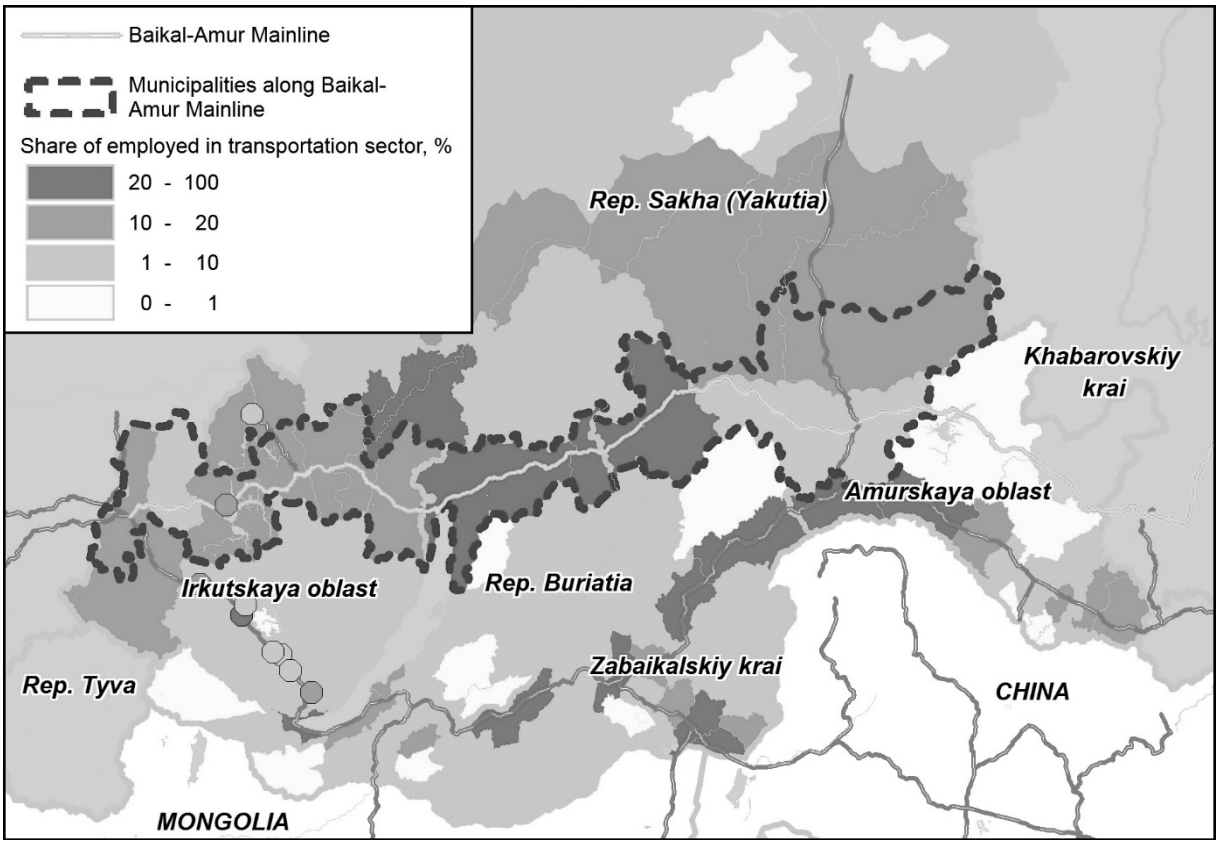

Figure 5. Study area

At the regional level, infrastructure is more adjusted to local engineering-geological conditions, and depends on major infrastructure and its configuration. In particular, we can see dramatic change in accessibility with construction of the Eastern Siberia–Pacific Ocean oil pipeline and adjacent service roads. However, the users of this private road are charged with the high price to access the road. From another side, control over the traffic and maintenance of infrastructure reduce poaching, forest wildfires.

At the local level, the development of forestry and access roads often has a seasonal and/or temporary character. They are often used by either heavy or light off-road vehicles. Lower quality of these roads leads to a shorter amortization period for vehicles. From an environmental perspective, they serve both as a barrier and cause to forest wildfires. Lack of maintenance leads to garbage accumulation and on wetlands and open areas the vehicles often create multiple tracks.

From social perspective, increased uncontrolled and unregulated accessibility along the roads for special and common use from one side increase opportunities for inter-settlement communication, access to services, opportunities to travel longer distances for subsistence activities. From another side, it leads to depletion of hunting and fishing resources due to poaching.

At the level of informal roads, we find that their share exceeds the share of the roads of all other levels combined, and the environmental impact estimated according to SNIP regulations can reach up to 12 % of the territory. These informal roads are used for both traditional activities by local residents and recreational fishing and gathering by non-locals.

The main function of traditional roads is to connect dwelling with subsistence place in the best way considering available infrastructure, natural conditions, vehicle capacities, and driver's skills and abilities. That makes these roads highly adaptive to changes. Particularly, they change location depending on emerging new infrastructure, technologies, environmental and resource conditions. Usually, they are narrow (about 2–3 meters wide) and stretch over short distances. However, with the development of technologies and infrastructure and lack of resources nearby the distance can increase. The most adapted to local conditions vehicles: snowmobiles and swamp buggies that have lighter imprint in the landscape. Within the time frame, their function is carried on for multiple generations while traditional ecological knowledge and values are preserved. Therefore, they are highly dependent on the existence of local and indigenous cultures.

To illustrate the dynamics of SETS, we take an example of the road between Zhigalovo and Ulkan settlements. It was planned to be constructed in the 19th century and depicted on the map from that period as the planned road to Bodaibo. Nonetheless, the plans have not been accomplished for almost a century.

The map of 1937 shows the absence of roads at that time. Most of the transportation and communication was still by the rivers and using traditional ways, which for Evenki was by reindeer trails.

In the 1960s, the geological explorations started in the region and led to development of geophysical line clearings.

In 1984, the main parts of the BAM were completed and forestry development along the BAM started. In addition, Krivolukskaya geological oil-gas exploration expedition was based in Zhigalovo for prospecting the area. In 1987, the Kovyktinskoye gas deposit was discovered. Used by these agencies local roads were impassable by ordinary motorized vehicles.

In 1992, TNC-British Petroleum, Interros and Irkutsk region founded collaborative Russia Petroleum enterprise for its exploration. They started permanent road construction that by 2004 was not completed. In 2011, with the changing political climate, Russia Petroleum sold license for exploration to Gasprom and the road was left for local uses.

In 2014, agreement about Strength of Siberia pipeline construction was signed between leaders of Russia and China and in 2018, Gasprom started re-construction of the road Zhigalovo — Kovyktinskoye as a part of their major infrastructure.

The investigated road from Vershina Khandy is formed by an old fishing route (7.2 km), an abandoned seismic line clearing (5.3 km), road created by locals informally (4.0 km), a private forest road (currently rented by Rusforest Magistralny LLC) (18.4 km), and a public road to the village of Magistralny (4.7 km).

Three types of characteristic surfaces with different relief are distinguished in this territory: denudation on wavy watersheds, the structural-erosive-denudation on the river valleys slopes, and the erosion-accumulative relief on floodplains and river terraces, lacustrine-accumulative and biogenic relief is widespread in the bottoms of the basins [18]. The studied territory has an average geomorphological hazard with a high probability of occurrence of karst, cryogenesis, planar and linear erosion processes [19]. Permafrost cracking and swelling of soils, thermokarst, and ice heaves are especially common for hollows and river basins bottoms.

Informal roads form country-road landscapes without a raised subgrade or paved surface prone to road erosion. Nearly two thirds of the road have roadside secondary birch forbs, while larch and spruce-larch moss forests with spruce form the background. In 8 kilometers from the village road lays over peatland with permafrost occurrences. In summer, local residents can cross it only by heavy or light cross-country vehicles. The road use is accompanied by thawing, watering, and subsidence of soils. At the same time, the moss cover dies, supplanted by sedges and reed grass. Local efforts to by-pass disturbed surface result in “multitracking”. Ravines (erosion potholes) were observed on the sections of the road with a slope steepness reaching 10°. Given the width of the carriageway of informal roads (an average of 6 m), the area of directly affected landscapes is approximately 1000 hectares, without taking into account indirect impact.

Discussion

Based on this short analysis of existing transportation infrastructure in the study area, its morphology and properties, we find it important to study hierarchies of infrastructure. Because uneven infrastructure access is illustrative of existing power relations; where local communities have limited options for negotiations.

Unequal status of different roads and hierarchy of relations between them are especially evident at the intersections. Unfortunately, it was impossible to take a picture of the right-of-way sign that ensures undisturbed movement of the vehicles along the oil service roads. However, the quality of their roads is also contrasting both in comparison with forest and winter roads for common use. Often, they are represented by bundles of different infrastructure components: both power lines and pipelines, or fibre-optic lanes or other objects that makes the lines large and inaccessible for the use by ordinary drivers.

Meanwhile, the service roads are often shorter, the lines are straighter, they have better location, and the other roads may toggle in parallel, contributing to the forest fragmentation. It is especially evident in Tokma area, nevertheless, in the Vershina Khandy area, we see path dependency on the previous seismic line clearings location. The gas pipeline has not been built yet, but one can assume significant disruptions in local mobilities since the line crosses the main access roads to the village.

Hierarchies of infrastructure determine infrastructural violence, while the other users lacking power have to seek consensus and negotiate use of infrastructure. Ownership recognized only at the higher levels of hierarchy while customary low is neglected.

Such hierarchies have certain impact on landscape, such as fragmentation, contamination, and degradation and on local (im)mobilities by restricting, regulating, and channeling them.

Intersectionality of roads affects social intersectionality. The travel by roads with lower quality is not physically demanding, it also provides visible marks of power hierarchies when crossing well-maintained elements of infrastructure of higher level.

Implications of the road development for technological-infrastructural domain are increased by those who travel between BAM settlements and regional center of Irkutsk; lower crossing capacities for the vehicles and driving skills are required with road quality improvement; amortization period for vehicles increased. In the social-cultural domain, there is an increased accessibility of subsistence resources to non-locals, opportunities for local Evenki to sell their products of subsistence activities to the passersby. Access to the regional center for the local communities significantly improved and for local entrepreneurs new opportunities were open for shipping goods. In the environmental domain, road caused erosion on steeper slopes, waterlogging in swampy areas, spread of invasive species along with the road and dust.

Based on research of SETS in the study area we distinguish the following driving forces of dynamics sets (Fig. 6).

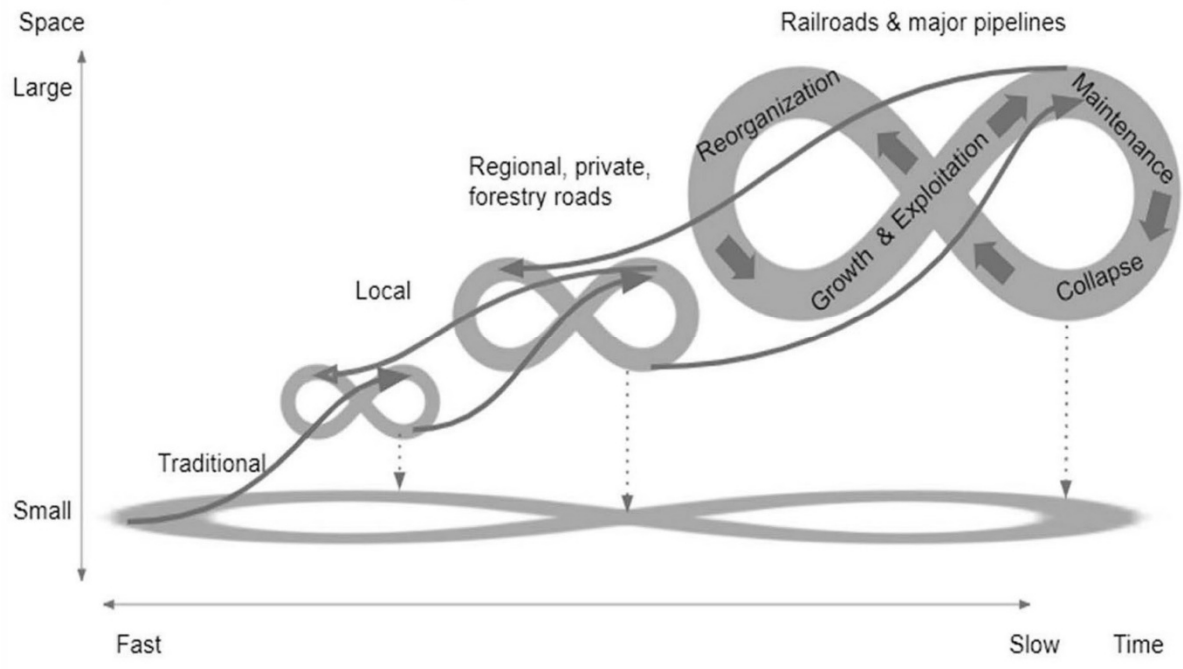

Figure 6. Dynamics in transportation SETS components of the study area

Large scale infrastructure (railroad and major pipelines) corresponds to large social-ecological systems and requires significant state and international investments for their creation and maintenance. Their relations with the lower levels are strongly hierarchical in the case study in Russia. At the regional scale, prospects of economic development which follow development of major infrastructure are important. Local SETS develop faster and have smaller cycles of functioning and can at the latter stages transform into the regional SETS, as the case with Zhigalovo – Ulkan road demonstrates.

Informal roads have the lowest scale and have both fast and slow cycles since they constantly adapt to changes at the higher scales. As for traditional roads, the most important factor for their existence is preservation of local and indigenous cultures. Some of these roads can evolve into local SETS.

Moreover, collapse of any SETS of any scale can theoretically lead to their transformation into traditional roads. Degrees of flexibility decrease with growing scale of infrastructure while the rigidity increases: federal infrastructure is the most rigid. The higher level also requires higher level of predictability (e.g. in terms of minutes for railroad).

Conclusions

Our study demonstrates that the panarchymodel is useful for studies of SETS. In difference with the social-ecological systems approach, in studies of SETS, we emphasize importance of new technologies, maintenance efforts, crucial role of investments and social values embedded in infrastructure. Technologies and infrastructure directly affect ecological flows and human mobilities, and without their consideration the knowledge on human-nature relations will be incomplete. However, application of the same methods for studies of SETS as for SES is possible, because adaptive cycles and interactions across scales have some similarities.

More studies are needed to determine the input of each driving force and measure the interactions within SETS. Using the panarchy approach, we can better understand sustainability, resilience, and adaptive capacities of such complex systems as SETS for informed decision making and local knowledge co-production.

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Әлеуметтік, экологиялық және технологиялық жүйелер (ӘЭТЖ) ретінде бейресми жолдар: тұрақты даму мәселелері және ландшафттың өзгеруіне әсері

Әлеуметтік-экологиялық жүйелер мен әлеуметтік-техникалық жүйелерді зерттеуді тереңдету міндеттерін басшылыққа ала отырып, мақала авторлары Байкал аймағындағы бейресми жолдардың әлеуметтік, табиғи және технологиялық (инженерлік) элементтерін қамтитын әлеуметтік-экологиялық-технологиялық жүйелерге (ӘЭТЖ) жан-жақты тақырыптық талдау ұсынған. Сонымен қатар олардың пікірінше қайта бағдарлану, атап айтқанда, ӘЭТЖ байланысты жүйелер мен инфрақұрылымды түсінуді жақсарту үшін өзара әрекеттесу мен конвергенция үшін қосымша мүмкіндіктер жасайды деп көрсетеді. Тарихи тұрғыдан алғанда, көлік инфрақұрылымы Солтүстік Еуразияның табиғи және әлеуметтік жүйелерінің өзгеруіне ықпал етті: Транссібір және Байкал-Амур темір жолдары, ал қазіргі уақытта Шығыс Сібір — Тынық мұхиты мен Сібір қуаты құбырлары әлеуметтік-экологиялық қайта құрудың негізгі қозғаушы күштері болды. Жергілікті жерлерде бейресми жолдар ӘЭТЖ ең жарқын және сипатты үлгілерінің бірі болып табылады. Бейресми жолдардың дамуы мен өзгеруін зерттеу әлеуметтік-экономикалық процестер, экологиялық динамика және технологиялық прогресс арасындағы қатынастарды зерттеуге мүмкіндік береді. Осылайша, бейресми жолдардың әртүрлілігі нақты әлеуметтік, табиғи немесе технологиялық факторлардың саясат пен ережелерден туындамайтындығының маңыздылығын көрсетеді, бұл инфрақұрылымдық жиынтықтардың тұрақтылық мәселелерін жақсы түсінуге мүмкіндік береді. Байкал аймағында 2019 жылы жүргізілген сұхбаттар мен бақылаулар бейресми жолдардың тұрақтылығына әсер ететін мына факторлар анықталған: әлеуметтік (бейресми жолдарды орналастыруға, салуға, қызмет көрсетуге, пайдалануға және одан бас тартуға қатысатын субъектілерді анықтау), технологиялық (жол жамылғысы, ені, жиілігі және әр түрлі көлік түрлерін пайдалану сипаты), экологиялық (геоморфология, ландшафттың осалдығы және бұзылуы). ӘЭТЖ дамуы мен қайта құрылуының тұрақтылығы мәселелері көлік қозғалысының қалыптасқан тәжірибесін, жергілікті қоғамдастықтардың әлеуметтік құрылымы мен экономикасын өзгерту, орман өрттерінің көбеюі және осы аумақта мәңгі тоңның эрозиясы мен деградациясының дамуы, сондай-ақ көлік пен байланыстың жаңа технологияларын дамытуды жоспарлау болып табылады.

Кілт сөздер: бейресми жолдар, пайданы бөлу, кен өндіруші кәсіпорын, көлік инфрақұрылымы, байырғы халықтар, геожүйелерді қайта құру.

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Неформальные дороги как социальные, экологические и технологические системы (СЭТС): проблематика устойчивого развития и влияние на преобразования ландшафта

Руководствуясь задачами углубления исследования социально-экологических систем и социотехнических систем, авторы статьи представили комплексный тематический анализ социально-эколого-технологических систем (СЭТС) и динамических систем, включающих социальные, природные и технологические (инженерные) элементы неформальных дорог в Байкальском регионе. Кроме этого, по их утверждению, переориентация на СЭТС создает дополнительные возможности взаимодействия и конвергенции для улучшения понимания сопряжённых систем и инфраструктуры, в частности. Исторически сложилось так, что транспортная инфраструктура, в целом, способствовала изменениям в природных и социальных системах в Северной Евразии: Транссибирская и Байкало-Амурская железные дороги, а в настоящее время трубопроводы Восточная Сибирь – Тихий океан и Сила Сибири были основными движущими силами социально-экологических преобразований. В местном масштабе неформальные дороги служат одним из наиболее ярких и характерных примеров СЭТС. Изучение развития и трансформации неформальных дорог позволяет исследовать взаимосвязи между социально-экономическими процессами, экологической динамикой и технологическим прогрессом. Таким образом, разнообразие неформальных дорог демонстрирует важность конкретных социальных, природных или технологических факторов в трансформации СЭТС, в значительной степени не обусловленных политикой и нормативными актами, предоставляя уникальную возможность для лучшего понимания проблем устойчивости, с которыми сталкиваются инфраструктурные СЭТС. Проведенные в 2019 г. в Байкальском регионе интервью и наблюдения на местах позволили выявить следующие факторы, влияющие на устойчивость неформальных дорог СЭТС: социальные (выявление субъектов, участвующих в размещении, строительстве, обслуживании, использовании и отказе от неформальных

дорог), технологические (дорожное покрытие, ширина, частота и характер использования различными видами транспорта), экология (геоморфология, уязвимость и нарушенность ландшафта). Проблемы устойчивости развития и преобразований СЭТС заключаются в изменении сложившейся практики передвижения транспорта, социальной структуры и экономики местных сообществ, учащении лесных пожаров и развитии эрозии и деградации вечной мерзлоты на данной территории, а также в стимулировании развития новых технологий транспорта и связи.

Ключевые слова: неформальные дороги, распределение выгод, добывающая промышленность, транспортная инфраструктура, коренные народы, трансформация геосистем.

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Систематический обзор методов оценки влияния массового туризма на природно-территориальные комплексы Субарктики и Арктики

В статье впервые представлен систематический обзор иностранных практико-ориентированных научных трудов, описывающих методы изучения влияния туристской деятельности на природно-территориальные комплексы Субарктики и Арктики с общим анализом их эффективности для планирования туристско-рекреационного пространства. Результаты большинства прикладных исследований свидетельствуют о том, что субарктические и арктические природные комплексы менее толерантны и наиболее подвержены к негативному воздействию от массового туризма, медленно восстанавливаются. Например, наиболее устойчивые к фактору туризма и рекреации ерниково-моховые и травяно-моховые тундры, а лишайниковые, пушицево-осоковые тундры наиболее уязвимые. Степень устойчивости природных комплексов к туристско-рекреационным воздействиям определяется не величиной общего запаса надземной биомассы, а его структурой. На первоначальном этапе проектирования туристско-рекреационного пространства, в природной среде Арктики и Субарктики, в первую очередь, необходимо проводить исследования по оценке линейной и площадной рекреационной нагрузки, во избежание негативных последствий массового туризма.

Ключевые слова: массовый туризм, рекреационное природопользование, Арктика, Субарктика, рекреационная нагрузка, природно-территориальные комплексы, методы исследования, систематический обзор.

Введение

Северные территории — это труднодоступные и экзотические по своей природе регионы, которые в последние десятилетия стали привлекательными не только своими ресурсами, промышленностью и экономическим потенциалом, но и с точки зрения развития туристско-рекреационной деятельности [1]. Активное развитие массового туризма в Арктике и Субарктике в большинстве случаев ведет к нерациональному рекреационному освоению территорий, что чаще всего приводит к негативным экологическим последствиям.

Многочисленные исследования в области рекреационной экологии свидетельствуют о том, что восстановление растительного надпочвенного покрова после наносимого ущерба от массового туризма происходит очень медленно и может занять десятилетия [2]. Данную точку зрения поддерживает в своих исследованиях о скорости восстановления арктической тундры на Аляске D.A. Walker, который пришел к выводу о том, что большинство однократных нарушений приводит к быстрому восстановлению, но постоянные многократные нарушения наносят масштабный ущерб экосистемам. По словам M. Colin, из-за низкого порога чувствительности экосистем даже самые незначительные изменения, в некоторых арктических ландшафтах могут вызвать серьезные долгосрочные негативные последствия для жизнедеятельности растений и животных.

Ущерб также наносят и транспортные средства повышенной проходимости, пересекающие чувствительную арктическую поверхность суши. Например, в норвежском архипелаге Шпицберген существует проблема, вызванная нерегулируемым передвижением вездеходной техники, в т.ч. снегоходов [3]. Туристы, использующие снегоходы для путешествий, оказывают разрушительное воздействие на рост растений, особенно там, где небольшая мощность снежного покрова. Нерегулируемое использование снегоходов привело к тому, что норвежская экологическая организация Naturvern Forbundett выступила против увеличения числа туристов. A. Viken утверждает, что в результате интенсивного передвижения транспортных средств на архипелаге Шпицбергена потребуются сотни лет, чтобы их следы исчезли [4].

Выявленные проблемы во взаимоотношении человека с природой побудили необходимость в проведении междисциплинарных научных изысканиях, направленных на поиск механизмов оптимизации рекреационного природопользования. Особенной глубокой научной проработки требуют субарктические и арктические регионы, так как в северных широтах даже незначительное влияние могут нанести непоправимый вред и без того хрупкой природе.

Первые наблюдения влияния рекреационной деятельности на природные среды появились в 20–30-х гг. прошлого столетия в Америке и Англии [5]. В мировой научной практике, в том числе и отечественной, основа рекреационных исследований была заложена в конце 60-х – начале 70-х гг. XX века [6]. Подобные исследования проводились исключительно в умеренном, субтропическом, тропическом, субэкваториальном климатических поясах. В субарктических и арктических территориях вопросы влияния туризма на экосистемы были единичны и приурочены к определенной местности.

В России после вступления в силу «Стратегии развитии Арктической зоны РФ до 2020 года» и Государственной программы «Социально-экономическое развитие Арктической зоны РФ на период до 2020 г.» на высшем уровне была закреплена задача — превращение арктического региона в привлекательную туристскую дестинацию, активизировался процесс развития туристской отросли [7]. С этого времени отмечается всплеск научных исследований, посвященных различным тематикам, от обзоров туристских и рекреационных резусов северных регионов Российской Федерации до конкретных проблем развития арктического туризма — логистика, ценообразование и формирование туристского продукта, развитие отдельных видов туризма, оценки инфраструктуры и возможностей её быстрого масштабирования [8–11]. Однако из всего многообразия исследовательских работ вычленить труды, которые были бы концептуально сфокусированы на экологическую составляющую в северных регионах, крайне трудно [12–14]. Это связано с тем, что при всем разнообразии существующих методических подходов, используемых для планирования, мониторинга и оптимизации рекреационного природопользования, адаптированных для субарктических и арктических регионов, в том числе высокоширотных горных систем, фактически нет.

В связи с этим целью настоящего исследования является анализ научных источников, посвященных методам оценки влияния массового туризма на природно-территориальные комплексы Субарктики и Арктики и определения их эффективности для планирования и развития туристско-рекреационного пространства.

Методы и этапы исследования

Анализ научных трудов осуществлялся путем использования технологии систематического обзора научно-исследовательских работ. Систематический обзор (далее — СО) направлен на предоставление полной и исчерпывающей информации научных трудов, относящихся к исследовательскому вопросу. СО подразумевает проведение пяти этапов [15]: 1) определение темы и проблематики исследования; 2) идентификация соответствующих исследований; 3) разработка критериев включения и исключения научных исследований; 4) составление матрицы исследования; 5) сопоставление, обобщение и представление данных проведенного исследования.

В рамках настоящего исследования систематический обзор осуществлялся путем реализации четырех этапов. На первом этапе была сформулирована проблематика работ для определения направлений исследований, в которых освещены методики оценки влияния рекреации на природно-территориальные комплексы (далее — ПТК) северных регионов.

На втором этапе велась работа по созданию библиографической базы по проблематике исследования. Поиск осуществлялся в естественнонаучных тематических направлениях в трёх электронных библиотеках: крупнейшей электронной библиотеке России «eLIBRARY.RU», научной библиотеке disserCat и ведущей иностранной платформе рецензируемой научной литературы «Elsevier». Идентификация нужной литературы осуществлялась с использованием комбинаций ключевых слов из следующих категорий поиска (табл. 1).

На третьем этапе было реализовано включение и исключение работ на основе разработанных критериев отбора для более четкого выявления направлений научных исследований (табл. 2). Включались только те публикации, в рамках которых были описаны методы, критерии оценки влияния рекреации на природно-территориальные комплексы. Особое внимание уделялось публикациям, посвященным изучению экологического состояния природно-территориальных комплексов Субарктики и Арктики в условиях интенсивного рекреационного освоения.

Таблица 1

Категории поиска по проблематике исследования

Категории поиска	Ключевые слова
География исследования	Заповедник, заказник, национальный парк, природный парк, лесопарки
Методы исследования	Определение критической нагрузки, временная методика, метод пробных площадей, трамплеометрический метод, моментный метод, математический метод, трансектный метод, оценка воздействия на окружающую среду, оценка текущей ёмкости, учет посетительской нагрузки, предел допустимых изменений, социологический (опросы, анкеты), геоинформационный, статистический, медико-биологический, эстетический, экспериментальный методы
Виды туристской и рекреационной активности	Пеший, водный, горнолыжный, конный, велосипедный, экологический, прогулочно-промысловый, рыболовный и охотничий, джипинг, туры выходного дня

Таблица 2

Критерии включения и исключения научных работ по теме исследования

Критерии	
включения	исключения
Субарктическая и арктическая зона, тундра и лесотундра, северная тайга, горные территории	Населенные пункты, городские парки. Южные широколиственные леса, степи, пустыни и полупустыни, южная тайга, тропические леса
Природные ресурсы, историко-культурные ресурсы, социально-экономические ресурсы, фактическая и имитированная оценка, разработаны механизмы рационального рекреационного природопользования	В статьях представлен обзор рекреационных ресурсов. В работах преобладает теоретический материал. Нет конкретных предложений по оптимизации рекреационных ресурсов
Влияние рекреации и туризма на окружающую среду (шумовое, уплотнение почвы, загрязнение поверхностных и грунтовых вод, вытаптывание надпочвенного покрова, исчезновение редких представителей флоры и фауны, эрозионные процессы)	

В рамках четвертого этапа был проведён детальный анализ каждой включенной публикации и составлена матрица исследования, на основе которой проведен анализ эффективности методов при реализации проектов по планированию туристско-рекреационного пространства.

Результаты и обсуждение

В общей сложности проанализировано 833 научных работ, из них 428 иностранных исследований. Всего в исследование включены 65 иностранных (Северная Америка (Аляска), Канада, Норвегия, Швеция, Исландия, Финляндия, Дания, Великобритания (гонная местность) и российских публикаций (субъекты, входящие в состав Арктической зоны Российской Федерации). Временной отрезок анализируемой литературы составляет 92 лет (1929–2021 гг.). Данный период времени позволил выявить основные фазы становления методологических основ исследований в области рекреационной экологии.

Обзор научных трудов помог определить ключевые направления в изучении влияния массового туризма на ПТК Субарктики и Арктики.

Первое направление несет в себе количественный подход, который основывается на фактическом полевом описании участков интенсивного туристско-рекреационного использования и экспериментах по определению устойчивости растительного покрова к различным видам рекреации и туризма.

Второе направление представляет собой качественную оценку состояния туристских троп и мест отдыха туристов (кемпинг), включающий в себя: визуальный мониторинг, использование ГИС-технологий, GPS, аэрофото, видеосъемки и др.

1. Фактические полевые и экспериментальные исследования. Изучение изменений физических и морфологических характеристик растительности и почв в результате рекреационной активности является одной из распространённых тем иностранных исследований [16–18]. Впервые комбинацию аналитических и экспериментальных подходов в этой области применил английский ученый

G.H. Bates в 30-х гг. XX века. Результаты его исследований позволили сделать вывод о том, что рекреационная деятельность оказывает негативное механическое воздействие на растительность, так и косвенное, изменяя физические свойства почв [19]. Следующие три десятилетия последовали многочисленные эксперименты в США. Однако ранние работы в основном носили описательный характер и имели жёсткую привязку к определённой территории, редко публиковались [20]. В скандинавских странах (Норвегии, Швеции и Финляндии) исследования экологических последствий, вызванные рекреационной деятельностью, появились намного позже, чем в США. Подавляющее большинство научных исследований не опубликованы или доступны на государственных языках [21]. С конца 70-х – начала 80-х гг. XX века возросший спрос на отдых во всем мире привел к усилению влияния рекреации на природную среду. В результате чего эксперименты по вытаптыванию были активно интегрированы с системой управления рекреационной территории. Начиная с 1990-х гг. и по настоящее время, экспериментальный подход постоянно совершенствуется [22]. Алгоритм проведения подобных исследований подробно описан в работах N.G. Bayfield (1979, 1993), S. Kellomakii (1977, 1980), D.N Cole (1986, 1995) и других. Суть экспериментального подхода заключается в том, что на заложенных экспериментальных тропах, обычно в трех или пяти кратных повторностях (размеры троп варьируются от 0,3×3 м до 0,4×1,5 м), выполняется контролируемое вытаптывание растительного покрова, с фиксацией количества проходов (см. рис.).

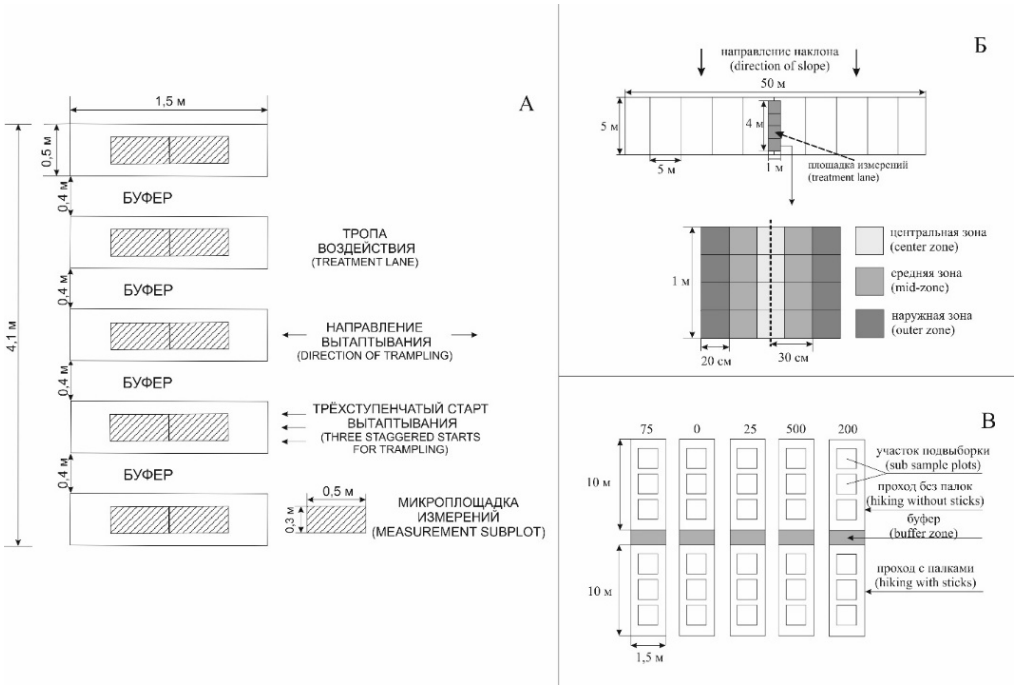

Рисунок. Примеры заложения экспериментальных площадок для выполнения, контролируемого вытаптывания, предложенные: *А* — Cole D.N, Bayfield N.G. (1993); *Б* — Thurston E., Reader R.J. (2001); *В* — Gatzouras M. (2015)

В центре каждой тропы закладываются микроплощадки размерами (1×1 м; 0,3×0,5 м; 0,4×0,4 м), на которых измеряются следующие параметры:

– визуальная оценка проективного покрытия каждого вида сосудистого растения, мхов и лишайников (в процентах);
– визуальная оценка почвы, не покрытой растительностью (в процентах);
– определение высоты растительности с помощью точечного квадрата с 5-ю колышками высотой 5 см;
– отбираются пробы почв на глубине 10 см, для определения форм азота.

Далее устойчивость каждого отдельно вида растительности рассчитывается показатель относительного проективного покрытия (relative cover — *RC*):

$$RC = \frac{\text{сохранившийся покров на вытоптанных участках}\ (\text{surviving cover on trampled subplots})}{\text{исходное покрытие на вытоптанных участках}\ (\text{initial cover on trampled subplots})} * cf * 100\ \%,$$

где

$$cf = \frac{\text{исходное покрытие на конкретных участках}\ (\text{initial cover on control subplots})}{\text{сохранившийся покров на конкретных участках}\ (\text{surviving cover on control subplots})}.$$

Полученные результаты визуализируются в виде графиков для оценки износа каждого отдельного вида растения или, в целом, растительного сообщества.

Минус метода заключается в том, что вытаптывание осуществлял один и тоже человек, что оказывает влияние на конечный результат. Кроме того, интенсивность вытаптывания одинаковая, что снижает применение данного метода при организации зон отдыха.

В северных широтах данный метод применялся в Финляндии (Kellomaki, 1975,1977,1980; Torn, Rautio и др., 1999), Канаде (Taylor, Reader, Larson, 1993; Thurston, Reade, 2001), США (Аляске) (Monz, 2002), Норвегии (Gellatly, Whalley, Gordon, Ferguson, 1986), Исландии (Gatzouras, 2015), а также в России на Полярном, Северном и Южном Урале (Андреяшкина, Пешкова, 1997).

Анализ данных работ позволяет сделать вывод о том, что субарктические и арктические растительные сообщества наиболее чувствительны к воздействию и медленно восстанавливаются, из-за низкой продуктивности в сочетании маломощности почв, короткого вегетационного периода и сурового климата.

2. Методы мониторинга рекреационных троп и мест отдыха туристов (кемпинг). Многократное использование троп и кемпинга фрагментирует природную среду и приводит к дальнейшим изменениям через расширения тропы (появлению второстепенных троп), формированию эрозионных процессов (например, оврагов), угнетению растительности и увеличению проникновения синантропных видов растений, а также наносится значительный ущерб почве, а именно уплотняя её и угнетая корневую систему [23–25]. В связи с чем в иностранных научных трудах существуют разнообразные методы оценки образования эрозионных процессов в результате интенсивного использования линейной и площадной туристской инфраструктуры (табл. 3).

Таблица 3

Примеры методов мониторинга туристских троп и кемпинга (составлено автором)

Метод	Краткая характеристика
1	2
Классификация условий (Condition Class Method)	Присваивается определенный класс нарушенному участку тропы или кемпингу. Недостатки метода заключаются в том, что он опирается на одну качественную величину. Он прост в использовании, не требует больших затрат и специальной подготовки
Инвентаризация эрозионных процессов (Census of Erosional Events)	Определяются эрозионные процессы. После чего проводится их инвентаризация. Минус метода заключается в том, что требует высокой квалификации специалиста, который будет проводить исследование. Плюс метода — в короткие сроки позволяет оценить состояние тропы и предоставляет исчерпывающую информацию о частоте, степени и распространении проблем эрозионных процессов
Метод поперечного сечения (Cross-Section Area Method)	С обеих сторон тропы натягивается веревка или мерная рулетка, закрепленная на хорошо зафиксированных колышках или деревьях, затем отвесом или уровнем проводятся вертикальные измерения. Площадь вертикального сечения вычисляется (A) по формуле: $A = \frac{V_1+2V_2+\cdots 2V_n+V_{n+1}}{2} x L$, где $V_1 - V_{n+1}$ — вертикальные измерения (см); L — интервал (5 или 10 см) горизонтальной натянутой веревки или мерной рулетки. Затем строится профиль тропы. Недостаток метода заключается в чрезвычайно трудоемком процессе установки необходимого оборудования для проведения измерений. Необходима высокая квалификация специалистов. Требует больших затрат для обучения специалистов. Процесс измерений занимает много времени. Использование данного метода позволяет получить очень точные измерения эрозионных процессов

Продолжение таблицы 3

1	2
Фотографическая оценка стереоизображений (Stereo Photography)	По заложенному трансекту делается серия фотографий, при этом для сохранения масштаба необходимо иметь подробную топографическую карту местности. Затем полученные данные анализируются и оцифровываются на стереоплоттере. Недостаток метода заключается в получении качественных снимков, связанные с наличием растительности и природными условиями. Позволяет точно идентифицировать динамический процесс эрозии троп
Аэрофотосъемка (Aerial Photo Appraisal)	Проведение аэрофотосъемки троп. Осуществляются дешифрирование и оценка стереоизображения. Минус метода — трудно выдержать определенный масштаб аэрофотоснимков. Качество фото зависит от погодных условий проективного покрытия и сомкнутости крон. Трудность дешифрирования снимков, определение вытоптанной и угнетенной растительности. Плюс метода — определение реальных тенденций эрозионных процессов
Многоиндикаторный метод (Multiple indicator methods) с использованием GPS и GIS	Метод основывается на визуальных оценках изменений состояния природной среды в местах отдыха туристов (кемпинг). После чего проводится классификация кемпинга по уровню влияния на природную среду. Плюс метода — в простоте его использования
Трамплеометрический метод (Trampleometers)	В почву через равный интервал втыкают тонкие малозаметные кусочки проволоки длиной 3–5 см. Расстояние между кусочками проволоки может варьироваться и зависит от интенсивности движения на тропе, а также длины трансекта. Например, для транксекта в 10 м подходит интервал 10 см, с длиной 150 м и более — 20 см и 30 см. Затем через каждые 2–24 ч фиксируется количество согнутых проволок, после чего их снова выпрямляют для дальнейших измерений. Полученные данные визуализировались в виде гистограммы, которая дает более четкое представление о степени вытаптывания тропы. Данный метод является эффективным даже в местах со сравнительно невысокой посещаемостью

Изложенные выше методы используются как отдельно, так и в синтезе, что позволяет значительно упростить процесс анализа данных и получить достоверную информацию о современном состоянии сети туристских троп и мест отдыха (кемпинга). Полученные материалы дают возможность менеджерам туристской дестинации сформулировать более эффективную модель управления туристским пространством, в целях минимизации влияния туристских троп и кемпингов на природную среду.

Комбинации данных методов широко использовались для мониторинга горных тропиночных сетей на северо-западе Англии (Coleman, 1977, 1981), субальпийской и альпийской растительности высокогорья и нагорья Шотландии (Watson 1984,1985, 1991; Aitken 1985; Lance 1989, 1991; Legg 2000; Morroco, Ballantyne 2007), гор Северной Ирландии (Ferris, Lowther, Smith 1983) и северной Норвегии (Gellatly, Whalley, Gordon, 1986; Pounder, 1985).

Примером использования комбинации методов «Классификации условий (Condition Class Method)», «Многоиндикаторный метод (Multiple-indicator methods)» с добавлением технологии системы определения местоположения (GPS) и ГИС-технологий являются работы, проведенные R. Olafsdottir, M.C. Runnstrom (2007, 2013), в которых осуществлялась оценка состояния тропичной сети в двух популярных природных заповедников «þórsmörk» и «Fjallabak» в Исландии. Основными показателями оценки выступили: 1) ширина тропы; 2) глубина тропы; 3) изменение экосистемы — отношение состояния растительного покрова и почвы на тропе по сравнению с их состоянием вокруг тропы; 4) эрозия почвы.

Оценка индикаторов осуществлялась на площадках 2×2 м, с каждой стороны тропы. Для упрощения проведения исследования авторами предложена система классификации состояния туристских троп. Для интегральной оценки каждому выделенному показателю присваивается балл от 0 до 3, в зависимости от их состояния. Затем общий показатель состояния туристской тропы определяется путем суммирования присвоенных баллов. По итогам проведенного исследования авторами составлена система классификации пеших маршрутов для оценки их состояния, позволяющая проводить регулярный мониторинг состояния троп, в целях отслеживания изменений, тем самым повышая целостное понимание существующих проблем и принятия необходимых управленческих решений для рационального использования уязвимых экосистем исландской горной местности.

Таким образом, устойчивость каждого природно-территориального комплекса может варьировать в ту или иную сторону, что зависит от ряда факторов, таких как механический состав почв; влажность почвы; мощность гумусового горизонта почвы; уклон поверхности; состав древостоя и строение корневой системы основных пород деревьев; запас биомассы и видовой состав растительности [26] (табл. 4).

Таблица 4

Сводная матрица систематического обзора методов оценки влияния массового туризма на ПТК Субарктики и Арктики (составлено автором)

Авторы / год	Страна*	Методы исследования**					Индикаторы***				Основные выводы
		ПН	ПИ	ПЭ	ГИС/ GPS	Соц. иссл.	В	Р	П	С	
R.B. Bryan (1977)	Ш	X	X					X	X		Маломощные и однородные почвы подвержены более сильным изменениям
S. Kellomaki (1975, 1977)	Ф			X			X				Изучено влияние дозированных рекреационных нагрузок на различные типы растительности лесов. Отнесены в группу устойчивых видов злаки и некоторые виды разнотравных сообществ
I.M. Bjonness (1981)	Н	X			X	X	X			X	Классификация устойчивости растительности к вытаптыванию и определение зон интенсивного использования
E.J. Pounder (1981, 1985)	Н	X		X			X	X			Критический порог для альпийской растительности не должен превышать 17 тыс. проходов
A.F. Gellatly, W.B. Whalley, J.E. Gordon, R.I. Ferguson (1986)	Н			X			X		X		Путем проведения эксперимента было установлено, что после 200 проходов растительность угнетается на 30 %, почва изменяет свои свойства (становится рыхлой)
Н.И. Андреяшкина, Н.В. Пешков (1997)	Р			X				X			К фактору рекреации наиболее устойчивы ерниково-моховые и травяно-моховые типы тундры, а особенно уязвимы цветковые растения
A. Törn, J. Rautio, Y. Norokorpi, A. Tolvanen (2006)	Ф			X			X			X	Конные маршруты так же, как и пешеходные, меняют физические свойства тропы (глубину, ширину и плотность почвы), при этом ежегодное число пеших туристов в 150 раз превышает число конных. Выявлено, что верховая езда оказывает наибольшее влияние на физические характеристики троп
C.A. Monz (2002)	США Аляска		X	X			X				Дриадовая тундра наиболее устойчивая к вытаптыванию, чем кочковатая тундра
C.A. Monz, P. Twardock (2010)	США Аляска		X		X		X	X	X		Многофакторный подход позволил провести оценку воздействия кемпинга на природную среду. Составлена классификация кемпингов с минимальным и максимальным воздействиями
R. Ólafsdóttir, M.C. Runnström (2013)	И	X	X		X		X	X			Разработана система классификации для оценки состояния туристских троп. Преимущество данной классификации — в простоте использования

Примечание. Страна*: К — Канада; Н — Норвегия; США — Аляска; И — Исландия; Ш — Швеция; Ф — Финляндия; В — Великобритания; Р — Россия.
Методы исследования**: ПН — полевые наблюдения; ПИ — полевые измерения; ПЭ — полевой эксперимент; ГИС — геоинформационные исследования; Соц. иссл. — социологические исследования.
Индикаторы***: В — вегетативные факторы; Р — рельеф; П — почвенные факторы, С — сезонность.

Заключение

Проведенный систематический обзор научной литературы, связанный с изучением влияния массового туризма на природно-территориальные комплексы Арктики и Субарктики, позволяет сделать следующие выводы:

1) методы исследования в рекреационной экологии на протяжении многих лет совершенствовались и дополнялись (от фактических наблюдений состояния ПТК до использования современных ГИС-технологий, аэрофотосъемки), вместе с ними внедрялись индикаторы оценки состояния ПТК;

2) большинство прикладных исследований используют перечисленные выше методики в синтезе, что увеличивает их эффективность и позволяет получить достоверную информацию о воздействии массового туризма на ПТК;

3) результаты большинства прикладных исследований свидетельствуют о том, что субарктические и арктические ПТК менее толерантны и наиболее подвержены к негативному воздействию от массового туризма, медленно восстанавливаются. Например, наиболее устойчивыми к фактору туризма и рекреации являются ерниково-моховые и травяно-моховые тундры, а лишайниковые, пушицево-осоковые тундры наиболее уязвимые. Степень устойчивости ПТК к туристско-рекреационным воздействиям определяется не величиной общего запаса надземной биомассы, а его структурой;

4) на первоначальном этапе проектирования туристско-рекреационного пространства в природной среде Арктики и Субарктики, в первую очередь, необходимо проводить исследования, направленные на оценку линейной и площадной рекреационной нагрузки, во избежание негативных последствий массового туризма.

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Р.И. Локтев

Жаппай туризмнің Субарктика мен Арктиканың табиғи-аумақтық кешендеріне әсерін бағалау әдістеріне жүйелі шолу

Мақалада туристік қызметтің Субарктика мен Арктиканың табиғи-аумақтық кешендеріне әсерін зерттеу әдістерін сипаттайтын шетелдік тәжірибеге бағытталған ғылыми еңбектерге жүйелі шолу жасалып, олардың туристік және рекреациялық кеңістікті жоспарлау тиімділігіне жалпы талдау жасалды. Көптеген қолданбалы зерттеулердің нәтижелері субарктикалық және арктикалық табиғи кешендер аз төзімді және жаппай туризмнің теріс әсеріне бейім, баяу қалпына келетіндігін көрсетеді. Мысалы, туризм мен рекреация факторына ең төзімді аласа қайың шоғырлы-мүкті және шөпті-мүкті тундра, қыналы, түкті-бұталы тундралар ең осал болып табылады. Табиғи кешендердің туристік және рекреациялық әсерлерге төзімділік дәрежесі жерүсті биомассасының жалпы қорының мөлшерімен емес, оның құрылымымен анықталады. Арктика мен Субарктиканың табиғи ортасында туристік-рекреациялық кеңістікті жобалаудың бастапқы кезеңінде, ең алдымен, жаппай туризмнің теріс салдарын болдырмау үшін сызықтық және аудандық рекреациялық жүктемені бағалау бойынша зерттеулер жүргізу қажет.

Кілт сөздер: жаппай туризм, рекреациялық табиғатты пайдалану, Арктика, Субарктика, рекреациялық жүктеме, табиғи-аумақтық кешендер, зерттеу әдістері, жүйелі шолу.

R.I. Loktev

Systematic review of methods for the assessing the impact of mass tourism on the natural-territorial complexes of the Subarctic and the Arctic

For the first time, the article presents a systematic review of foreign practical-oriented scientific works describing methods of studying the impact of tourism activities on the natural-territorial complexes of the Subarctic and the Arctic with a general analysis of their effectiveness for planning tourist and recreational space. The results of most applied studies indicate that Subarctic and Arctic natural complexes are less tolerant and most susceptible to negative effects from mass tourism. For example, the most resistant ones to tourism and recreation factor are pink-moss and grass-moss tundra, and lichen, fluff-sedge tundra are the most vulnerable. The degree of stability of natural complexes to tourist and recreational effects is determined not by the value of the total reserve of above-ground biomass, but by its structure. At the initial stage of the design of tourist and recreational space, in the natural environment of the Arctic and the Subarctic, first of all, it is necessary to

conduct studies to assess the linear and area recreational load in order to avoid the negative consequences of mass tourism.

Keywords: mass tourism, recreational environmental management, Arctic, Subarctic, recreational load, natural-territorial complexes, research methods, systematic review.

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Calculating scheme for ground freezing depth variations and its application in different landscapes

Snow study is important because snow, after the ocean, is the second largest interface between the atmosphere and Earth's surface and it covers considerable part of the land during winter. Changes in snow cover extent and snowpack properties in recent decades in response to warming are ongoing and will likely continue in future. Ground thermal regime, despite the simplicity of measuring the ground temperature, remains an insufficiently studied field of landscapes. For determination of air-temperature influence, snow cover thickness, absolute values and the dynamics on the depth of ground freezing and thawing, a number of ground freezing models have been developed. In this work, the calculation is done with calculating scheme for ground freezing constructed on the basis of three-layer media heat conductivity problem (snow cover, frozen and thawed ground) with phase transition on the boundary of frozen and unfrozen ground. The heat balance equation includes phase transition energy, inflow of heat from unfrozen ground and outflow to frozen ground, snow cover and atmosphere. The heat flux is calculated on basis of Fourier law as a product of heat conductivity and temperature gradient. It is supposed that temperature changes linearly in each media. The calculations of ground freezing depth variations are done for plain and mountain regions. The ground freezing depth calculation results correspond to the observed values. Hence, the influence of the recent climate and weather contrasts and snow cover spatial and temporal variations on underlying ground freezing depth variations are investigated and reviled. This is vital, although climatic norms between 1961–1990 and 1991–2020 did not illustrate significant changes, but some strong weather variation extremes and contrasts (such as hotness in last 2020 year and weather anomalies of this 2020/2021 winter) are present in recent decades causing danger and risks for population and economics.

Keywords: calculation scheme, air temperature, snow cover, ground freezing, landscapes, mountain regions.

Introduction

As snow is one of the largest interfaces between the atmosphere and Earth's surface covering considerable part of the land during winter it is important to study snow. Changes in snow cover extent and snowpack properties in recent decades in response to warming are ongoing and will likely continue in future. Despite the simplicity of measuring the ground temperature, ground thermal regime remains today an insufficiently studied field of landscapes. This topic was essentially explored by A.V. Pavlov [1]. To determine the influence of air-temperature and snow cover thickness, absolute values and the dynamics on the ground freezing and thawing depth, a number of ground freezing models have been developed. For example, for his ground freezing depth estimation scheme, V.A. Kudriavtsev [2] characterized warming and cooling action of snow cover on the ground depending on snow accumulation regime, its duration and suggested equation for estimation of ground freezing depth including snow cover thickness, its thermal properties and amplitude of yearly air temperature oscillations. Applying this model, our calculation scheme for plain areas were done for observation site of Lomonosov Moscow State University for bare and covered with snow surface and for Moscow region. Verifying and proving the method consistency of the calculation, scheme was done according to the ground freezing depth and thermal regime observation data for plain regions where the data is available. For the rock ground freezing modeling, the model Alpine3D [3] consisting of the 3D atmospheric processes model coupled with the 1D energy balance model SNOWPACK was used. In this article, during the construction of debris flow and snow avalanche protecting installation in the mountain regions, the problem of fixation and stability of these constructions under the conditions of seasonally or permanently frozen ground arise. For this reason, the freezing depth of the soil is estimated based on the developed calculation scheme data on the thickness of the snow cover and air temperature for the Terskol weather station of the Elbrus region for winter periods 2015/16–2019/20. The calculating scheme for ground freezing is constructed on the basis of three-layer media heat conductivity problem (snow cover, frozen and thawed ground) with phase transition on the boundary of frozen and unfrozen ground. The heat balance equation includes phase transition energy, inflow of heat from unfrozen ground and outflow to frozen ground, snow cover and at-

mosphere. The heat flux is calculated on basis of Fourier law as a product of heat conductivity and temperature gradient. It is supposed that temperature changes in each media linearly. The results of ground freezing depth calculations indicate that ground under snow cover stays frozen in the Elbrus region from December to April. At the same time, the ground under the snow-covered surface freezes according to calculations on average by 20 or more cm. If the snow cover is partially or completely blown away, the ground may freeze to a depth of 1 m or even more and last for a longer period. Thus, the proposed method allows to evaluate soil freezing as a factor of soil stability for the protection of constructions.

Experimental

In this paper, we calculate freezing depth based on data on air temperature and snow cover thickness applying the proposed calculation scheme for weather station of Lomonosov Moscow State University and Moscow region weather stations (for number of winter seasons for verifying and proving the consistency), and for Terskol meteorological station (for the snow-covered soil surface of the winter seasons 2015/16–2019/20). The calculation scheme was based on the problem of thermal conductivity of a three-layer medium (snow, frozen and thawed soil) with a phase transition at the boundary of frozen and thawed soil. The heat balance equation included the energy of the phase transition, the inflow of heat from the thawed ground and the outflow to the frozen ground and, in the presence of snow cover, through it to the atmosphere. The heat flux was calculated considering Fourier law, as the product of the thermal conductivity and the temperature gradient. It was assumed that the temperature in each medium varies linearly (for example, [4, 5]). For snow cover and frozen ground, the formula of thermal conductivity of a two-layer medium was used.

The calculation of ground freezing based on data on air temperature and snow cover thickness and thermal conductivity during the winter period made it possible to estimate the intensity of the freezing front movement during this period. The dependence of the speed of the freezing front movement was found according to the calculated scheme. The scheme took into account the freezing of the ground from below on the frozen ground mass in winter based on data on the daily air temperature (the thickness and thermal conductivity of the snow cover).

The heat balance equation was written as

$$F_1 = cLV + F_2,$$

or as:

$$dh_{fg}/dt = V = (F_1 - F_2)/cL, \quad (1)$$

where F_1 — heat outflow through the frozen ground (and snow cover) from the freezing front (W/m^2) to the atmosphere; $c\ L\ V = c\ L\ dh_{fg}/d\tau$ — consumption heat at the phase transition; c — moisture content of the soil (1–4 kg/cm*m^2), (last value corresponds to the complete filling of pores with water from a lightweight clay with a density of 2000 kg/m^3 and a porosity 0,617 [1]); L — energy of the phase transition (335 kJ/kg); $V = dh_{fg}/dt$ — the speed of the freezing front (cm/s); F_2 — heat exchange in the cooling melt the ground before the freezing front (W/m^2).

The heat flux was expressed according to the Fourier law: $F = -\lambda\ \mathrm{grad}\ T$. The heat flow through the frozen ground from the freezing front to the atmosphere in the case of snow cover was expressed in terms of thermal conductivity and heat flow of a combination of two media (snow cover and frozen ground):

$$F_1 = -\lambda\frac{\Delta T}{\Delta x} = -\frac{\Delta T}{\frac{\Delta x_s}{\lambda_s} + \frac{\Delta x_{fg}}{\lambda_{fg}}} = \frac{-T_{air}}{\frac{h_s}{\lambda_s} + \frac{h_{fg}}{\lambda_{fg}}}, \quad (2)$$

here T_{air} is the air temperature, h_s and h_{fg} are the snow thickness and freezing depth, and λ_s and λ_{fg} are the thermal conductivity of snow and frozen ground.

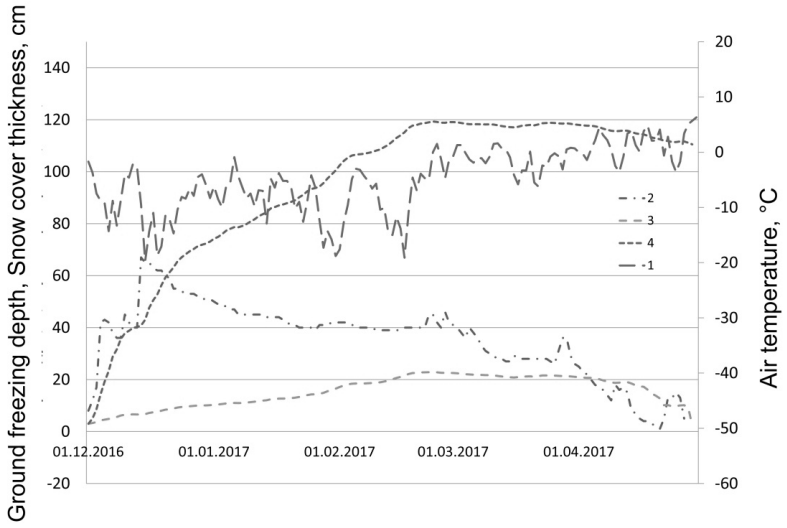
It was assumed that at a depth of 10 m in the ground, there is a point of zero annual temperature fluctuations T_0 with an average annual value of about 7 °C. Therefore

$$F_2 = -\lambda_{thg}\frac{\Delta T}{\Delta x} = \lambda_{thg}\frac{T_0}{10 - h_{thg}}, \quad (3)$$

here λ_{thg} is the thermal conductivity of thawed soil. Calculations were performed in one-day increments. At first, it was considered that the thickness of the frozen ground h_{fg} was 0.5 cm. The freezing rate V and the value of the frozen ground thickness h_{fg} was calculated for the next day (time step). According to [6], the average thermal conductivity of thawed and frozen clay soil could be taken as 1.4 and 1.8 W/m°C. The average thermal conductivity *of* snow λ_c was calculated relatively to the density according to the formula of A.V. Pavlov [1] and was taken equal to 0.18 W/m°C.

Results and Discussion

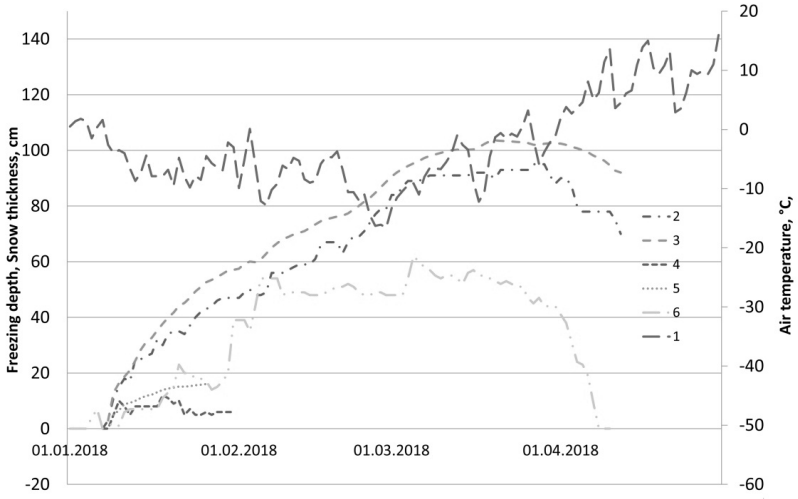
In this paper, a difference scheme was constructed for the derived first-order time differential equation for changing the depth of soil freezing by approximating this differential equation by the explicit Euler method: $h_{fg}(t_{n+1}) = h_{fg}(t_n) + \Delta T\, V(t_n)$. According to the obtained difference scheme, each winter season of recent decade calculations of ground freezing depth variations were performed of plain observation site of Lomonosov Moscow State University for verification and mountain of Terskol meteorological station. An example of the calculation results of mountain of Terskol meteorological station for the winter season 2016/17 is shown on the Figure 1.



1 — air temperature; *2* — thickness of snow cover; *3* — estimated depth of freezing of the ground under the snow cover; *4* — estimated depth of freezing of exposed ground

Figure 1. Changes in air temperature and freezing depth based on calculations for snow-covered and exposed ground surfaces of a weather station Terskol for winter period 2016/17

The example of results of calculations of ground freezing depth for plain under bare and covered with snow site surface of the meteorological observatory of Lomonosov Moscow State University for the winter period 2017/18 and their comparison with the observed data are displayed in the Figure 2.



The results of calculations for ground freezing depth for the bare (*3*) and covered with snow site surface (*5*) and their comparison with the observed data (*2* and *4* correspondingly). Air temperature (*1*) and snow cover thickness (*6*)

Figure 2. Variations of air temperature and ground freezing depth according to the data of calculations and observation under bare and covered with snow site surface of the meteorological observatory of Lomonosov Moscow State University for the winter period 2017/18

The results of calculations of maximal ground freezing depth for the bare site surface of the meteorological observatory of Lomonosov Moscow State University for the winter periods of 2011/12–2017/18 and their comparison with the observed data are demonstrated in Table 1 indicating general consistency of the calculating method.

Table 1

Comparison of calculated and observed maximal ground freezing depth under bare and covered with snow site surface of the meteorological observatory of Lomonosov Moscow State University for the winter periods of 2011/12–2017/18

Winter period	Maximal ground freezing depth under bare site surface, cm		Maximal ground freezing depth for the covered with snow site surface, cm	
	observed	calculated	observed	calculated
2011/12	120	110	18	10
2012/13	118	120	8	12
2013/14	100	87	18	4
2014/15	95	85	30	7
2015/16	78	88	25	30
2016/17	100	100	3	7
2017/18	95	105	14	18
Max diff.	13		23	
Min diff.	–10		–5	
Aver. diff.	1,6		4	

From the Table 1 one can see that averaged difference of calculated and observed maximal ground freezing depth under bare site surface of the meteorological observatory of Lomonosov Moscow State University for the winter periods of 2011/12–2017/18 is 1.6 cm and under the covered with snow site surface it is 4 cm. The main advantage of the calculating scheme is that it reproduces the dynamic of the ground freezing process well. So, the calculation method is physically well-justified. The solution method thoroughly describes the process of changing the freezing depth during the winter season. It is important for the successful operation of the method to set the initial data as accurately as possible.

The proven consistency of the method allows to predict that the results of calculating the maximum ground freezing depth for Terskol weather station are valid. These results are demonstrated in Table 2.

Table 2

Variations in the maximum ground freezing depth, average snow cover thickness for February and the sum of negative monthly temperatures for Terskol weather station for winter periods 2015/16–2019/20

Winter period	Sum of negative monthly temperature, °C	Averaged February snow cover thickness, cm	Max. freezing depth of snow-covered ground, cm	Max. freezing depth of exposed ground, cm
2015/16	–18,7	60	21	97
2016/17	–27,7	40	23	119
2017/18	–14,2	70	8	83
2018/19	–19,4	60	20	96
2019/20			20	

Conclusions

As indicated in Table 2 the thickness of the accumulated snow cover on the mountain Terskol weather station can reach half a meter or more. At the same time, the ground under the snow-covered surface freezes according to calculations by an average of 20 centimeters or more. In the case of partial or complete blowing off of the snow cover, freezing of the ground can occur to a depth of 1 meter or more and last for a longer period. Thus, the proposed method for calculating the dynamics of the ground freezing depth on basis of data on air temperature and snow cover thickness allows to assess the variation of ground freezing depth in different landscapes. It is also necessary to mention that for the mountain Terskol weather station, we do not have values of ground freezing depth for verification, but only air temperature and snow cover thickness. Howev-

er, we rely on the proven general consistency of the calculating scheme for the plain territory where the verification data of ground freezing depth is available.

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Д.М. Фролов

Топырақтың қату тереңдігінің өзгеруінің есептік сызбасы және оны әртүрлі ландшафттарда қолдану

Қарды зерттеу өте маңызды, өйткені мұхиттан басқа, қар атмосфера мен жер беті арасындағы екінші үлкен байланыс болып табылады, ал қыста қар жердің едәуір бөлігін қамтиды. Соңғы онжылдықтарда жылынуға жауап ретінде қар жамылғысының ауданы мен қасиеттерінің өзгеруі жалғасуда және болашақта да жалғасуы мүмкін. Топырақтың жылу режимі, топырақ температурасын өлшеу қарапайымдылығына қарамастан, бүгінде ландшафттардың аз зерттелген аймағы болып қала береді. Абсолютті мәндер мен ауа температурасының динамикасы мен қар жамылғысының қалыңдығы топырақтың қату және еріту тереңдігіне әсерін анықтау үшін топырақты қатырудың бірқатар модельдері жасалды. Мақалада есептеу мұздатылған және мұздатылмаған Gru шекарасында фазалық ауысумен үш қабатты ортаның (қар жамылғысы, мұздатылған және еріген топырақ) жылу өткізгіштік міндеті негізінде салынған топырақты мұздатудың есептік схемасы бойынша жүзеге асырылған. Жылу балансының теңдеуі фазалық ауысу энергиясын, мұздатылмаған топырақтан жылу ағынын және мұздатылған жерге жылу ағынын, қар жамылғысы мен атмосфераны қамтиды. Жылу ағыны Фурье заңына сәйкес жылу өткізгіштік пен температура градиентінің көбейтіндісі ретінде есептелді. Әр ортадағы температура сызықтық өзгереді деп болжанған. Топырақтың қату тереңдігінің өзгеру есептері жазық және таулы аудандар үшін есептелді. Топырақтың қату тереңдігін есептеу нәтижелері байқалған мәндерге сәйкес келеді. Осылайша, соңғы климаттық және ауа-райының қарама-қайшылықтарының әсері, сондай-ақ қар жамылғысының кеңістіктік және уақытша өзгерістері, топырақтың қату тереңдігінің өзгеруі зерттелген және талқыланған. Бұл өте маңызды, өйткені климаттық нормалар 1961 жылдан 1990 жылға дейін және 1991 жылдан 2020 жылға дейін айтарлықтай өзгерген жоқ, бірақ ауа-райының ауытқуы мен қарама-қайшылықтары өте қатты болды (мысалы, өткен 2020 жылы өте ыстық ауа-райы және 2020/2021 ж. қыстағы ауа-райының ауытқуы). Бұл халық пен экономика үшін қауіп пен қатер тудырады.

Кілт сөздер: есептік схема, ауа температурасы, қар жамылғысы, топырақтың қатуы, ландшафттар, таулы аудандар.

Д.М. Фролов

Расчётная схема изменения глубины промерзания грунта и ее применение в различных ландшафтах

Изучение снега важно, потому что, за исключением океана, снег является вторым по величине связующим звеном между атмосферой и поверхностью Земли, а зимой снег покрывает значительную часть суши. Изменения площади и свойств снежного покрова в последние десятилетия в ответ на потепление продолжаются и, вероятно, найдут продолжение в будущем. Термический режим грунта, несмотря на простоту измерения его температуры, на сегодняшний день остается мало изученной областью ландшафтов. Для определения влияния абсолютных значений, динамики температуры воздуха и толщины снежного покрова на глубину промерзания и оттаивания грунта разработан ряд моделей промерзания грунта. В статье расчет проводился по расчетной схеме промерзания грунта, построенной на основе задачи теплопроводности трехслойных сред (снежный покров, мерзлый и талый грунт), с фазовым переходом на границе мерзлого и незамерзшего грунта. Уравнение теплового баланса включает энергию фазового перехода, приток тепла из незамерзшей почвы и отток тепла в мерзлую землю, снежный покров и атмосферу. Тепловой поток рассчитывается по закону Фурье как произведение теплопроводности и градиента температуры. Предполагается, что температура в каждой среде изменяется линейно. Расчеты изменения глубины промерзания грунта выполнены для равнинных и горных районов. Результаты расчета глубины промерзания грунта соответствуют наблюдаемым значениям. Таким образом, исследуется и осуждается влияние недавних климатических и погодных контрастов, а также пространственных и временных вариаций снежного покрова на вариации глубины промерзания подстилающей почвы. Это действительно важно, потому что, хотя климатические нормы в период с 1961 по 1990 г. и с 1991 по 2020 гг. изменились не очень существенно, однако проявились экстремальные погодные колебания и контрасты (например, очень жаркая погода в прошлом 2020 г. и погодные аномалии этой зимы 2020/2021 г.) в последние десятилетия. Это создаёт опасность и риски для населения и экономики.

Ключевые слова: расчетная схема, температура воздуха, снежный покров, промерзание грунта, ландшафты, горные районы.

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Stability of phytomass dynamics in protected low mountain-steppe landscapes and pastures in the Southern Urals

In the steppe zone, the high sensitivity of plant cover to humidity contrasts raises the question of what landscape conditions provide a stable predictable phytoproductivity. Authors of the article tested the hypothesis about the inequality of the spatial factors of variability of functioning under the conditions of the reserved regime and anthropogenic impact on the example of the Aytuarskaya steppe. Based on the deviations of the intra-seasonal increments of the normalized difference vegetation index (NDVI) for 33 pairs of terms from the mean values, the measure of instability of the types of dynamics of green phytomass (Shannon's index) was calculated. To identify the clusters of high and low phytoproductivity, the Hot Spot Analysis was applied based on Getis–Ord statistics. On grazed areas, the background type of dynamics of green phytomass is not dominant in area in contrast to protected areas. The reserve regime stabilizes the dynamics of phytomass due to a higher subordination to landscape-scale processes. Summer loss of phytomass outside the reserve occurs over a larger relative area than in the reserve. Zones of the most unstable phyto-production functioning with high variability of the shape of spots of increased phytomass are characteristic of catchment depressions, lower parts of slopes, and narrowed sectors of gullies.

Keywords: steppe, phytomass, NDVI, seasonal dynamics, instability, hot spot, relief, Urals.

Introduction

The current trend in landscape research involves supplementing the structural characteristics with functional ones while delineating natural complexes. In the steppe zone, with its almost ubiquitous plowing, the high sensitivity of the vegetation cover to humidification contrasts the question of what landscape conditions provide a stable predictable phytoproductivity is critical. From the point of view of environmental planning, the spatial structure is easier to describe than the time series of functioning. Hence, the question of the relationship between the spatial structure and the variability of functioning modes is the question of the predictability of the consequences of external influences, including anthropogenic loads.

Considerable experience has been obtained in compiling dynamic portraits of phytocoenoses types based on the inter-annual variability of the normalized difference vegetation index (NDVI) [1, 2]. The researchers established the dependence of the total aboveground phytomass production in plant communities of the arid zone on soil moisture, in protected areas particularly. Changing the reserve regime for economic use and vice versa, as a rule, induces changes in the course of phytomass production. A significant part of such studies is devoted to the dynamics of the phytomass in pastures [3, 4]. In degraded communities, the relationship between changes in herbage productivity and soil moisture is not always unambiguous, which is most often associated with the introduction of species resistant to soil drought into degraded communities [5]. Most remote sensing studies of phytoproductivity focus either on directed changes in the vegetation cover associated with climatic changes or fires [6], or on spatial patterns that exert control over trends in productivity changes under the anthropogenic impact [7]. One of the problems in the analysis of time series is the influence of inter-annual phenological shifts in the development of vegetation. Therefore, to ensure the comparability of information for different years not direct NDVI values are used, but their deviations from the mean long-term value [1].

Understanding the regularities of the spatial and temporal organization of the phytomass dynamics and the range of possible states for each specific area of the landscape will reduce the risks of both agriculture and animal husbandry associated with fluctuations in phytomass production. The goal of the study is to determine the spatial differences in the variability of the types of intraseasonal dynamics and the spatial mosaicity of phytoproductivity in protected and pasture low-mountain-steppe landscapes.

Experimental

The territory is located within the Alimbet-Kargalinsky physical-geographical region of the Sarinsko-Guberlinsky district of the Ural-Tanalyk province [8] near the confluence of the Aytuar river in the Ural river (center — 51°05′N 57°40′E). Most territory (except for the north-western section) belongs to the Orenburg State Nature Reserve. The characteristic alternation of protrusions of different layers on the ridges and slopes creates a high facies mosaicity of steppe communities. They differ in lithomorphism ranging from *Stipa zalesskii* (species names are given according to [9]) dominated steppes on well-developed chernozems on the plateau up to *Elytrigia pruinifera* dominated petrophytic communities on the petrozems of steep rocky slopes. In the hollows and the bottoms of the gullies, one can observe xeromesophytic variants of the steppes (*Poa transbaicalica, Stipa pulcherrima*, various forbs), shrub thickets (*Amygdalus nana, Cerasus fruticosa*, *Caragana frutex, Spiraea hypericifolia)* or coppices of black alder, aspen, birch on hydrometamorphized chernozems. In the 1980–1990s, according to local residents, up to 30 thousand heads of goats were grazed. By 2010 no more than 200 heads, mainly sheep, were grazed north of the village Aytuar.

To explain the spatial differences in the variability of the phytoproduction process, we classified the Landsat 8 multichannel satellite image using the k-means method and distinguished 10 types of phytocoenoses (Fig. 1). Field verification was performed in June 2019. The territory was provided with 216 landscape descriptions in 2011–2019.

NDVI values were calculated in SAGA GIS software based on 33 Landsat images from 1984–2019. For each of the 80,860 pixels, the following calculations were conducted:

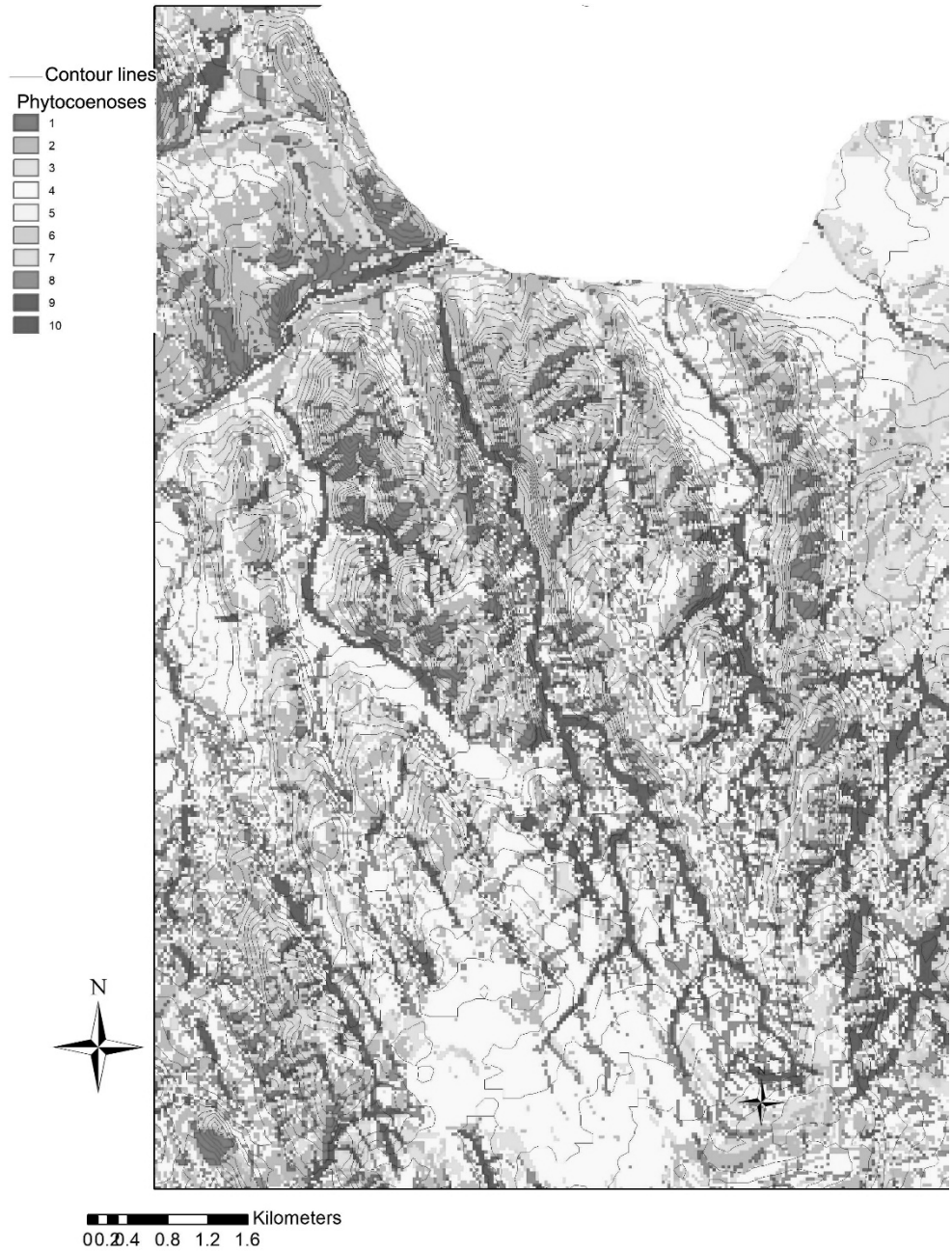
1) Difference in NDVI values between survey dates during one growing season (increment with a positive or negative sign). Totally 38 pairs of dates were processed.

2) Average (background) increment of NDVI over the landscape for each pair of dates. The hypothesis of a normal distribution of increments, or at least the presence of a modal interval near the mean, was tested. For all pairs of dates, the second case was confirmed.

3) A measure of the deviation of the increment from the mean over the landscape (in units of standard deviation) for each pair of dates. For each pixel, we checked whether it had a modal increment of NDVI (deviation from the mean value no more than 0.5 standard deviation (STD) or deviates from it in the interval of 0.5–1.5 STD or more than 1.5 STD in positive or negative direction.

According to the results, for a given pair of date search pixel was assigned one of five “deviation classes”, below referred to as the *types of green phytomass dynamics*. Dynamics types 1 and 2 correspond to the strategy of rapid accumulation of phytomass in spring and small losses in summer (STD<–1.5 and –1.5<STD<–0.5, respectively). Type 1 corresponds to the preservation of almost all late spring — early summer phytomass. Dynamics type 3 (–0.5<STD<0.5) corresponds to a background mode of intraseasonal change for the landscape. This means a moderate loss of phytomass in the second half of summer. Types 4 and 5 (0.5<STD<1.5 and STD>1.5, respectively) correspond to a slow accumulation of phytomass in spring and a strong loss in summer, in comparison, respectively, with background and high values in late spring — early summer. Then, for each pixel, the following procedure was carried out: 1) calculation of the probability of each gradation (type of dynamics); 2) calculation of the measure of uncertainty (i. e. instability) of the dynamics of NDVI (H) according to the Shannon’s formula. We tested the hypotheses that the measure of the dynamics instability depended on the phytomass itself and this dependence varied over the seasons. We calculated Spearman's correlation coefficient between the NDVI values for each period and the values of the uncertainty measure by means of the Statistica 7.0 software.

To identify the locations of clusters of high and low values of phytomass, we applied the Hot Spots Analysis (in GIS ArcMap 3.0) based on the calculation of Getys-Ord statistics for a neighborhood with a radius of 300 m. In each pixel, for each of 38 pairs of dates, we evaluated the statistical significance of the NDVI difference from the neighborhood. Clusters of increased phytomass are below referred to as hot spots (HS), clusters of decreased phytomass — as cold spots (CS). In the last decade, the method has been increasingly used to explain the reasons for the mosaic nature of agricultural productivity, the emergence of urban heat islands, fires, etc. [10]. The morphometric parameters of the relief were calculated in GIS SAGA 7.0 from a digital elevation model with a resolution of 30 m.

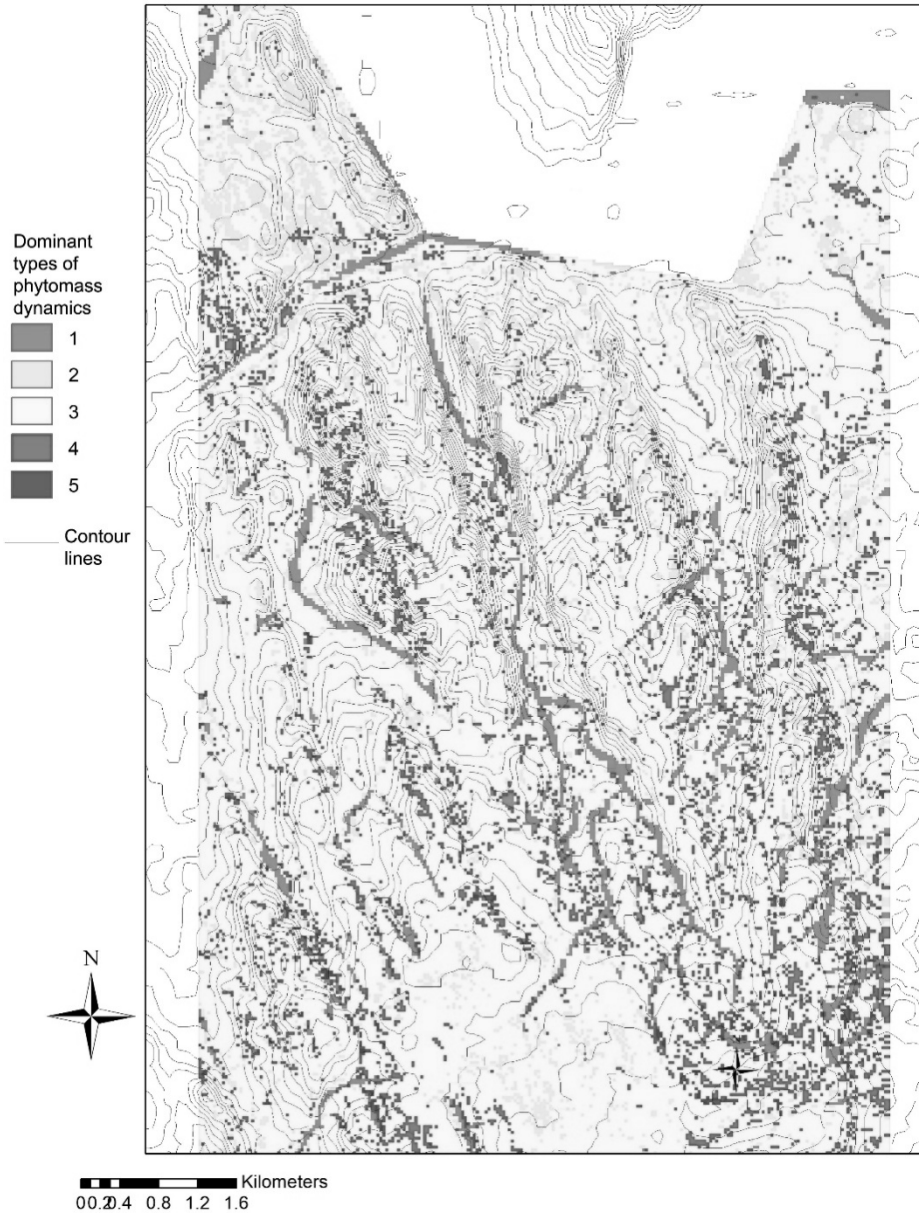


1 — petrophytic steppes; *2* — dry steppes dominated by *Festuca valesiaca; 3* — feather-grass-forb steppes; *4* — typical feather-grass steppes; *5* — meadow steppes and meadows; *6* — shrubs with a predominance of xerophilic species; *7* — shrub steppes with dominance of *Spiraea hypericifolia*, *Elytrigia repens, Poa transbaicalica, and Stipa zalesskii*; *8* — shrubs with a predominance of xeromesophilic species with undergrowth of aspen; *9* — shrubs with a predominance of mesophilic species with undergrowth of black alder and poplar; *10* — thickets of black alder, aspen, birch with mesohygrophytic meadows. *K* — means classification based on a series of Landsat satellite images from 2018–2019, resolution 30 m

Figure 1. Types of phytocoenoses of the Aytuarskaya steppe

Results and Discussion

The map of the prevailing types of intra-seasonal dynamics of phytomass (Fig. 2) shows their uneven spatial distribution and sensitivity to the landscape pattern.



1 — more than 1.5 standard deviation (STD) below the average increment; *2* — deviation by 0.5–1.5 STD below average; *3* — deviation within the background increment (± 0.5 STD from the mean); *4* — deviation 0.5–1.5 STD above the average; *5* — deviation more than 1.5 STD above the average increment.
Calculation based on a series of 33 Landsat satellite images from 1984 to 2019, resolution 30 m

Figure 2. Types of intra-seasonal dynamics of green phytomass (according to NDVI), maximum frequency

Concave landforms are the most clearly distinguished by high probability of the dynamics type 1. Convex landforms are indicated by domination of the dynamics type 4. It is worth noting that in the grazed areas (northwestern part), the variety of types of dynamics is reduced, in comparison with the protected central and southern parts of the landscape. In contrast to the reserve, the background type of dynamics 3 is not dominant in the pastures, and can be supplanted by the type 2.

The reserve regime in zonal steppe phytocoenoses stabilizes the dynamics of green phytomass due to the higher frequency of background dynamics (type 3), i. e. subordination to landscape-scale processes. This is interpreted as a uniform mode of functioning inherent in a holistic geosystem. Production of phytomass in spring with the possibility of its preservation or renewal by the end of summer (types 1–2) in grazed areas occurs with a higher frequency than in the nature reserve. This strategy is inherent for shrub communities (commonly, in concave landforms) which often expand at the expense of steppe communities due to grazing. In the most intensively grazed sector, where petrophytic steppes and communities with domination of

Festuca valesiaca prevail, dynamics with partial preservation of spring phytomass (type 2) is the most typical. This indicates a rather high degree of pasture digression with the predominance of drought-resistant species ignored by sheep and cattle. At the same time, type 2 of dynamics can be dominant in pastures while type 1 — only within a deeply incised small valleys with riparian forests in the northeastern corner and on the floodplains of the Aytuar and Ural rivers. In the reserve, type 1 dynamics is manifested not only along streams, but also in numerous gullies and drainage depressions.

The maximum positive Spearman's correlation (0.3–0.4) between the NDVI values and the H values was revealed in July and August. This dependence almost disappears in April and May. In other words, the maximum instability of phytomass dynamics (H=1.17–1.26) is characteristic of those landscape units that are able to maintain the maximum phytomass in dry hot summer months, i.e. gullies and floodplains. Basically, these are areas with the maximum occurrence of the 1st type of dynamics (30–40 %). A positive but weaker, correlation persists in autumn.

The most productive communities on pastures (besides riparian forests) are steppes with dominance of *Stipa zalesskii, Poa transbaicalica, Elytrygia repens*, *Spirea hypericifolia,* and various forbs occupying gullies and the most concave parts of the valley bottoms. In the reserve, higher abundance of *Poacea* species favours elevated probability of 3rd and 4th types of phytomass dynamics. This results in decrease of average measure of instability H which accounts for 1.11 versus 1.19 on pastures. On pastures, types of dynamics 1 and 2 occur more often (Table 1), since the bulk is made up of non-food shrubs while most grasses and forbs are grazed. A similar pattern is characteristic of phytocenoses dominated by *Scorzonera austriaca, Poa transbaicalica, Festuca valesiaca* on pastures, which is confirmed in the literature [11], as well as of typical *Stipa* — dominated steppes (Tab. 1).

Table 1

Median frequency of phytomass dynamics types (1–5) and measures of instability of phytomass dynamics types (H)

Phytomass dynamics types (1–5) and instability measure H	Petrophytic steppes		*Stipa zalesskii* and *Festuca valesiaca* dominated steppes		*Stipa zalesskii* dominated steppes		Shrubby steppes with dominance of *Spiraea hypericifolia*	
	Reserve	Pasture	Reserve	Pasture	Reserve	Pasture	Reserve	Pasture
H	1.35	1.43	1.19	1.28	0.98	1.16	1.04	1.11
1	0.03	0.06	0.00	0.03	0.00	0.03	0.00	0.03
2	0.27	0.30	0.24	0.36	0.15	0.27	0.15	0.24
3	0.39	0.30	0.42	0.33	0.57	0.45	0.51	0.51
4	0.28	0.24	0.27	0.27	0.21	0.21	0.27	0.15
5	0.03	0.06	0.00	0.00	0.00	0.00	0.03	0.00

In this case, the increased frequency of the strategy of maintaining the phytomass (usually characteristic of less xerophytic communities) in pastures is explained by its initially low phytomass in the beginning of grazing in early spring. High grazing loads in the 1980s favored the same mode of phytomass dynamics. In addition, the phytomass in the petrophytic steppes is preserved slightly better in summer than in areas with the background dynamics. This is associated with the predominance of poorly eaten drought-resistant species. In the reserve, a similar regime is typical for narrow watershed ridges and steep west-facing slopes. Thus, the summer loss of phytomass outside the reserve occurs over a larger relative area than in the reserve. The instability of the phytomass dynamics (H) for all types of phytocenoses is lower in the reserve, which proves the stabilizing role of the reserve regime. Hence, the absence of anthropogenic disturbance reduces the contribution of local factors to the variation of phytomass but increase the dependence on landscape-scale factors.

The Hot Spots Analysis showed evidence that seasonal dynamics of patches of increased and decreased green phytomass (HS and CS, respectively) clearly differs in the protected and grazed areas. Within the reserve, the total area and the number of emerging CSs are greater than on pastures to the north of Aytuar village. The main differences in the seasonal dynamics of HS and CS are manifested in spring and autumn. In the second half of April, the only HS corresponds to the most strongly grazed site near the northern outskirts of the village. In the first decade of May, patches of increased phytomass begin to form on gently sloping pasture areas to the north of the reserve. By mid-May, HS in the pasture shrinks and disappears. In

the 1980s-1990s by the end of the month, it used to be transformed into CS due to intensive grazing. However, since the 2010s this site has not differed from the background conditions due to decrease of pasture loads. In June-August, there was no fundamental difference in the formation of HS and CS in the reserve and on pastures. By the beginning of October, the total area and the number of emerging CSs within the reserve is greater than on pastures.

Comparison of the frequency of HSs in 1984–1998 and 2007–2019 illustrated that the establishment of the reserve regime resulted in significant changes in the functioning. The frequency of HSs along with the thalweg increased which is explained by restoration of tree and shrub thickets. On the pasture during this period, the decrease in loads caused a noticeable decrease in the occurrence and area of CSs. In fact, CS remains stable only along the main path of livestock movement from the village to the pastures. In the rest of the territory of pastures, the phytomass is distributed relatively evenly, which is partly explained by the compensating role of the phytomass of non-food species.

Now, we turn to the comparison of the spatial mosaicity of the phytomass and the characteristics of its variability over time. It is indicated by frequency of occurrence of spots of increased (HS) and decreased (CS) phytomass. The measure of instability of the intra-seasonal dynamics (H) indicates variability of phytomass. As a spatial unit, we took the drainage basin, for which descriptive statistics of these indicators were calculated.

The direct relationship between the average H over the catchment area and the fraction of the area with ever emerging HS (Fig. 3) designates that spots of increased phytoproductivity, as a rule, do not obey the background intra-seasonal dynamics (type 3). A high proportion of the most frequently occurring HSs (with a frequency of more than 0.7) are characteristic of those watersheds in which the instability of intra-seasonal dynamics is high. The catchments 39 and 41 which are noticeably out of this rule (Fig. 3), are still subject to pasture loads, although incomparably less than in the 1980s. In catchment 39, even with a small fraction of HS, a high average instability of the dynamics of green phytomass is observed. In contrast, in catchment 41, the dynamics are somewhat more stable than expected with such a high proportion of HSs.

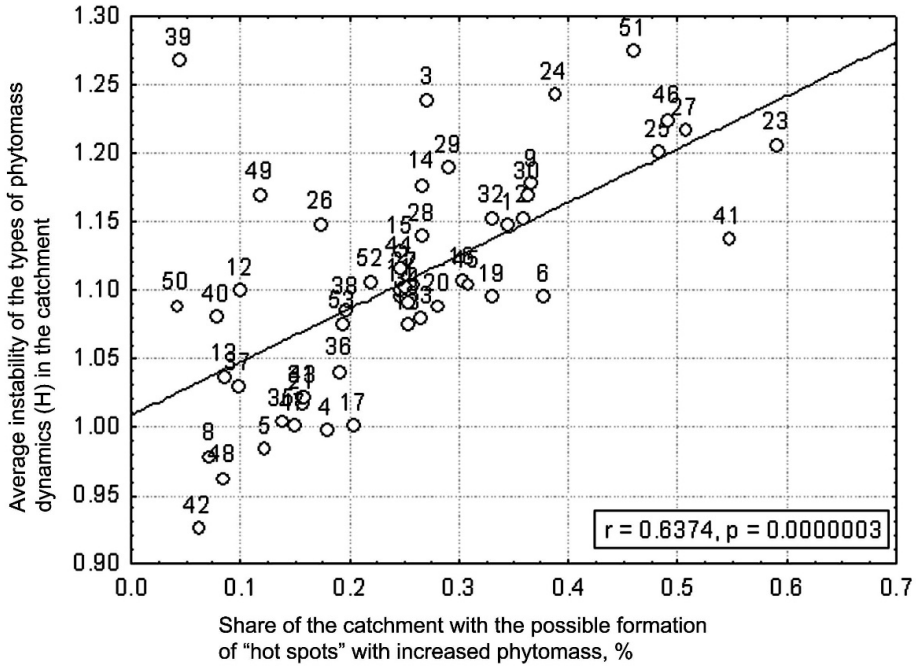


Figure 3. Dependence between the share of the catchment area with the possible formation of "hot spots" with increased phytomass and the average instability of the types of phytomass dynamics (H) in the catchment for the period 1984–2019. Digits correspond to numbers of catchments

Although high instability H occurs with any frequency of occurrence of HSs, a group of pixels stands out with a combination of maximum instability of intra-seasonal dynamics and average (0.4–0.6) frequency of HS occurrence. In other words, these are territories with a combination of unstable difference from the surroundings and unstable intra-seasonal dynamics. They occupy 2 % of the territory. It is only in this range

of the HS frequency that the instability of the dynamics H is everywhere high and cannot be low (less than 0.8). These are areas in which the frequency of deviations from the background dynamics is maximal while development of HSs is instable. In other words, some strong local factors are manifested from time to time. Such pixels usually surround the area of permanent HSs along the thalwegs or occupy drainage depressions. They most often correspond to the 1st and 5th types of dynamics, especially in woody thickets and mesophytic shrubs.

According to the results of discriminant analysis, the convergence index and cross-sectional curvature make the greatest contribution among the morphometric parameters of the relief to the development of unstable phytocoenoses (the frequency of HSs 0.4–0.6, H more than 1.2), especially on slopes. This means that a periodically occurring increased inflow of moisture (gullies, narrowed parts of small valleys) causes the occurrence of HS, which does not exist permanently and often disappears. Such areas can be called strips of functional instability. They are confined to the lower part of the slope with an increased catchment area. The inflow of moisture into the lower part of the slope, causing the occurrence of HS, is an event of almost equiprobability, with no such event (i.e. to a frequency of about 0.5). In other words, from time to time, the activation of lateral moisture flows actually integrates the foot slope and the bottom of the erosional landform resulting in similarintensity of phytomass production.

The largest area of zones of functional instability (41 %) falls on mesophytic meadows and woody aspen-birch-black alder thickets, less (15 %) — on meadow steppes. Such zones are practically do not occur in dry and typical steppes, and rarely occur in phytocoenoses with xerophytic and mesoxerophytic shrubs.

Conclusions

In contrast to most studies of phytoproduction functioning, focused on the patterns of time series and their variations depending on lithogenic conditions, we identified spatial patterns of stability of functioning generated by radial and lateral connections. The proposed method makes it possible to clarify the degree of stability and sharpness of landscape boundaries by measures of instability of the types of dynamics and variability of the areas of “hot spots” of phytomass. In addition to the traditional criterion of homogeneity of the abiotic template, we applied the criterion of the integrity of the functioning mode. The following conclusions were obtained.

1. The stability of the dynamics of green phytomass is always higher in the reserve than outside it. The conservation regime in typical steppes stabilizes the dependence of the dynamics of green phytomass on landscape-scale processes. Anthropogenic loads increase the dependence on local factors.

2. Summer loss of phytomass outside the reserve occurs over a larger relative area than in the reserve. In the most arid conditions and under pasture loads, the phytomass in summer can hardly decrease due to the predominance of drought-resistant and poorly eaten species.

3. Owing to the establishment of the reserve regime, the frequency of occurrence of spots of increased phytomass associated with tree and shrub thickets along the thalwegs has increased. On the pasture, the decrease in loads resulted in a noticeable decrease in the frequency of occurrence and the area of spots of low phytomass.

4. The highest proportion of frequently occurring spots of increased phytomass is characteristic of catchments with maximum instability of intra-seasonal dynamics, with the exception of catchments with intense pasture loads.

5. Zones of the most unstable phytoproductive functioning with high variability of the shape of patches with increased phytomass are characteristic of catchment depressions, lower parts of slopes, narrowed sectors of valleys.

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А.В. Хорошев

Оңтүстік Оралдың қорғалатын төментаулы-дала ландшафттары мен жайылымдарындағы фитомасса динамикасының тұрақтылығы

Дала аймағындағы өсімдік жамылғысының ылғалдылық контрастына жоғары сезімталдығына қандай ландшафт жағдайлары тұрақты болжамды фитоөнімділікті қамтамасыз етеді деген сұрақ туғызады. Автор Айтуар даласының мысалында қорық тәртібі мен антропогендік әсер жағдайында жұмыс істеудің өзгергіштігінің кеңістіктік факторларының айырмашылығы туралы гипотезаны тексерген. NDVI өсімдіктер индексінің орташа мәнінен 33 мерзімге арналған маусым ішіндегі өсінділерінің ауытқуларына сүйене отырып, жасыл фитомасса динамикасының тұрақсыздығы (Шеннон индексі) есептелген. Фитоөнімділігі жоғары және төмен кластерлерді анықтау үшін Гетис-Орда статистикасы негізінде ыстық нүкте талдауы қолданылды. Жайылымдық аумақтарда жасыл фитомасса динамикасының фондық түрі ерекше қорғалатын аумақтарға қарағанда ауданы бойынша басым емес. Қорық тәртібі ландшафтық масштабтағы процестерге көбірек бағыну арқылы фитомассаның динамикасын тұрақтандырады. Фитомассаның жазғы уақытта қорықтан тыс жоғалуы қорыққа қарағанда салыстырмалы түрде үлкен аумақта болады. Жоғары фитомасса дақтарының көтерілу өзгергіштігі бар ең тұрақсыз фитоөнімдердің жұмыс істеу аймақтары су жиналатын ойпаттарға, беткейлердің төменгі бөліктеріне, шұңқырлардың тарылған секторына тән.

Кілт сөздер: дала, фитомасса, NDVI, маусымдық динамика, тұрақсыздық, ыстық нүкте, рельеф, Орал.

А.В. Хорошев

Устойчивость динамики фитомассы в охраняемых низкогорно-степных ландшафтах и пастбищах Южного Урала

В степной зоне высокая чувствительность растительного покрова к контрастам влажности ставит вопрос о том, какие ландшафтные условия обеспечивают стабильную предсказуемую фитопродуктивность. Автором проверена гипотеза о различии пространственных факторов изменчивости функционирования в условиях заповедного режима и антропогенного воздействия на примере Айтуарской

степи. На основании отклонений внутрисезонных приращений индекса растительности NDVI для 33 сроков от средних значений рассчитывалась мера нестабильности типов динамики зеленой фитомассы (индекс Шеннона). Для выявления кластеров высокой и низкой фитопродуктивности был применен анализ горячих пятен на основе статистики Гетиса–Орда. На пастбищных участках фоновый тип динамики зелёной фитомассы не является доминирующим по площади, в отличие от ООПТ. Заповедный режим стабилизирует динамику фитомассы за счёт большей подчиненности процессам ландшафтного масштаба. Летняя потеря фитомассы за пределами заповедника происходит на большей относительной площади, чем в заповеднике. Зоны наиболее неустойчивого фитопродукционного функционирования с высокой изменчивостью формы пятен повышенной фитомассы характерны для водосборных понижений, нижних частей склонов, суженных секторов лощин.

Ключевые слова: степь, фитомасса, NDVI, сезонная динамика, нестабильность, горячая точка, рельеф, Урал.

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Ландшафты Тигирекского заповедника: прошлое, настоящее, будущее

Заповедники были полигонами, где происходило формирование основ ландшафтного картографирования. В статье охарактеризованы основные особенности ландшафтной структуры Тигирекского государственного заповедника (Русский Алтай). Многие ландшафтные границы обусловлены тектоникой. Высотная поясность является основной закономерностью ландшафтной дифференциации. В заповеднике представлены разнообразные горные породы, создающие контрастные условия для биоты и почвообразования. Относительно теплый и влажный климат Северо-Западного Алтая, в сочетании с плоским рельефом долин вполне благоприятствуют накоплению торфа. Представлена карта на уровне видов ландшафтов. Карта сопровождается подробной легендой. Несмотря на высокое ландшафтное разнообразие Тигирекского заповедника, занимаемой им площади явно недостаточно для горных условий, чтобы он мог в полной мере выполнять функции по сохранению биоты. Расширение заповедника необходимо и для большего охвата охранным режимом высокогорий и верхней части лесного пояса. Отмечено, что ландшафтно-картографический анализ может иметь ключевое значение для экологического мониторинга и оценки культурных, регулирующих и поддерживающих экосистемных услуг на заповедных территориях. Большой научный интерес ландшафты Тигирекского заповедника представляют в контексте их реакции на глобальные климатические изменения и имевшие место в прошлом антропогенные воздействия.

Ключевые слова: Тигирекский заповедник, Алтай, ландшафт, ландшафтное разнообразие, торфяники, верхняя граница леса, экосистемные услуги, экологический туризм.

Введение

В СССР заповедники являлись теми полигонами, где происходило становление и развитие ландшафтоведения, в частности, отработка методик полевого ландшафтного картографирования. Так, студенты географического факультета МГУ, прослушавшие впервые введенный в 1947 г. курс «Основы ландшафтоведения», уже в 1948 г. проходили производственную практику в составе экспедиций в Приокско-Террасном заповеднике. Как отмечал основоположник учения о морфологии ландшафта Н.А. Солнцев, задачей ландшафтного отряда являлось изучение и картирование ландшафтов Приокско-Террасного государственного заповедника, в результате чего была дана физико-географическая характеристика заповедника, основанная на ландшафтном принципе, и построена крупного масштаба карта ландшафтов и урочищ. В процессе исследования конкретных ландшафтов возникли новые идеи, наметились новые теоретические проблемы, подлежащие разрешению в будущем. Наконец, был поставлен для дальнейшей разработки вопрос о методике комплексных ландшафтных исследований [1]. Как отмечалось в ряде работ [2–6], в заповедниках на ландшафтной основе может решаться целый комплекс научно-организационных, фундаментальных и мониторинговых задач: планирование учетных маршрутов, постоянных и временных пробных площадей в соответствии с ландшафтной структурой; ландшафтная привязка приуроченности отдельных видов растений и животных, в том числе редких и нуждающихся в охране; выявление наиболее и наименее изученных типов природных комплексов; экстраполяция результатов наблюдений, описаний и измерений, полученных в конкретных ландшафтных выделах на другие участки заповедника с аналогичными ландшафтными условиями; выявление закономерностей пространственного распределения качественных и количественных характеристик биоты, в том числе ареалов видов, их потенциальной численности и др.

Знаковая работа «Оценка экосистем на пороге тысячелетия» [7] сформулировала новую парадигму для охраняемых территорий. Эта парадигма подразумевает более широкий и более адаптивный социально-экологический подход к особо охраняемым природным территориям (ООПТ) и окружающим их ландшафтам, базирующийся на концепции экосистемных услуг. Согласно новой природо-

охранной парадигме, ООПТ не только сохраняют биоразнообразие, но и предоставляют разнообразные экосистемные услуги, которые способствуют благополучию человека [8, 9].

Однако традиционно большинство ООПТ, особенно с жестким режимом охраны, не проектировались с учетом необходимости предоставления обществу обеспечивающих, регулирующих и культурных услуг [10, 11]. Поэтому в научной среде нет согласия относительно эффективности и целесообразности новой природоохранной парадигмы. Особое беспокойство в этой связи вызывают горные ООПТ, так как они являются флагманами охраны природы по всему миру. Известно, что высокое биологическое разнообразие, водные ресурсы и духовные ценности гор лучше всего сохраняются в условиях ООПТ с жестким охранным режимом [12, 13]. С другой стороны, в ряде исследований показано, что многофункциональные ландшафты обеспечивают больший объем экосистемных услуг, чем одностороннее использование, даже если это жесткая охрана. Исходя из столь противоречивых мнений, внедрение концепции экосистемных услуг в управление ООПТ является сложной задачей, так как усиление прямого антропогенного воздействия на заповедные территории породит целый ряд проблем. Ситуацию усугубляет то, что формирование большинства ООПТ происходило в условиях представлений о стабильности природы. Сегодня же климатические изменения и возникающие в результате этого неопределенности становятся дополнительным фактором беспокойства за будущее горных ландшафтов.

Территория Тигирекского заповедника, единственного заповедника в Алтайском крае, после продолжительного использования, длившегося не одну сотню лет, в самом конце XX в. была выведена из хозяйственного оборота. В связи с этим, Тигирекский заповедник является уникальным полигоном, где имеется прекрасная возможность проследить, как происходит динамика ландшафтов после прекращения хозяйственной деятельности на фоне климатических изменений.

Целью исследования является изучение пространственно-временной организации ландшафтов уникальной природной территории северо-западного Алтая — Тигирекского заповедника в контексте глобальных климатических изменений, смены режимов природопользования и новой природоохранной парадигмы.

Задачи:

– оценка репрезентативности ландшафтов заповедника в контексте расширения его границ;
– характеристика ландшафтов заповедника с позиций возможностей для индикации климатических изменений;
– оценка перспектив развития экологического и научно-познавательного туризма в заповеднике с учетом ландшафтного разнообразия.

Материалы и методы

Государственный природный заповедник «Тигирекский» образован в 1999 г. для сохранения биоразнообразия типичной черневой тайги и природных комплексов среднегорий Северо-Западного Алтая. Он является единственным заповедником в Алтайском крае и одним из самых маленьких в России. Заповедник состоит из трех кластеров — Белорецкого, Тигирекского и Ханхаринского, площадь его в нынешних границах составляет 415,1 км^2, а площадь охранной зоны — 262,6 км^2 [14]. На схеме физико-географического районирования вся рассматриваемая территория входит в состав Северо-Западной Алтайской провинции Алтайской (Русско-Алтайской) горной области [15, 16]. В прошлом эту местность называли Малый Алтай, рассматривали как часть Рудного Алтая.

Основу материала для данной статьи составили полевые ландшафтные описания и подготовленные по их результатам ландшафтные карты на всю территорию Русского Алтая [16], отдельные ключевые участки и кластеры заповедника [17–19]. Полевые ландшафтные описания выполнялись по стандартной методике [20]. Они включали характеристику литогенной основы (поверхностные отложения, рельеф, включая микро- и наноформы), увлажнения (характер и степень), почвы (полнопрофильные разрезы, либо прикопки), растительности (геоботанические описания).

Результаты и их обсуждение

Для Северо-Западной Алтайской провинции характерны высокие значения ландшафтного разнообразия. В частности, в пределах провинции представлено 47 видов ландшафтов, что является вторым по величине значением среди всех провинций Русского Алтая. Виды ландшафтов объединяются в 12 подтипов и 17 подродов [16, 21]. В то же время на территории заповедника под охраной нахо-

дится лишь 16 видов ландшафтов (рис. 1). В частности, в заповеднике не представлена верхняя высокогорная часть высотно-поясного спектра провинции.

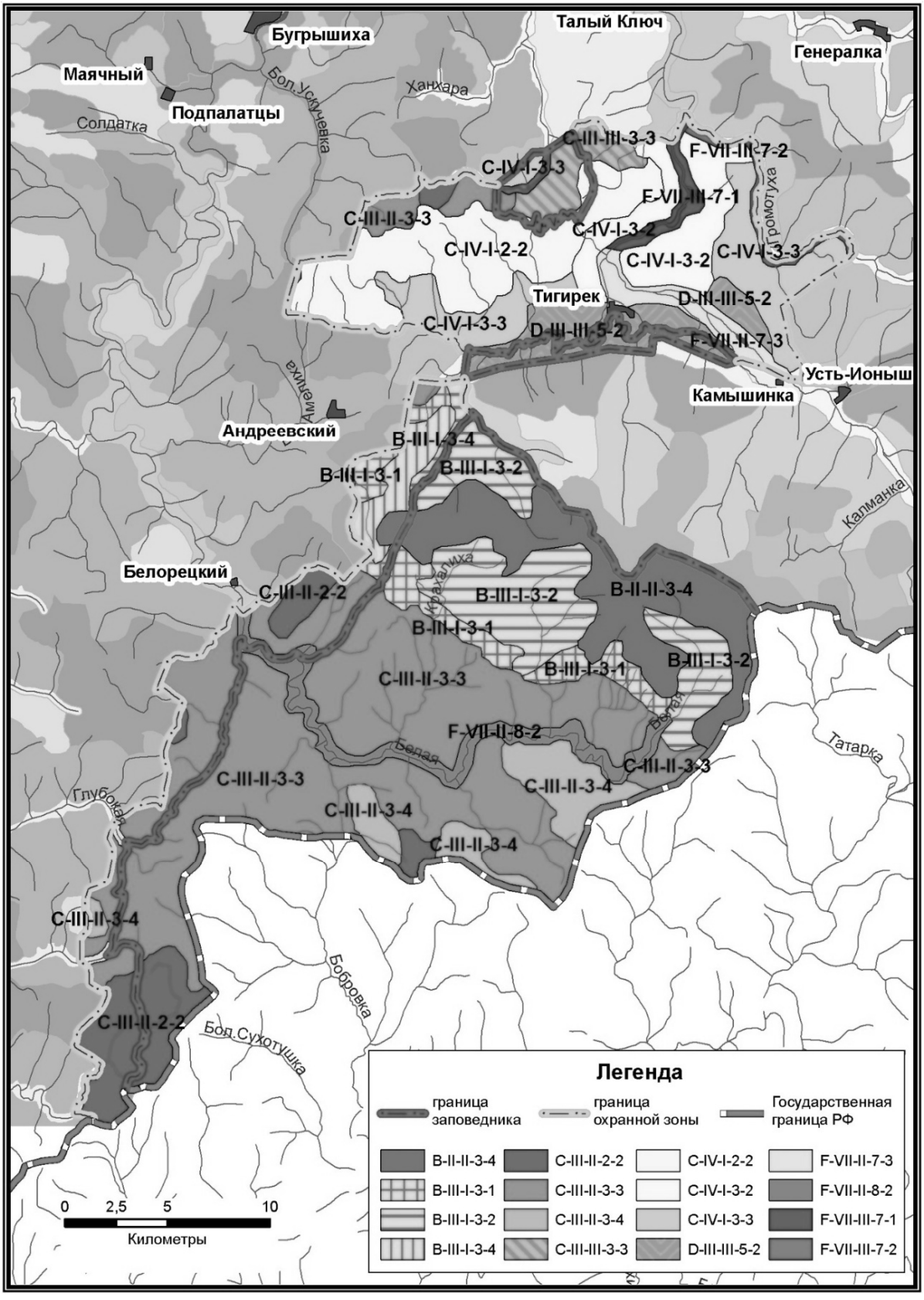

Рисунок 1. Виды ландшафтов Тигирекского заповедника (легенда в тексте)

Легенда ландшафтной карты Тигирекского заповедника:

Среднегорные подгольцово-субальпинотипные (II–II)

B-II-II-3-4 массивные с куполообразными и конусовидными вершинами, осложненные нивальными нишами, водосборными воронками, криогенно-склоновыми формами, с маломощным покровом суглинисто-щебнистых отложений, нередко с курумниками с кедровыми, лиственнично-кедровыми с участием березы и пихты редколесьями и редкостойными лесами, субальпинотипными низкотравными лугами на горно-луговых слаборазвитых почвах, участками высокотравных полидоминантных лугов на горно-луговых почвах, дриадовых, луговых осоково-дерновиннозлаковых и ерниковых тундр на горно-тундровых торфянисто-перегнойных почвах.

Среднегорные горно-таежные (III-I)

B-III-I-3-1 крупные тектоногенные уступы скалистые и скалисто-осыпные, с покровом грубообломочных продуктов физического выветривания, фрагментами солифлюкционно-дефлюкционных щебнистых суглинков, осложненные лавинными лотками и эрозионными бороздами с лиственничными и березово-лиственничными с участием кедра, местами — пихты, бадановыми, высокотравными и кустарниково-травяными редкостойными лесами и редколесьями на горно-лесных бурых оторфованных маломощных фрагментарных почвах, петрофитными кустарниковыми группировками.

B-III-I-3-2 крутосклонные с гребневидными водоразделами, густым эрозионным расчленением, маломощным покровом дефлюкционных щебнистых суглинков, нередко скально-осыпные с березово-елово-лиственничными с участием кедра и пихты кустарниковыми высокотравными и травяно-зеленомошными лесами на горнолесных бурых типичных, реже оподзоленных почвах.

B-III-I-3-4 массивные с куполообразными и конусовидными вершинами, осложненные водосборными воронками, с маломощным покровом суглинисто-щебнистых отложений, нередко с курумниками с кедрово-пихтово-лиственничными, пихтово-лиственнично-березовыми кустарниково-травяными, реже травяно- и кустарничково-зеленомошными лесами на горно-лесных бурых слабооподзоленных почвах.

Низкогорные чернево-таежные субнеморальные (III-II)

C-III-II-2-2 останцово-холмисто-увалистые с покровом суглинисто-щебнистых, реже щебнисто-глыбовых элювиальных отложений с березово-осиново-пихтовыми высокотравными и папоротниковыми кустарниковыми лесами на горно-лесных бурых, реже дерново-глубокооподзоленных почвах.

C-III-II-3-3 наклонные, расчлененные на серии округло-вершинных, реже плосковершинных гряд, с покровом суглинисто-щебнистых отложений: на вершинах и в верхних частях склонов маломощных элювиально-делювиальных; в нижних частях — делювиально-пролювиальных с березово-осиново-пихтовыми, местами с участием лиственницы высокотравными и папоротниковыми с неморальными реликтами кустарниковыми лесами на горно-лесных светло-серых и дерново-глубокооподзоленных почвах.

C-III-II-3-4 массивные с куполообразными и конусовидными вершинами, часто связанные с интрузивными образованиями, осложненные водосборными воронками, с маломощным покровом суглинисто-щебнистых отложений, нередко с курумниками с березово-пихтовыми с примесью осины, кедра и сосны высокотравными кустарниковыми лесами на горно-лесных бурых средне- и легкосуглинистых защебненных почвах, разнотравно-бадановыми лесами на горно-лесных примитивных фрагментарных почвах.

Низкогорные подтаежные (III-III)

C-III-III-3-3 наклонные, расчлененные на серии округловершинных, реже плосковершинных гряд, с покровом суглинисто-щебнистых отложений: на вершинах и в верхних частях склонов маломощных элювиально-делювиальных; в нижних частях — делювиально-пролювиальных с сосново- и лиственнично-березовыми злаково-, осочково-разнотравными, орляковыми кустарниковыми лесами на горно-лесных серых почвах.

Низкогорные лесостепные (IV-I)

C-IV-I-2–2 останцово-холмисто-увалистые с покровом супесчано-, суглинисто-щебнистых, суглинисто-дресвянистых элювиальных отложений, изредка с покровом лессовидных суглинков со злаково-разнотравными настоящими и луговыми степями, их петрофитными вариантами, разнотравно-злаковыми остепненными лугами, зарослями петрофитных кустарников на горных черноземах выщелоченных легкосуглинистых поверхностно защебненных, осиново-березовыми и сосново-лиственнично-березовыми перелесками на горно-лесных темно-серых и серых почвах, разнотравно-злаковыми лугами на луговых и лугово-черноземных почвах по днищам логов.

C-IV-I-3-2 крутосклонные приречные густо расчлененные с маломощным покровом супесчано- и суглинисто-щебнистых дефлюкционных и делювиальных отложений, часто скалистые и скалисто-осыпные с петрофитно-разнотравными кустарниковыми степями на горных примитивных черноземовидных почвах, густыми кустарниковыми зарослями, осиново-березовыми, с участием лиственницы, сосны, реже пихты, с разнотравно-злаковым травяным покровом на горно-лесных дерновых и дерново-карбонатных маломощных почвах.

C-IV-I-3-3 наклонные, расчлененные слабоврезанными пологосклоновыми логами и балками на серии плосковершинных, реже округловершинных гряд, с покровом суглинисто-щебнистых отложений: на вершинах и в верхних частях склонов маломощных элювиально-делювиальных; в нижних частях — делювиально-пролювиальных, с фрагментарным покровом лессовидных суглинков с осочково-разнотравно-злаковыми кустарниковыми степями, зарослями петрофитных кустарников с лугово-степным травостоем на горных черноземах выщелоченных и скелетных, сосново-лиственнично-березовыми изредка с участием пихты, разнотравно-злаковыми и вейниковыми лесами на горно-лесных темно-серых и серых почвах, разнотравно-злаковыми полидоминантными лугами на лугово-черноземных почвах по понижениям, западинам и основаниям склонов, полынно-злаковыми степями на горных черноземах южных по выпуклым световым склонам.

Межгорно-котловинные подтаежные (III-III)

D-III-III-5-2 полого-наклонные волнистые, местами террасированные, сложенные суглинисто-щебнистыми делювиально-пролювиальными отложениями, нередко перекрытыми маломощным покровом лессовидных суглинков с осиново-березовыми с участием лиственницы и пихты злаково-разнотравными и папоротниковыми кустарниковыми лесами на горно-лесных серых и темно-серых почвах; злаково-разнотравными полидоминантными и вейниковыми лугами (еланями) на лугово-черноземных почвах.

Горно-долинные лугово-лесные (VII-II)

F-VII-II-7-3 ящикообразные долины, врезанные в водно-ледниковые, озерно-ледниковые, делювиально-пролювиальные галечниково-суглинистые, песчано-галечниковые, суглинисто-щебнистые, покровные лессовидные отложения, реже в коренные кристаллические породы, с разветвленными руслами, частично перекрытые щебнисто- и дресвяно-суглинистыми делювиально-пролювиальными шлейфами и аллювиально-пролювиальными конусами выноса с прирусловыми ивово-березовыми лесами, низинными закустаренным и высокотравно-осоковыми лугами на аллювиальных луговых, настоящими разнотравно-злаковыми (ежовыми, овсяницевыми, полевицевыми, мятликовыми) лугами на черноземно-луговых выщелоченных почвах, березово-еловыми с участием пихты, лиственницы кустарниково-травяными лесами на горно-лесных серых оглеенных почвах.

F-VII-II-8-2 долины с несколькими уровнями фрагментарной поймы, комплексом низких, местами высоких надпойменных террас: верхний уровень поймы сложен с поверхности маломощным слоем супесчано-суглинистого аллювия, подстилаемого галечниково-валунным аллювием, нижний уровень — галечниково-валунный; наклонные поверхности террас песчано-галечниковые, нередко перекрытые суглинисто-щебнистыми отложениями делювиальных шлейфов и аллювиально-пролювиальных конусов выноса, иногда с маломощным слоем покровных супесей; с эрозионными останцами из плотных кристаллических пород с прирусловыми ивняками; лиственнично- и сосново-березовыми, местами с примесью ели кустарниково-травяными лесами на аллювиальных перегнойных оглеенных слоистых почвах, закустаренными разнотравно-злаковыми лугами на аллювиальных луговых почвах по основной пойме; участками осоковых кочковатых болот; вторичными разнотравно-злаковыми лугами на лугово-черноземных почвах, луговыми степями и остепненными лугами на черноземах выщелоченных, березово-лиственничными и лиственничными, местами парковыми, злаково-разнотравными лесами на горно-лесных черноземовидных и серых лесных почвах на террасах.

Горно-долинные лугово-степные (VII-III)

F-VII-III-7-1 ущелистые скалистые долины с порожистыми руслами, местами с четковидными расширениями, фрагментарными террасами и поймами, песчано-галечниково-валунные, с активным развитием наледных явлений с петрофитно-разнотравно-злаковыми кустарниковыми степями на слаборазвитых черноземовидных почвах, осоково-разнотравно-злаковыми лугами на аллювиальных луговых и дерновых почвах, разреженными ивово-тополевыми и березовыми лесами на аллювиальных дерновых слаборазвитых почвах.

F-VII-III-7-2 долины V-образные, с узкими поймами, местами с расширениями и фрагментами надпойменных террас, песчано-галечниковые, песчано-валунно-галечниковые с ивняками и ивово-

тополевыми прирусловыми закустаренными лесами на аллювиальных иловато-глеевых слоистых почвах, злаково-разнотравными лугами на аллювиальных луговых и лугово-черноземных почвах, разнотравно-типчаково-ковыльными кустарниковыми степями на черноземах обыкновенных.

Важнейшими особенностями территории Тигирекского заповедника, нашедшими отражение в ландшафтной структуре, являются следующие:

1. Характерное для Алтая северо-западное (так называемое «алтайское») направление основных орографических элементов — хребтов и разделяющих их магистральных речных долин. Это обусловливает, с одной стороны, унаследованность большого количества ландшафтных границ тектоническим рубежам, а с другой — высокую контрастность на внутриландшафтном уровне, в связи со значительной представленностью наветренных и подветренных склонов.

2. Высотная поясность как основная закономерность ландшафтной дифференциации в горах. При этом высотная поясность осложняется другими, характерными для горных систем континентальных районов факторами, — барьерным эффектом, гидроморфным и литоморфным факторами, солярной экспозицией. Кроме этого, имеют место случаи инверсии высотной поясности. Так, как отмечалось нами ранее [19], в пределах чернево-таежных низкогорий на гребневидных и конусовидных вершинах и привершинных световых склонах, подверженных активному воздействию ветров и инсоляции, формируются петрофитные варианты луговых степей и остепненных лугов в сочетании с мелкими березовыми перелесками.

3. Положение территории на северо-западной периферии Алтайских гор, с чем связано значительное количество атмосферных осадков за счет барьерного эффекта. В таких условиях в пределах Северо-Западной Алтайской физико-географической провинции, где расположен заповедник, формируется один из самых гумидных и, одновременно, теплых в горах Южной Сибири спектров высотной поясности. В частности, Северо-Западный Алтай является единственной провинцией, где в высокогорной части спектра наблюдается преобладание луговых формаций над тундровыми. Относительно теплый и влажный климат Северо-Западного Алтая, в сочетании с плоским рельефом долин вполне благоприятствуют накоплению торфа. Формирование торфяников в заповеднике происходит в широком высотном диапазоне (более 1000 м), начиная от низкогорий в окрестностях пос. Тигирек и заканчивая субальпийским поясом.

4. Ярусность рельефа, рельефообразующих процессов и ландшафтов в целом. Так, в пределах субширотно-ориентированной Тигирекской котловины, даже при ее небольших размерах, котловинный эффект проявляется в значительном снижении количества осадков, в том числе зимних. В то же время выраженность отдельных ярусов рельефа на различных участках неодинакова, а границы ярусов рельефа не всегда совпадают с высотно-поясными рубежами.

5. Разнообразие горных пород, выступающих почвообразующими породами и создающих контрастные условия для биоты. Это и карбонатные породы (известняки силура), с которыми связано остепнение, и кислые породы (граниты), создающие эффекты осеверения. Кроме этого, на фоне господства скальных пород, продуктов их выветривания и переотложения, в заповеднике достаточно широко распространены лёссовидные отложения, образующие местами на поверхности скальных пород чехол мощностью в несколько метров. На геологических картах лёссы показаны не так широко, главным образом в степных и лесостепных низкогорьях. На распространение лёссов в низкогорьях Северо-Западного Алтая неоднократно обращал внимание В.А. Николаев. Он справедливо отмечал, что лёсс перекрывает здесь не только шлейфы горных склонов и высоких террас речных долин, но нередко поднимается на гребневую часть хребтов [22]. В то же время, по его мнению, древесная растительность на лессах здесь никогда не поселяется. Следует отметить, что тщательного изучения распространенности лёссов в Северо-Западном Алтае никогда не проводилось. Как показали наши исследования, покровные лёссовидные отложения достаточно широко представлены в пределах чернево-таежного подпояса Белорецкого участка Тигирекского заповедника. Здесь они залегают как на склонах, так и на водоразделах, и на них формируются полнопрофильные серые лесные почвы, сильно контрастирующие с горно-лесными почвами, сформированными на продуктах выветривания кристаллических пород (рис. 2).

Рисунок 2. Серая лесная почва под березово-пихтовым злаково-разнотравным лесом в верховьях р. Алей

Несмотря на высокое ландшафтное разнообразие Тигирекского заповедника, занимаемой им площади явно недостаточно для горных условий, чтобы он мог в полной мере выполнять функции по сохранению биоты. Упорядоченность природы в горах по вертикали предполагает, что многие виды организмов мигрируют в течение года в направлении от нижних высотных поясов вверх и обратно. Учитывая этот факт, горные заповедники, как правило, проектируют таким образом, чтобы они охватывали весь спектр высотных поясов, от подножий гор до самых высоких вершин. Тигирекский заповедник этому условию не отвечает. Верхняя часть высотно-поясного спектра Северо-Западного Алтая в заповеднике не представлена. Это древнеледниковые и внеледниковые высокогорья с альпийскими и субальпийскими лугами, широким распространением многолетних снежников и погребенными под слоем обломочных отложений льдами. В то же время на смежных с заповедником участках в верховьях Ини и Коргона находился крупный очаг последнего оледенения. В границах Алтайского края только здесь представлено все многообразие форм рельефа и ландшафтов, связанных с деятельностью ледников. Это и ледниковые цирки с многочисленными озерами, отроговые долины, на днищах которых многочисленны ледниковые отложения — морены, фиксирующие кратковременные подвижки ледников, наблюдающиеся на фоне общего их отступания. Ландшафты, обязанные своему происхождению ледниковым процессам, чрезвычайно хрупки и неустойчивы, так как являются очень молодыми. В них нередко фиксируется многолетняя мерзлота, а иногда и просто лед, погребенный под обвалами, селями и лавинами. Особенно уязвимыми эти ландшафты становятся на фоне глобального потепления климата, наблюдающегося в настоящее время. Потепление может вызвать усиление деградации мерзлоты и термокарстовые процессы.

Расширение заповедника необходимо и для большего охвата охранным режимом верхней части лесного пояса — горной тайги. В новых границах охраной охватывается значительно больше специфической горной тайги. В горно-таежных лесах Северо-Западного Алтая представлено большинство из хвойных южно-сибирских пород — кедр, лиственница, пихта, ель, что является уникальным явлением. Например, пихта и лиственница, являющиеся породами-антагонистами, редко где встречаются вместе. Кроме этого, горно-таежные леса выполняют ряд важных экологических функций — водорегулирующие, противоэрозионные, противообвальные, противолавинные. Многообразны типологические группы таежных лесов. Экзогенные геологические процессы имеют разную специфику на склонах северных и южных экспозиций. Так, на южных склонах более энергичны осыпные и обвальные явления.

Расширение территории заповедника позволит взять под охрану ландшафты экспозиционной лесостепи, близкой по своим характеристикам лесостепи Центрального Алтая. Если лесостепь северных

низкогорий Алтая близка по структуре лесостепи юга Западной Сибири, где на северных склонах распространены осиново-березовые леса, а на южных — горные варианты луговых и настоящих степей, то ближе к центру Алтая структура лесостепи меняется. На северных склонах здесь формируются леса из лиственницы, нередко называемые парковыми, на южных, наряду с настоящими дерновинно-злаковыми степями, образуются мелкодерновинно-злаковые степи.

Большой научный интерес ландшафты Тигирекского заповедника представляют в контексте их реакции на глобальные климатические изменения и имевшие место в прошлом антропогенные воздействия. Здесь, в частности, имеется возможность наблюдать восстановление ландшафтов после распашки или рубок леса. Естественные ландшафты могут испытывать глубокие трансформации в результате хозяйственного воздействия. Однако далеко не всегда после прекращения воздействия ландшафт возвращается в исходное состояние, тем более на фоне потепления климата. Например, в долине Большого Тигирека, на месте некогда сведенных лесов, древесная растительность в настоящее время восстанавливается не везде. Отдельные участки долины густо заселены ковылем и другими дерновинными растениями, перекочевавшими сюда с южных солнцепечных известняковых склонов, ограничивающих с севера долину Большого Тигирека. При этом плотная дернина степняков препятствует лесовозобновлению, но многие лесные виды трав соседствуют здесь со степными, формируя новые, отсутствовавшие прежде, сообщества.

Важнейший источник информации о ландшафтных обстановках прошлого — торфяные болота. На территории Тигирекского заповедника обнаружены торфяники мощностью до 1,5 м (рис. 3). Большая часть из них так или иначе связана с долинами рек, поэтому в торфяниках записана информация не только о динамике самого болотного массива, но и о колебаниях водности рек. В частности, датировки органики, полученные нами из торфяной залежив пойме р. Белая, в ее верхнем течении, свидетельствуют о том, что Малый ледниковый период в Северо-Западном Алтае, как и во многих других регионах [23, 24], характеризуется снижением водности рек. Вероятно, такая ситуация имела место за счет общего снижения количества атмосферных осадков и уменьшения продолжительности теплых сезонов. В Малый ледниковый период более суровые и продолжительные зимы прерывались короткими и относительно прохладными сезонами с положительными температурами [24]. В результате в пойме р. Белая наблюдается перерыв в отложении аллювиальных толщ и активно развивается болотообразовательный процесс (слой торфа на глубине 40–67 см). Лишь в редкие годы этот процесс прерывается аллювиальным процессом (включения тяжелого суглинка). По окончании Малого ледникового периода происходит увеличение водности р. Белая, сопровождающееся сначала нерегулярным (24–40 см), а затем регулярным (0–24) выходом речного стока за пределы русловых бровок. В условиях поёмного режима, т.е. регулярного отложения на поверхности поймы слоев свежего речного аллювия, происходит формирование синлитогенных аллювиальных почв.

Рисунок 3. Торфяник в Тигирекском заповеднике

На вершинах Тигирекского хребта мы можем видеть хорошо сохранившиеся фрагменты деревьев, погибших во время Малого ледникового периода (рис. 4). Это еще один источник информации о динамике ландшафтов в прошлом. Кстати, многие путешественники, посещавшие Алтай в конце XVIII – первой половине XIX в., отмечали обилие погибших взрослых деревьев на вершинах горных хребтов, в том числе в Северо-Западном Алтае, где сейчас расположен Тигирекский заповедник. Так, на этот факт указывают члены экспедиции, организованной Дерптским университетом в 1826 г., К.Ф. Ледебур и А.А. Бунге. Оба естествоиспытателя неоднократно упоминают в своих дневниках об увиденных ими случаях массовой гибели леса, рассуждая о причинах этого и недоумевая, что они являются свидетелями глобального похолодания [25].

Рисунок 4. Погибший кедр на вершине Тигирекского хребта

В настоящее время на российские заповедники возложена задача по организации экологического туризма. В Северо-Западном Алтае, в том числе в охранной зоне Тигирекского заповедника, где грань между объектами культурного и природного наследия не всегда резкая, туризм должен иметь сильный крен в сторону научно-познавательного. Длительное время, осваивая ландшафты этой территории, человек, с одной стороны, привносил в них искусственные элементы, которые впоследствии стали культурным наследием, а с другой — наделял определенными смыслами естественные элементы ландшафтов, например, сакрализируя их. При грамотной организации ландшафты таких территорий могут стать поистине культурными, причем не только как арена деятельности, но и как феномены, наполненные определенными смыслами, и они, безусловно, будут востребованы среди экотуристов. Исходя из этого, и необходимо формировать сеть экотроп и маршрутов. Конечно, нельзя не согласиться с широко распространенным мнением, что любой маршрут — это некоторое ограничение степеней свободы путешественника, но в охранной зоне заповедника по-другому нельзя. Считаю, что научно-познавательный маршрут необходимо ориентировать на постижение ландшафта. Путешественник, следующий по маршруту, даже если он проходит маршрут не в первый раз, каждый раз должен заново открывать для себя ландшафт. Это можно сделать, если посещать территорию в разные сезоны года, в разное время суток при разной освещенности, используя разные точки наблюдений и т.д.

Заключение

1. Охарактеризованы основные особенности ландшафтной структуры Тигирекского заповедника. В ландшафтной структуре территории нашли отражение как региональные черты, обусловленные географическим положением, так и местные особенности, связанные с проявлением локальных ландшафтообразующих факторов и хозяйственной деятельностью человека.

2. Несмотря на высокое ландшафтное разнообразие Тигирекского заповедника, занимаемой им площади явно недостаточно для горных условий, чтобы он мог в полной мере выполнять функции по сохранению биоты.

3. Большой научный интерес ландшафты Тигирекского заповедника представляют в контексте их реакции на глобальные климатические изменения и имевшие место в прошлом антропогенные воздействия. Особенно интересны в этом отношении торфяные болота и ландшафты на верхней границе леса.

4. В охранной зоне Тигирекского заповедника, где грань между объектами культурного и природного наследия не всегда резкая, экологический туризм должен иметь сильный крен в сторону научно-познавательного и его необходимо ориентировать на постижение ландшафта.

Теоретические положения данного исследования сформулированы в рамках государственного задания Института водных и экологических проблем СО РАН (№ 1021032422891–7). Полевые работы, обработка и осмысление полевого материала осуществлялись при поддержке Русского географического общества в рамках проекта «Ландшафты Северо-Западного Алтая: от русских первопроходцев и малого ледникового периода до экологического туризма и глобального потепления» (грант № 03/2021-И).

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Д.В. Черных

Тигирек қорығының ландшафттары: өткені, қазіргісі, болашағы

Қорықтар ландшафттық картография жасаудың негізін құрайтын сынақ алаңдары болған. Мақалада Тигирек мемлекеттік қорығының (Орыс Алтайы) ландшафттық құрылымының негізгі ерекшеліктері сипатталған. Көптеген ландшафт шекаралары тектоникамен анықталады. Биіктік белдеулер ландшафт дифференциацияның негізгі заңдылығы болып табылады. Қорықта биота мен топырақтың түзілуіне қарама-қарсы жағдайлар жасайтын әртүрлі тау жыныстары бар. Солтүстік-Батыс Алтайдың салыстырмалы түрде жылы және ылғалды климаты аңғарлардың жазық рельефімен үйлесуі шымтезектің жиналуына әбден қолайлы. Карта ландшафт түрлері деңгейінде ұсынылған. Карта егжей-тегжейлі аңызға негізделген. Тигирек қорығының жоғары ландшафттық әртүрлілігіне қарамастан, биотаны сақтау функцияларын толығымен орындау үшін оның алып жатқан ауданы тау жағдайлары үшін жеткіліксіз. Қорықты кеңейту үшін таулы жерлер мен орман белдеуінің жоғарғы бөлігін қорғау режимімен көбірек қамту қажет. Ландшафттық-картографиялық талдау экологиялық мониторинг және қорықтық аумақтардағы мәдени, реттеуші және қолдаушы экожүйелік қызметтерді бағалау үшін маңызды мәнге ие болуы мүмкін екендігі атап өтілген. Тигирек қорығының ландшафттары жаһандық климаттық өзгерістерге және бұрын болған антропогендік әсерлерге реакциясы тұрғысынан үлкен ғылыми қызығушылық тудырады.

Кілт сөздер: Тигирек қорығы, Алтай, ландшафт, ландшафттық әртүрлілік, шымтезек батпақтар, орманның жоғарғы шекарасы, экожүйелік қызметтер, экологиялық туризм.

D.V. Chernykh

Landscapes of the Tigirek Reserve: past, present, future

Strict nature reserves are the grounds where the basis of landscape mapping was developed. The paper presents a number of markable features of landscape structure of Tigirek State Nature Reserve (Russian Altai) and the map at the level of species of landscapes. The map includes a detailed legend. Many landscape boundaries are caused by tectonics. Altitudinal zonation is the main regularity of landscape differentiation. The reserve contains a variety of rocks that create contrasting conditions for biota and soil formation. The warm and humid climate of the Northwestern Altai, combined with the flat relief of the valleys, is favorable for the accumulation of peat. Despite the high-diversity landscape of the Tigirek Reserve, the area occupied by it which is clearly insufficient for mountain conditions, so that it could fully perform the functions of preserving biota. Expansion of the reserve is necessary for greater coverage of the highlands and the upper part of the forest belt with the protection regime. The landscape-cartographic analysis based on the structural-genetic principle can be of key importance for environmental monitoring and evaluating cultural, regulation and maintenance ecosystem services in nature reserves. The landscapes of the Tigirek Reserve are of great scientific interest in the context of their response to global climatic changes and anthropogenic impacts that took place in the past.

Keywords: Tigirek Reserve, Altai, landscape, landscape diversity, peatlands, upper treeline, ecosystem services, ecological tourism.

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Landscape diversity of the forest-steppe in the Tyumen Oblast (Russia)

Forest-steppe landscapes are ecotonic systems that are characterized by a high degree of diversity due to the combination of zonal forest and steppe landscapes, as well as swamps and meadows. The research is based on a comprehensive analysis of literary sources, topographic and thematic maps, satellite images, as well as field expeditions of 1997–2020. In the south-western part of the Tyumen Oblast, 12 types of terrain are differentiated on an area of 30,000 km^2, including types of terrain of divides, ridges, flat ridges, flat depressions, hillock depressions, terraces, slopes, lakes and swamps, reed swamps, ravines and girders, floodplains of large rivers, small valleys. The main features of the spatial organization of landscapes in the region and the landscape structure at the level of components are characterized. In the conditions of the region, the main part of landscapes is convenient for economic development and used in various sectors of the economy. Meadow and steppe landscapes, and partly forests are plowed. Pastures and hayfields are widespread on the territory. Such economic activities as sand and peat extraction, wood harvesting, recreational nature use, as well as fishing, hunting, and gathering have been developed. Some landscapes are protected by state as nature reserves.

Keywords: type of terrain, landscape structure, forest-steppe, Tyumen Oblast.

Introduction

Taking into account the landscape structure of territories is important for understanding the features of natural processes, economic activities planning. On the example of the south-western part of the Tyumen Oblast with an area of 30,000 km^2, the landscape structure of the territory is characterized in detail at the level of types of terrain as combinations of landscape units and a set of landscape components; the main directions of economic use of landscapes are described.

Experimental

The landscape diversity of the forest-steppe on the example of the south-western part of the Tyumen Oblast is characterized on the basis of a comprehensive analysis of special literature, topographic and thematic maps, satellite images [1], field explorations in the period of 1997–2020. In the article, the structure of types of terrain is presented [2], the landscape components — features of the relief, geological foundation, climate, hydrological conditions, soils, vegetation; economic use of the territory are characterized.

Results and Discussion

The landscapes of the forest-steppe were formed under conditions of insufficient moisture (the hydrothermal coefficient is 1.0) at an average annual temperature of +0.4 °C, the average temperature in January is –18.0 °C, in July +19.0 °C. The sum of temperatures above +10 °C is 1800–1900°. The frost-free period lasts 120 days. An average of 335 mm of precipitation falls per year, of which 80–85 % is during the warm period.

In the northern forest-steppe, types of terrain of divides, ridges, flat ridges, flat depressions, hillock depressions, terraces, slopes, lakes and swamps, reed swamps, ravines and girders, floodplains of large rivers, and small valleys are differentiated [3, 4].

I. The type of terrain of divides is mapped on the Iset-Pyshma interfluve (Isetsky district), on the Tobol — Borovaya Ingala interfluve (Uporovsky district), in the central part of the Yalutorovsky district, on the watershed plains in the upper reaches of the Bochanka, Koktyul and right tributaries of the Uk River (Zavodoukovsky district). The type of terrain of divides includes flat and wavy watershed plains covered with chernozems and gray forest soils, without noticeable signs of erosion.

The type of terrain is confined to wavy loamy watersheds with absolute heights of 80–152.6 m (the highest point in the Tyumen Oblast without autonomous okrugs). The area is dominated by well-drained, mostly plowed, surfaces on the site of meadows in combination with birch, birch-aspen and birch-willow forests in depressions. The lithogenic complex is formed by alluvial deposits of the third and fourth above-

floodplain terraces and eluvial-deluvial cover deposits represented by sands, sandy loams, loams and clays. The landscape diversity is associated with the presence of a large number of depressions, valleys and the upper reaches of shallow girders [5].

The heavy-loamy variant of the type of terrain is represented by landscape units of high wavy plains with arable land in place of meadow steppes on leached chernozems and meadow saline soils in combination with birch grass forests (*Convallaria majalis* L., *Thalictrum simplex* L.) on gray forest soils. Rounded depressions are occupied by birch forests, willow bushes and low-lying sedge-grass swamps (*Caltha palustris* L., *Phragmites australis* (Cav.) Trin. ex Steud., *Typha latifolia* L.) on peat soils (Iset-Pyshma interfluve northwards Isetskoye village).

Within the medium-loamy variant of the type of terrain, arable land in combination with birch, birch-aspen and birch-willow forest outliers on meadow-chernozem soils predominate. Fragmentary low- and medium-aged birch and birch-aspen broad-grass forests (*Archangelica officinalis* Hoffm., *Conium maculatum* L.) are distributed on dark gray forest soils.

On the Iset-Pyshma interfluve northwards Sizikovo, Barkhatovo, Arkhangelskoye villages, there are meadows and arable land on leached chernozems and meadow soils in combination with birch grass forests on gray forest soils. The landscape structure is complemented by landscape units of elongated, closed, undrained depressions with sedge-grass swamps, often overgrown with birch and willow, on peat soils.

The light-loamy variant of the type of terrain within the flat plains is represented by field and meadow landscape units on meadow saline soils in combination with birch and birch-aspen forest outliers in depressions. The landscape structure is complemented by isolated massifs of birch grass forests (*Agrimonia pilosa* Ledeb., *Agrostis albida* Trin., *Athyrium filix-femina* (L.) Roth) on gray forest soils (the interfluve of the Tobol and Borovaya Ingala rivers northwards Suyerka village). Flat-closed depressions with sedge-grass swampy meadows (*Alopecurus arundinaceus* Poir., *Carex acuta* L., *Eleocharis palustris (*L.) Roem. & Schult.) on peat bog soils have a limited distribution.

In the conditions of the region, the landscape units of the type of terrain of divides are among the most convenient areas for agricultural development, which have been largely transformed into arable land. Grass meadows are used as hayfields and pastures. Forests are used for collecting of berries, mushrooms, and medicinal herbs, as well as for grazing livestock.

II. The type of terrain of ridges is confined to the drained watershed plains located southwards the Iset River, in the basin of the Yemurtla River, in the upper reaches of the Bochanka and Singarivers (Isetsky, Uporovsky, and Zavodoukovsky districts). Absolute heights vary from 100 to 140 m. There are numerous deep ravines in the valley of the Kizak River. Loamy, sandy loam and sandy eluvial-deluvial and deluvial cover deposits, alluvial deposits of the third and fourth above-floodplain terraces are common. Combinations of forest landscape units and dry grass meadows are typical for ridges. Significant areas are occupied by arable land on the site of reduced forests. Swamp landscapes are rare and confined to flat-closed depressions.

By area, landscape units of medium-loamy variant with plowed meadow steppes on leached chernozems, meadow soils in combination with birch grass (*Aegopodiumpodagraria L., Lactucaserriola L., Sanguisorba officinalis* L.) and sedge-grass (*Carex cespitosa* L., *Puccinellia tenuissima* Litv. ex V.I. Krecz., *Scirpus sylvaticus* L.) forests on gray forest soils (Goryunovo and Kolesnikovo villages) are dominated. Landscapes of old-age birch sedge-grass forests on gray forest soils in combination with grass dry meadows (*Medicago falcata* L., *Phleum pratense* L., *Plantago lanceolata* L.) and arable lands on meadow soils (Kirsanovo village) have been formed in shallow depressions. Eastwards Bateni and Bityuki villages, landscape units of grass and sedge-grass meadows and arable lands are mapped on the site of reduced forests in combination with numerous birch and willow forest outliers on leached chernozems and gray forest soils (Lipikha and Nifaki villages).

The heavy-loamy variant is characterized by landscape units of arable lands and meadows with birch and birch-aspen forest outliers on leached chernozems in combination with birch and birch-aspen grass and sedge-grass forests on gray forest soils (Masali and Pyatkovo villages). Meadows, as a rule, are confined to the southern slopes of ridges or to the areas with clearly expressed signs of salinity [6].

The sandy loam variant is represented by landscape units of drained plains with pine and pine-birch sedge-grass (*Calamagrostis canescens* (Weber) Roth, *Carex vaginata* Tausch, *Filipendula vulgaris* Moench) forests on gray forest and sod-podzolic gley soils (Kirsanovo village). Within the contours of the sandy variant, under good aeration conditions, landscape units of pine and pine-birch berry-mossy (*Linnaea borealis* L., *Lycopodium clavatum* L., *Rubus saxatilis* L.) and grass forests on podzolic soils were formed (Kirsanovo village and Lebedevka settlement).

In the basin of the Yuzya River, on high-plains pine-birch berry-mossy (*Dryopteris filix-mas* (L.) Schott, *Rubus saxatilis* L., *Trientalis europaea* L.) and grass (*Calamagrostis epigeios* (L.) Roth, *Lathyrus pisiformis* L., *L. vernus* (L.) Bernh., *Linnaea borealis* L.) and birch grass (*Paris quadrifolia* L., *Urtica dioica* L., *Vicia cracca* L.) forests are widely distributed on podzolic, sod-podzolic gley and gray forest soils. Near settlements and villages forests have been cut down and plowed (Bateni and Bityuki villages). In the area of Staraya Shadrina and Gubina villages, old-age pine berry-mossy forests in combination with dry grass meadows (*Alopecurus pratensis* L., *Lotus corniculatus* L., *Trifolium hybridum* L.) and arable lands on podzolic soils are dominated.

The forests of the type of terrain of ridges are regularly cut down. Dry meadows are used as hayfields and pastures. In the forests, residents collect berries, mushrooms, medicinal herbs. The high degree of plowing of the territory leads to a shortage of pasture lands, consequently, people use forests as pastures.

III. The type of terrain of flat ridges is formed on flat-undulating inclined plains composed of loamy alluvial deposits of the fourth above-floodplain terrace. The type of terrain is mapped on the interfluves of the left tributaries of the Iset River in the Isetsky district. The prevailing absolute heights are 80–100 m. The relief is complicated by numerous depressions and ridges with a height difference of up to 1–5 m. The ground water level varies from 0.5 to 5 m. The landscape structure consists of forest landscape units in combination with dry grass meadows, some of which have been transformed into arable lands. Swamps are rare and confined to flat-closed undrained rounded, less often elongated, depressions.

The most widespread ones are the landscape units of the heavy-loamy variant. The landscape units of plains with birch grass forests (*Berteroa incana (*L.) DC., *Chamaenerion angustifolium* (L.) Scop.) on dark gray forest soils dominate. Smaller areas are occupied by grass meadows (*Melilotus albus* Medikus, *Trifolium hybridum* L., *T. pratense* L., *Tussila gofarfara* L.) and arable lands on leached chernozems. The landscape structure is complicated by numerous birch-aspen and birch-willow forest outliers on gray forest soils. Landscapes of birch grass-marsh forests and mesotrophic sedge-willow swamps on low-lying peat soils have been formed in flat-closed undrained wet depressions (Ishimsky settlement, Sozonovo village).

The medium-loamy variant is characterized by the predominance of dry-grained grass (*Artemisia absinthium* L., *A. pontica* L., *Plantago major* L.) meadows and arable lands on meadow soils. The landscape structure is complemented by landscape units of birch grass and sedge-grass forests on gray forest soils. Forests and meadows are used as hayfields and pastures. Forests are used for berries, mushrooms, medicinal herbs collecting. Some of the forests and meadows have been transformed into arable lands, but the total ploughing of the territory does not exceed 30 %.

IV. The type of terrain of flat depressions is mapped on the above-floodplain terraces of the Tobol River (Lebedevka and Zavodopetrovsky settlements, Korkino and Polyakovskaya villages), as well as in the North-West of Yalutorovsky (westwards Kiyova village) and in the East of the Uporovsky (eastwards Kiselyovo village) districts. Absolute heights vary from 110 to 140 m. The area is dominated by arable lands in combination with meadow steppes, birch and birch-aspen forests along the depressions.

The structure of the sandy variant is dominated by landscapes of pine-birch lichen (*Polygonatum odoratum* (Mill.) Druce, *Pulsatilla patens* (L.) Mill.), berry-mossy (*Chimaphila umbellata* (L.) W.P.C. Barton, *Fragaria vesca* L., *Pyrola rotundifolia* L.), and grass forests on podzolic soils. The light-loamy variant includes birch grass (*Geranium sylvaticum* L., *Pulmonaria mollis* Wulfen ex Hornem.) and sedge-grass (*Carex hirta* L., *Equisetum sylvaticum* L., *Filipendula ulmaria* (L.) Maxim.) forests on gray forest soils.

Within the medium-loamy variant, wavy-drained surfaces with plowed meadow steppes on chernozem and meadow-chernozem soils with birch, birch-aspen and birch-willow forest outliers dominate (upper reaches of the Begila and the Uk rivers). Meadow-chernozem soils are characterized by a high humus content (6–8 %) and a close to neutral acidity (pH 6–7) [7]. The landscape units are convenient for economic development and have been mostly transformed into arable lands.

V. The type of terrain of hillock depressions is mapped on the watershed plains in the Zavodoukovsky, Isetsky, Uporovsky, and Yalutorovsky districts. It is characterized by rounded concave depressions, often occupied by lakes. Absolute heights vary within a wide range — from 60–70 m in the lower reaches of the Iset River to 100–140 m in the South of the Isetsky and Uporovsky districts. Erosion processes are poorly expressed. The groundwater level varies widely — from 0.5 to 7–8 m.

The landscapes of sandy and sandy loam variants include high-drained plains with pine-birch reed grass (*Calamagrostis langsdorffii* (Link) Trin., *Melica nutans* L.) and grass (*Asarum europaeum* L., *Oxalis acetosella* L.) forests on podzolic, sod-podzolic and sod-podzolic gley soils in combination with lakes (Pamyatnoye and Singul Tatarsky villages). To a lesser extent, smoothed manes with berry-mossy pine forests

are common on podzolic (Nizhneingal and Tatarsky Singul villages) and shallow depressions with sedge-grass birch forests on sod-podzolic gley soils (Drobinino and Tyumentsevo villages). The landscapes of the loamy variant include birch reed grass and grass forests on sod-podzolic soils in combination with grass and sedge-grass meadows on chernozems.

The landscapes of the type of terrain of hillock depressions are actively used in economy. Industrial logging is carried out in the forests; residents collect berries, mushrooms, medicinal herbs. Meadows and forests are used as pastures; fishing is carried out in lakes. Part of the forest and meadow landscapes has been transformed into arable land. The combination of forest landscape units with clean lakes creates favorable conditions for the organization of recreational activities — resorts operate within the type of terrain. Within the area, two region class reserves are organized — Rafailovsky is on the right bank of the Iset River and Komissarovsky is in the upper reaches of the Yemurtla River.

VI. The type of terrain of terraces is mapped in Zavodoukovsky and Uporovsky districts on the above-floodplain terraces of the Tobol River, as well as in the valleys of the Yemurtla, Kizak, and Koshair rivers. The flattened relief is typical; it is complicated by the remnants of the fluvial network and forms of Aeolian processing. Absolute heights vary from 60 to 100 m. Erosion processes are poorly expressed. The ground water level varies from 3 to 10 m. A combination of forest, meadow and swamp landscape units is characteristic.

Landscapes of the sandy variant have become the most widespread. Landscape units of drained wavy above-floodplain terraces with pine and pine-birch lichen (*Antennaria dioica* (L.) Gaertn., *Equisetum hyemale* L., *Polygonatum odoratum* (Mill.) Druce), heather (*Calluna vulgaris* (L.) Hull, *Calamagrostis epigeios* (L.) Roth) and berry-mossy (*Fragaria vesca* L., *Maianthemum bifolium* (L.) F.W. Schmidt*, Vaccinium myrtillus* L.) forests on podzolic soils dominate. The landscape structure is complemented by landscape units of pine-birch-aspen and birch reed grass (*Calamagrostis epigeios* (L.) Roth, *C. phragmitoides* Hartm., *Diphasiastrum complanatum* (L.) Holub) and grass (*Angelica sylvestris* L., *Crepis tectorum* L., *Hieracium umbellatum* L.) forests on podzolic and sod-podzolic soils that occur, in most cases, in the site of burn [8, 9].

The loamy variant is characterized by the predominance of landscape units of the terraces with pine-birch grass (*Bromopsis inermis* (Leyss.) Holub*, Lathyrus pratensis* L., *Poapratensis ssp. pratensis, Ranunculus repens* L.) and sedge-grass (*Carex vaginata* Tausch, *C. vulpina* L.) forests on gray forest soils (upper and middle reaches of the Yemurtla River). The landscape structure is complemented by landscape units of grass meadows (*Phleum phleoides* (L.) H. Karst., *Poa angustifolia* L., *Puccinellia hauptiana* V.I. Krecz.) on chernozems (Berdyugino, Morevo, Slobodchiki, Staraya Nerda, and Yemurtla villages).

In many places, forests have been replaced by meadows used as hayfields and pastures. Industrial sand mining was carried out in the quarries (Tumashovsky settlement). In the South of the Zavodoukovsky district, the Komissarovsky region class reserve is organized on the above-floodplain terraces of the Yemurtla River.

VII. The type of terrain of slopes is mapped in the areas of the valleys of the Tobol, Uk, and Begila rivers and contiguous watershed plains in the Zavodoukovsky district. The landscapes are represented by slopes with an inclination of more than 3°. Absolute heights vary from 80 to 130 m.

Within the type of terrain, all types of plant communities characteristics of the forest-steppe zone are found. The upper and middle parts of slopes are occupied by pine-birch berry-mossy (*Fragaria vesca* L., *Vaccinium myrtillus* L.) and grass (*Angelica sylvestris* L., *Butomus umbellatus* L.) forests on sod-podzolic soils (Zavodoukovsk town, Sungurovo village). There are also birch grass forests on gray forest soils in combination with grass meadows (*Atriplex patula* L.*, Scorzonera purpurea* L., *Thlaspi arvense* L.) on leached chernozems and meadow soils (Markovo, Semenovo, Staraya Zaimka villages).

In the lower part of the slope, birch-aspen grass forests grow on gray forest soils (Semenovo and Staraya Zaimka villages) in combination with sedge-grass meadows on meadow salted soils (Staraya Zaimka and Yakovlevo villages). Landscape units of the type of terrain have been largely transformed into arable land. Haymaking and grazing are carried out on the meadows. Forests are used for collecting berries, mushrooms, and medicinal herbs, as well as additional pasture lands. In the past, industrial sand mining was carried out in several quarries.

VIII. The type of terrain of lakes and swamps is mapped on the flat, limited, drained above-floodplain terraces of the Tobol River in the Uporovsky and Yalutorovsky districts. It is characterized by lake-covered depressions, closed depressions with sedge-grass swamps and swampy birch woodlands. The prevailing absolute heights are 60–65 m. The ground water level varies from 0.5 to 1.5 m. The background landscape

structure is formed by forest-meadow flatlands with a combination of birch sedge-grass forests, dry grass meadows and arable lands.

Typical are flat, low, undrained over-flood terraces with sedge-grass swamps (*Carex vaginata* Tausch, *Phragmites australis* (Cav.) Trin. ex Steud*., Schoenoplectus lacustris* (L.) Palla*, Typha latifolia* L.) on peat soils. To a lesser extent, grass-marsh birch forests (*Equisetum palustre* L., *Eriophorum vaginatum* L., *Ledum palustre* L.) are common on peat soils. In economic terms, the landscapes are poorly developed. Mostly landscape units are used as hunting grounds. Part of swamps has been transformed into arable land. Haymaking is carried out in the meadows. On the lake terrace of the Moshkara — the Moshkara regional class reserve is created.

IX. The types of terrain of reed swamps is confined to flat depressions within the lake-alluvial plains on the interfluve of the Iset and Ingala rivers (Isetsky and Yalutorovsky districts), flat above-floodplain terraces of the Tobol River (Zavodoukovsky, Uporovsky, Yalutorovsky districts). The most characteristic location of the type of terrain is flat, low, undrained terraces. Typical, in this respect, is the Zamannoye Swamp, which is located on the first over-floodplain terrace of the Tobol River in Zavodoukovsky and Yalutorovsky districts. The prevailing absolute heights are 55–60 m. Dominant landscape units are characterized by a close occurrence of groundwater and peat accumulation processes.

Sedge-willow swamps are widely distributed in combination with pine-birch forests of different ages (*Ledum palustre* L., *Menyanthes trifoliata* L., *Myrtus communis* L., *Origanum vulgare* L.) and sedge-sphagnum (*Carex limosa* L., *Equisetum palustre* L.) forests. Less common are birch-willow grass-marsh, birch grass-marsh and sedge-sphagnum forests on peat soils. In economic terms, the landscape units of the type of terrain are poorly developed. Haymaking is carried out in the meadows; forests and swamps are used for collecting berries.

X. The type of terrain of ravines and girders is mapped in the basins of the Yemurtla and Kizak rivers (Zavodoukovsky and Uporovsky districts). Large differences in relative heights (50–70 m) and significant slopes of the territory (0.006–0.016) predetermined the intensive development of erosion processes. Ravines are constantly growing, reaching a length of 10 km (Masali village).

In the basin of the Kizak River, steep-walled ravines deeply embedded in heavy loam have wet bottoms with a temporary stream network. Typical are birch and birch-aspen and willow grass and sedge-grass (*Carex praecox* Schreb., *Poa angustifolia* L., *Puccinellia hauptiana* V.I. Krecz.) forests on gray forest soils (Masali and Markovo villages). Slightly, grass and sedge-grass meadows (*Agrostis albida* Trin., *Carex rostrata* Stokes*, Festuca ovina* L., *F. rubra* L., *Phleum phleoides* (L.) H. Karst.) are distributed on leached chernozems (Vidonovo village).

Steep slopes of ravines and girders are occupied by birch sedge-grass forests on sod-podzolic soils (Pyatkovo village). In gentle slope girders, pine-birch grass forests on sod-podzolic soils are common (Krasheninino and Panteleyevka villages). Sometimes ponds are created in such girders (Kolesnikovo village). Ravine and girder forests are used for collecting berries, mushrooms, medicinal herbs. In the ponds, the residents reserve water, breed fish.

XI. The type of terrain of floodplains of large rivers is differentiated in the valleys of the Iset and Tobol rivers. 1–6 km wide floodplains are composed mainly of loam, only in the area of Aslany village are mapped the landscape units of sandy variant. Absolute heights vary from 50 to 55 m. In the structure of floodplains, the near-river, central and near-terrace floodplains are clearly differentiated. Typical are landscape units of ridges up to 5 m high, emerging early from flooding. Their surface is dominated by grass meadows (*Bromopsis inermis* (Leyss.) Holub*, Filipendula ulmaria* (L.) Maxim*., Phleum pratense* L.) on alluvial sod-meadow soils. The landscape structure is complemented by landscapes of saucer-shaped depressions with aspic sedge-grass (*Agrostis stolonifera* L.*, Allium angulosum* L., *Glyceria fluitans* (L.) R. Br., *Potentilla anserina* L., *Stachys palustris* L.) meadows on alluvial gley soils.

In the central floodplain, ridges and flat surfaces with 3–5 m high in combination with inter-ridge depressions are common. The ridges are covered with grass meadows (*Bromopsis inermis (*Leyss.) Holub, *Lathyrus pratensis* L.) on alluvial turf soils. Thickets of shrubby willows and sparse forests of black poplar (*Populus nigra* L.) are common on the slopes of the ridges. Flat and shallow depressions are typical for the near-terraced floodplain. Landscapes of wet sedge-grass meadows were formed on peat soils. Floodplain landscape units are valuable forage lands, used as hayfields and pastures. The raised and drained floodplain areas are largely plowed.

XII. The type of terrain of small valleys is mapped in the valleys of tributaries of the Iset and Tobol rivers. The marks of absolute heights vary widely — from 50 to 120 m. Loamy variants predominate, only in the floodplain of the Yuzya River, sandy loam and sandy variants are common in fragments.

In the basin of the Iset River is dominated by landscapes of flat floodplains with birch and willow grass (*Geranium sylvaticum* L., *Lathyrus pratensis* L.) and sedge-grass (*Carex rostrata* Stokes*, Phleum pratense* L., *Poa palustris* L.) forests on gray forest and alluvial soils. Birch forests are widespread in the upper reaches of the Yemurtla River. In the floodplain, grass (*Lotus corniculatus* L., *Melilotus officinalis* (L.) Pall., *Tanacetum vulgare* L.*, Trifolium hybridum* L.) and sedge-grass (*Carex rostrata* Stokes*, Carex vaginata* Tausch*, Elytrigia repens* (L.) Nevski) meadows on leached chernozems, meadow and alluvial soils are common. In the floodplain of the Uk River is typically a combination of willows and sedge and grass meadows on alluvial turf soils. The small-valley landscapes are mainly used as hayfields and pastures. In a number of places on the rivers, ponds have been created (Begila and Chukhonka rivers); they are used for recreational purposes.

Conclusions

The diversity of the forest-steppe landscapes in the southwestern part of the Tyumen Oblast is characterized by a high degree both at the level of natural complexes and at the level of landscape components. In the region, 12 types of terrain of divides, ridges, flat ridges, flat depressions, hillock depressions, terraces, slopes, lakes and swamps, reed swamps, ravines and girders, floodplains of large rivers, small valleys are differentiated and characterized in detail. Forest-steppe landscapes are convenient for economic development and have been largely transformed as a result of mainly agricultural activities and partly industrial and recreational activities. Such types of traditional nature use as gathering, hunting and fishing are paramount for residents.

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Тюмень облысының орманды даласының ландшафттық әртүрлілігі (Ресей)

Орманды дала ландшафттары — бұл аймақтық орман және дала ландшафттарының, сондай-ақ батпақтар мен шалғындардың үйлесуіне байланысты әртүрліліктің жоғары деңгейімен сипатталатын экотоникалық жүйелер. Зерттеулер әдеби дереккөздерді, топографиялық және тақырыптық карталарды, спутниктік суреттерді, сондай-ақ 1997–2020 жылдардағы дала экспедицияларын жан-жақты талдауға негізделген. Тюмень облысының оңтүстік-батыс бөлігінде 30 000 км^2 ауданда жер бедерінің 12 түрі сараланған, оның ішінде бөлу рельефінің түрлері, жоталар, жазық жоталар, жазық ойпаттар, таулы ойпаттар, террастар, беткейлер, көлдер мен батпақтар, қамыс батпақтар, жартастар мен бөгеттер, ірі өзендердің алқаптары, кіші аңғарлар. Аймақтың ландшафттарын кеңістіктік ұйымдастырудың кейбір ерекшеліктері сипатталған, компоненттер деңгейіндегі ландшафт құрылымына сипаттама берілген.

Аймақ жағдайында ландшафттардың негізгі бөлігі экономикалық даму үшін ыңғайлы және экономиканың әртүрлі салаларында қолданылады, негізінен шалғынды және дала ландшафттары, сондай-ақ жартылай жыртылған ормандар. Аумақта жайылымдар мен шабындықтар кең таралған. Құм мен шымтезек өндіру, ағаш дайындау, рекреациялық табиғатты пайдалану, сондай-ақ балық аулау, аң аулау, жинаушылық сияқты экономикалық қызмет түрлері дамыды. Кейбір ландшафттарды табиғи қорықтар сияқты мемлекет қорғайды.

Кілт сөздер: рельефтің түрі, ландшафт құрылымы, ормандыдала, Тюмень облысы.

А.В. Маршинин

Ландшафтное разнообразие лесостепи Тюменской области (Россия)

Лесостепные ландшафты — экотонические системы, для которых характерна высокая степень разнообразия благодаря сочетанию зональных лесных и степных ландшафтов, а также болот и лугов. Исследования основаны на комплексном анализе литературных источников, топографических и тематических карт, спутниковых снимков, а также полевых экспедиций 1997–2020 гг. В юго-западной части Тюменской области на площади 30 000 км^2 дифференцировано 12 типов рельефа местности, включая типы рельефа разделительной местности, хребтов, равнинных хребтов, равнинных впадин, холмистых впадин, террас, склонов, озер и болот, тростниковых болот, оврагов и ригелей, пойм крупных рек, малых долин. Описаны некоторые особенности пространственной организации ландшафтов региона, дана характеристика ландшафтной структуры на уровне компонентов. В условиях региона основная часть ландшафтов удобна для экономического развития и используется в различных отраслях экономики, в основном, это луговые и степные ландшафты, а также частично леса распаханы. На территории широко распространены пастбища и сенокосы. Развиты такие виды хозяйственной деятельности, как добыча песка и торфа, заготовка древесины, рекреационное природопользование, а также рыболовство, охота, собирательство. Некоторые ландшафты охраняются государством как природные заповедники.

Ключевые слова: тип местности, ландшафтная структура, лесостепь, Тюменская область.

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Legacy of the great plan of environment transformation in Russia

In October 1948, a comprehensive long-term plan for the transformation of environment was adopted in the USSR in order to ensure maximum sustainable yields in the main agricultural regions of the country. The project, designed for the period 1949–1965, was developed as a reaction to the consequences of severe 1946 drought, but its content is undoubtedly a strategic document of national importance. The created forest belts and reservoirs had to significantly diversify the flora and fauna of the country. Consequently, the plan combines the tasks of environmental protection and obtaining maximum sustainable yields. The paramount feature of this plan was its thorough scientific support based on the ideas of a whole galaxy of prominent Russian scientists and practitioners. This plan anticipated the emergence of the national concept of rational nature management. It was not fully implemented. However, the very fact of its adoption and partial implementation has become a bright page in the history of domestic land use and an instructive example of a combination of economic, social and environmental interests. Numerous manifestations of this plan legacy in modern conditions are perceived as a multifunctional historical heritage that deserves a high national status.

Keywords: legacy, cultural landscapes, agriculture, nature management, environment transformation, heritage sites.

Introduction

In the history of Russia, there were many projects for the transformation of nature. As a result of their implementation, economic, cultural landscapes of local and regional scale were formed. Among them there are a plenty of landscapes that can rightfully be attributed to the category “Unique economic landscapes” (classification of cultural landscapes of the UNESCO World Heritage Center) or to the category “Standard of environmental management efficiency” (according to the similar classification of V.A. Nikolaev). A special place among such projects belongs to the so-called Stalin's plan for the transformation of nature — one of the most ambitious in world history and throughout the years remains one of the most productive [1, 2].

The essence of the plan was the purposeful transformation of agricultural landscapes to ensure their optimal efficiency through scientifically grounded systemic reclamation measures. It so happened that the multi-year program of this project was not fully implemented. However, even in such a situation, this project left behind a kind of historical legacy. One of the manifestations of this heritage is the transformed steppe landscapes on vast territories with such iconic elements as forest belts and water bodies. These landscapes are unmistakably determined from the ground and when observed from the air, clearly visible in aerial photographs and images from space. Essentially, they really ensure the agro-economic stability of the respective regions, convincingly demonstrating the advantages of a scientifically grounded culture of environmental management.

Possessing features of objects of mixed natural and cultural heritage, these landscapes, with rare exceptions, do not have the corresponding status. However, in our opinion, they undoubtedly deserve it due to their value from the standpoint of the history of nature management and ecological culture. To confirm this thesis, let us take a further historical excursion.

Project background

Russia is a country with the deep traditions and great achievements in agriculture. For centuries, the Russian peasant fed his country and ensured its export. In many ways, the success of Russian agriculture is associated with the presence of a huge territory of black earth soils in the country — the most fertile lands in the world for growing grain and the most other popular crops. At the same time, unfortunately, the entire territory of the country is located in the so-called “zone of risky farming”. The risks in it are associated with numerous natural disasters, the worst of which is drought — the ruthless enemy of the Russian countryside and its peasants for centuries.

Drought in Russia is not such a rare occurrence indeed. Yet, sometimes its scale reaches the dimensions of a national catastrophe, manifested in the spread of hunger in the places of this disaster and the death of tens and hundreds of thousands of people from it. Such catastrophes, in particular, were the droughts of 1891 and 1921. Nevertheless, the drought of 1946, which hit a huge part of the country, was the most terrible in its consequences. The situation was aggravated by the dire consequences of the just-ended war with fascist Germany and its European satellites.

In these conditions, the government of the country decides to take radical measures to prevent similar phenomena in the future. It attracts leading specialists in the USSR to develop an unprecedented project of guaranteed provision of favorable natural conditions for the development of agriculture in the main agricultural zones of the country (Fig. 1). In modern times, it could be called a sustainable agriculture program.

Figure 1. Schematic map of the 1948 environment transformation plan on the Soviet post stamp*

Plan and Its Context

In October 1948, authorities of the USSR adopted a comprehensive long-term plan for the transformation of nature in order to ensure maximum sustainable yields in the main agricultural regions of the country. In terms of its economic, environmental, and geographical characteristics, this plan had no precedent in either domestic or world history. The project, designed for the period 1949–1965, was developed as a reaction to the consequences of the severe drought of 1946, but in its content it was undoubtedly a strategic document of national importance [3].

Despite the noted circumstances, this plan still remains ignored by analysts of the history of environmental management. The initial reasons for this annoying fact are likely to lie in the political aspects of the life of Russian society. It is believed that the named plan was developed and adopted on the initiative of the Soviet leader Josef Stalin. Almost immediately, it received in society the title "*Stalin's plan for the transformation of nature"*, which reflected both its essence and status (Fig. 2).

The immediate goal of the plan was to prevent droughts, sand and dust storms in the southern regions of the USSR (Western Kazakhstan, the Volga Region, the North Caucasus, Eastern Ukraine). In accordance with this plan, it was necessary to change the climate on an area of 120 million hectares, equal to the territories of Britain, France, Italy, Belgium and the Netherlands combined.

The central place in the plan was occupied by field-protective afforestation and irrigation. In total, it was planned to reforest more than 4 million hectares of the territory and create state field-protection belts with a length of over 5300 km [4]. These strips were supposed to protect the fields from hot southeastern winds — dry winds. In addition to the state forest protective belts, forest belts of local importance were planted along with the perimeter of individual fields, the slopes of ravines, existing and newly created reservoirs on the sands (Fig. 3).

* Hereinafter, photographs and scans of the authors and from open sources on the Internet.

Figure 2. Poster of the end of 1940th “Win the Drought”

Figure 3. Field protection forest belts

The plan also provided for the introduction of a grass farming system developed by the outstanding Russian scientists P.A. Kostychev and V.R. Williams. According to this system, part of the arable land in crop rotations was sown with perennial legumes and bluegrass grasses. Herbs served as a fodder base for animal husbandry and a natural means of restoring soil fertility.

The taken measures have led to a significant increase in grain yield. As a result of an increase of investment in agriculture and an improvement in the technical equipment of collective and state farms, it was possible to create a solid forage base for the development of animal husbandry.

The plan envisaged not only absolute food self-sufficiency of the Soviet Union, but also building up the export of domestic grain and meat products from the second half of the 1960s. The created forest belts and reservoirs had to significantly diversify the flora and fauna of the USSR. Thus, the plan combines the tasks of environmental protection and obtaining maximum sustainable yields.

Scientific support

The most important feature of the 1948 plan was its thorough scientific support, based on the ideas of a whole pleiad of prominent Russian scientists and practitioners of agriculture. The leading place among them rightfully belongs to the professor of St. Petersburg University Vasily Dokuchaev — the founder of modern soil science (Fig. 4).

In 1892, a year after a terrible drought that engulfed almost the entire black earth zone of European Russia, he published the book “Our Steppes Before and Now”. In this book, he simply and clearly explained the causes of steppe droughts, which he saw not so much changes in natural conditions as in the predatory nature management of that time, in the depletion of the natural fertility of *chernozem* (black) soils. There he also proposed and substantiated a coherent system of measures that could protect the steppe zone of Southern Russia from crop failures.

Figure 4. Monument to V.V. Dokuchaev in Moscow near the Moscow State University

Dokuchaev's system is based on his idea of "harmony with nature" and includes [3]:

– regulation of runoff of large and small rivers and arrangement of local water basins for irrigation of adjacent lands;
– securing ravines with the help of forest plantations, wattle fences and hedges, arranging ponds to retain snow and rainwater, in order to irrigate the underlying slopes and the bottom of the gullies, prohibiting plowing of steep slopes;
– regulation of watersheds using a system of shallow ponds, rows of hedges for accumulating snow and retaining spring and rainwater;
– afforestation of all sands, mounds and generally uncomfortable plots for arable land;
– development of norms that determine the relative areas of arable land, meadows, forests and waters, that is, the correct organization of steppe territories;
– application of the most favorable methods of soil cultivation for the use of moisture and adaptation of varieties of cultivated plants to local soil and climatic conditions.

Having developed a program for combating drought and having organized a number of experimental sites for many years of testing their proposals, Dokuchaev created the basis for that grandiose plan for transforming the nature of the steppes. The scientist understood that the program he proposed to combat drought was a national task. However, it was impossible to implement it in the conditions of pre-revolutionary Russia. The ideas of the great Russian scientist about the radical transformation of the nature of the steppes were in demand only after 50–60 years, under the conditions of a planned socialist economy with the active scientific support within the framework of a national project.

Implementation of the plan

The implementation of the plan began almost immediately after the adoption of the government decree. Among other things, this was facilitated by the active work deployed in the country to clarify the meaning of the plan. Prominent scientists, university professors, municipal and regional authorities, cultural figures and the media took an active part in it (Fig. 5). The topic of this plan has become one of the main points in the country's information and educational policy. Nature conservation courses have become ubiquitous in university curricular. In the field of education, the topic of nature conservation and transformation has dramatically expanded its presence.

Figure 5. Poster encouraging participation in the implementation of the forest planting plan

The adopted plan received the broadest public support. Undoubtedly, this was facilitated by its popularization. However, the paramount factor was conscious support of this plan on the part of the country's peasants. As bearers of traditional ecological culture, they saw in this government project a reflection of the popular ideas of increasing the efficiency of agriculture based on centuries of experience. The urban population, most of which at that time were peasants in their very recent past, did not remain aloof from this project.

The most important advantage of this long-term plan was the possibility of obtaining economic results literally from the first years of the creation of its infrastructure. So, it actually happened. By 1952, the infrastructure envisaged by the plan was basically created and started to work. The quality of agricultural lands, protected by forest belts and provided with modern reclamation, gradually increased — erosion decreased, water balance was ensured, and as a result, the yield of fields and the productivity of forage lands increased. The taken measures have led to an increase in the yield of grain crops by 30 %, vegetables — by 50–75 %, herbs — by 100–200 %. The situation changed in full accordance with the scientific forecast, which promised the country a significant progress in the agricultural sector and environmental well-being.

The fate of the plan and its meaning

However, with the death of Stalin in 1953, the fulfillment of the plan was curtailed. Many forest belts were cut down, several thousand ponds and reservoirs for fish farming were abandoned; hundreds of forest protection stations created in 1949–1955 were eliminated. Instead of the Stalin's plan, the new Soviet leader Nikita Khrushchev put forward another plan based on increasing the production of grain crops due to the development of virgin lands. Unfortunately, this plan was not scientifically justified, which facilitated its negative environmental consequences, without providing sufficiently targeted economic results.

In spite of being only implemented partially, Stalin's plan for the transformation of nature and its adoption became a bright page in the history of domestic environmental management and an instructive example of the combination of economic, social and environmental interests. The forest belts created at that time firmly fit into the landscape of a number of the most considerable agrarian regions of the country, still ensuring their well-being results (Fig. 6).

Figure 6. Dokuchaev's heritage, the legacy of the Stalin's plan

Despite the decades of the actual hushing up of this grandiose national ecological and economic project, a number of its elements have been in demand both in Russia and abroad. Particularly impressive ones are the large-scale afforestation of semi-desert and desert territories in China, as well as in some another countries. At the same time, it seems that many elements of the current forestry policy and environmental policy of this country as a whole are based on the ideas of the scientific heritage of V.V. Dokuchaev and the lessons of the Stalin's Plan for the Transformation of Nature.

Artifacts of Outstanding Land Use Systems as Historical Heritage

The retrospective analysis undertaken above facilitated to make the following estimates:

– agricultural landscapes formed as a result of the implementation of the Stalin's plan have a stable economic and high historical and cultural value;
– they have been demonstrating their high economic value for about 70 years, which ensures recognition of the effectiveness of the land use systems they have formed;
– historical and cultural value of these landscapes is based on the synthesis of local agricultural traditions with scientifically based innovations;
– culture of farming, formed in the process of the formation of progressive systems of land use, is in demand in modern conditions and in the future, especially in connection with the ongoing climate changes.

These features give reason to consider the artifacts of the project under consideration as a formed phenomenon of heritage, both material (outstanding in terms of their productivity systems of nature management) and intangible (based on the scientific substantiation of V.V. Dokuchaev and other domestic scientists, the experience of effective environmental management). In this case, we can talk both about cultural heritage sites of the national level, and about proposals for the inclusion of especially outstanding cultural landscapes in the World Heritage List. One of the most convincing arguments in favor of the formulated proposal is the presence of such properties on the World Heritage List. Here are some examples (from among those personally surveyed by the author).

One of the most famous and popular World Heritage Sites in Switzerland (Romandy) is the Lavaux Terraced Vineyards (since 2007). The landscape of this World Heritage Site on the northern shore of Lake Geneva is breathtaking in all seasons, attracting a huge number of tourists. It is no coincidence that the image of this landscape is present on the 200-franc note (Fig. 7). However, the Lavaux vineyards became a World Heritage Site not because of their aesthetic merits. They were nominated for the World Heritage list by the government of this country as a unique example of centuries-old interaction between man and the environment, focused on the optimal use of local resources for the production of high-quality agricultural products. In this case, it is wine, which is highly valued here and plays an important role in the economy of the region.

Figure 7. Lavaux vineyard landscape on a Swiss banknote

Lavaux vineyards are nominated according to three criteria: iii (demonstrating the cultural traditions of extinct or modern civilizations), iv (unique buildings or architectural ensembles, including landscape) and v (a prime example of a traditional settlement or land use system). The World Heritage List took into account that "local communities actively support measures to protect nature, thereby striving to counter the threat of galloping urbanization".

Another illustrative example of this kind is the Indonesian site "Cultural Landscape of Bali Province: Subak System as a Manifestation of the Tri Hit Karana Philosophy" (2012). Subak is a traditional water management-based agricultural (terraced rice) system that has shaped the modern landscape of Bali (Fig. 8).

It is believed that it is this system that has allowed the Balinese to become the most successful rice growers in the archipelago.

Figure 8. Bali *Subak* system landscape

Subak was included in the world heritage according to four criteria: ii (unique object of architecture, monumental art, urban planning, as well as especially valuable areas of the cultural landscape), iii (see above), v (see above) and vi (demonstration of modern ideas, beliefs, trends in art, living traditions of mankind).

The list of such objects in the world heritage can be significantly extended. At the same time, these examples are enough to be convinced of the possibility of interpreting the artifacts of the Stalinist plan for the transformation of nature as a heritage phenomenon that fully coincides with the criteria for identifying the cultural heritage of UNESCO.

In this regard, we believe that the time has come for the recognition of the nature management sphere formed in the course of the implementation of the largest project in Russian history as a phenomenon of historical heritage. The inclusion of the artifacts of this project (in one form or another) in the register of national cultural heritage is also becoming relevant. In addition, it is legitimate to raise the question of our country nominating an object associated with this project and having a symbolic meaning.

There are many options for choosing such an object. As an example, let us point out the State Nature Reserve of federal significance “Kamennaya Steppe” with an area of 5232 hectares [4]. It is located in the Talovsky district of the Voronezh region, on the watershed of the Bityug and Khoper River basins and was created on May 25, 1996 by a decree of the Government of the Russian Federation. This protected area has the profile of an integrated (landscape) reserve. It was created to protect the unique semi-cultural forest-steppe landscapes. On the territory of the reserve, undisturbed classic chernozem soils have been preserved. It is also important that this reserve is directly related to the research of V.V. Dokuchaev. An experimental agricultural station named after this great scientist operates on its territory. The history of this “Dokuchaevsky oasis” is connected with another outstanding scientist of our country — Academician N.I. Vavilov, who worked here in the 1920s.

Conclusions

Stalin's plan for the transformation of nature is perceived in our time as an outstanding event in the history of nature management in Russia. His project received an unprecedented scientific basis, it was enthusiastically supported by the entire vast country. It has become one of the national development priorities. However, the fate of this plan turned out to be dramatic; it was actually curtailed without any real reason [5–7].

At the same time, its story is highly instructive. This plan largely anticipated the emergence of the domestic concept of rational nature management and, to a certain extent, the Western concept of sustainable development. This is especially true for our time — the era of transition to a “green” economy as the main condition for sustainable development.

This plan left behind numerous valuable artifacts, a kind of legacy of the scientific ideas of great scientists and a grandiose implemented project. Now, after seven decades, this legacy is increasingly perceived as the historical legacy of Russia, and possibly of neighboring countries — Kazakhstan and Ukraine.

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Ресейдегі қоршаған ортаны трансформациялаудың ұлы жоспарының мұрасы

1948 жылдың қазан айында КСРО-да елдің негізгі ауылшаруашылық аудандарында жоғары тұрақты өнімділікті қамтамасыз ету үшін қоршаған ортаны қайта құрудың ұзақ мерзімді жоспары қабылданды. 1949–1965 жылдарға арналған жоба 1946 жылғы қатты құрғақшылықтың әсеріне реакция ретінде жасалды, бірақ оның мазмұны сөзсіз мемлекеттік маңызы бар стратегиялық құжат болып табылады. Құралған орман алқаптары мен су қоймалары елдің флорасы мен фаунасын едәуір әртараптандыруы керек еді. Сонымен қатар жоспар қоршаған ортаны қорғау және жоғары тұрақты өнім алу міндеттерін біріктіреді. Бұл жоспардың маңызды ерекшелігі мынада: көрнекті орыс ғалымдары мен практиктерінің идеяларына негізделген, яғни жан-жақты ғылыми қамтамасыз етілуі болды. Бұл жоспар табиғатты ұтымды пайдаланудың ұлттық тұжырымдамасының пайда болуын көздеді, бірақ толық орындалмады. Дегенмен оның қабылдануы мен ішінара жүзеге асырылуының өзі отандық жер пайдалану тарихының жарқын парағы және экономикалық, әлеуметтік және экологиялық мүдделер үйлесімінің тағылымды үлгісі болды. Қазіргі жағдайда осы жоспардың мұрасының көптеген көріністері жоғары ұлттық мәртебеге ие көпфункционалды тарихи мұра ретінде қабылданады.

Кілт сөздер: мұра, мәдени ландшафттар, ауыл шаруашылығы, табиғаттыпайдалану, қоршаған ортаны қайта құру, мұра объектілері.

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Наследие великого плана трансформации окружающей среды в России

В октябре 1948 г. в СССР был принят Комплексный долгосрочный план преобразования окружающей среды с целью обеспечения высоких устойчивых урожаев, в основных сельскохозяйственных районах страны. Проект, рассчитанный на период 1949–1965 гг., разрабатывался как реакция на последствия сильной засухи 1946 г., но, по своему содержанию, несомненно, являлся стратегическим документом государственной важности. Созданные лесополосы и водоёмы должны были значительно разнообразить флору и фауну страны. Таким образом, план сочетает в себе задачи охраны окружающей среды и получения высоких устойчивых урожаев. Важнейшей особенностью этого плана было его основательное научное сопровождение, основанное на идеях целой плеяды выдающихся российских учёных и практиков. Этот план предполагал появление национальной концепции рационального природопользования, которая не была выполнена в полном объеме. Однако сам факт его принятия и частичного осуществления стал яркой страницей в истории бытового землепользования и поучительным примером сочетания экономических, социальных и экологических интересов. Многочисленные проявления наследия этого плана в современных условиях воспринимаются как многофункциональное историческое наследие, заслуживающее высокого национального статуса.

Ключевые слова: наследие, культурные ландшафты, сельское хозяйство, природопользование, преобразование окружающей среды, объекты наследия.

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Geosystems of the Primorsky ridge (Baikal region) — classification and mapping

In this article, the application of landscape approach for geosystem classification and mapping was discussed on the example of the landscapes of the Primorsky ridge (Baikal region). Authors of this study used the geosystem concept formulated by V. Sochava and method of factorial-dynamical series of facies developed by A. Krauklis for modeling landscape structure of study area. The basis for the development of a hierarchical classification of geosystems was the data of fieldwork at 70 plots. The ordination of the plots by three parameters (topographic wetness index, slope steepness and humus thickness) was carried out using the method of ternary plots to group geosystems into classes and determine their dynamic state. The landscape map was compiled at the local scale (1:50 000) based on fieldwork, DEM, and remote sensing data. As a result, 14 groups of facies were identified in the study area. They were represented by both climax and succession stages, as well as anthropogenic modifications. The main classes of facies formed under the influence of local environmental factors were revealed using factor-dynamic analysis. They are represented by the following dynamic series: sublithomorphic, subhydromorphic, and subxerolithomorphic. The 66 % of the study area is occupied by landscapes of the sublitomorphic series.

Keywords: factoral-dynamical series of facies, landscape approach, geosystem structure, hierarchical classification, landscape typological map, satellite images, digital elevation model, ordination.

Introduction

The optimal and sustainable land use is achieved on the basis of understanding the processes occurring in the natural system. The classification of geosystems and their mapping is one of the main methods for studying the spatial structure of landscapes. Despite the active development of geo-information technologies, remote sensing methods and improvement of computer processing of spatial data, which greatly facilitates the work, to date, a unified approach to the compilation of landscape maps has not been developed. This circumstance is inextricably linked with the absence of a generally accepted taxonomic system of landscape units, which is due to the issues of landscape modeling that are still unresolved in the theory of landscape science (reflection of emergent properties, geostationary and geodynamic essence of the landscape, determination of hierarchical levels of landscape organization) [1].

Various approaches are used to identify the structural units of landscapes. One of such approaches is the theory of geosystems [2]. The geosystem approach is widely used in the applied aspects of landscape science, landscape ecology, and landscape planning [3–6].

The study of the landscape structure using various models allows to get a more complete picture of the processes of integration and differentiation in the geographic envelope [7].

Typification and classification of geosystems are aimed at identifying the general properties of geosystems and their invariants for different locations (conditions) [8]. In most cases, the typification of landscapes is based on morphological and functional indicators [9].

The aim of the study is to compile a hierarchical classification of the geosystems of the Primorsky Ridge in the Baikal region and to carry out large-scale mapping of a test site of this territory.

Landscapes of the Primorsky Ridge (Baikal region) were selected as the object of research. The study area with an area of 283.4 km^2 shown in Figure 1 is located in the southern part of the ridge, within the central ecological zone of the Baikal natural territory which is insufficiently studied in terms of landscape [10]. The relief of the territory is low-mountainous (460–1177 m), characterized by deep dissection (up to 600 m) and significant steepness of slopes (up to 60 °). The annual arrival of total solar radiation is 4400–4600 mJ/m^2 [11]. The climate is humid with moderately cold summers and winters. The annual amount of precipitation on the windward (northwestern) slopes and crests of the ridge is 400–600 mm, on the leeward (facing Baikal) — 200–300 mm [12]. The thickness of the snow cover reaches 60 cm [11].

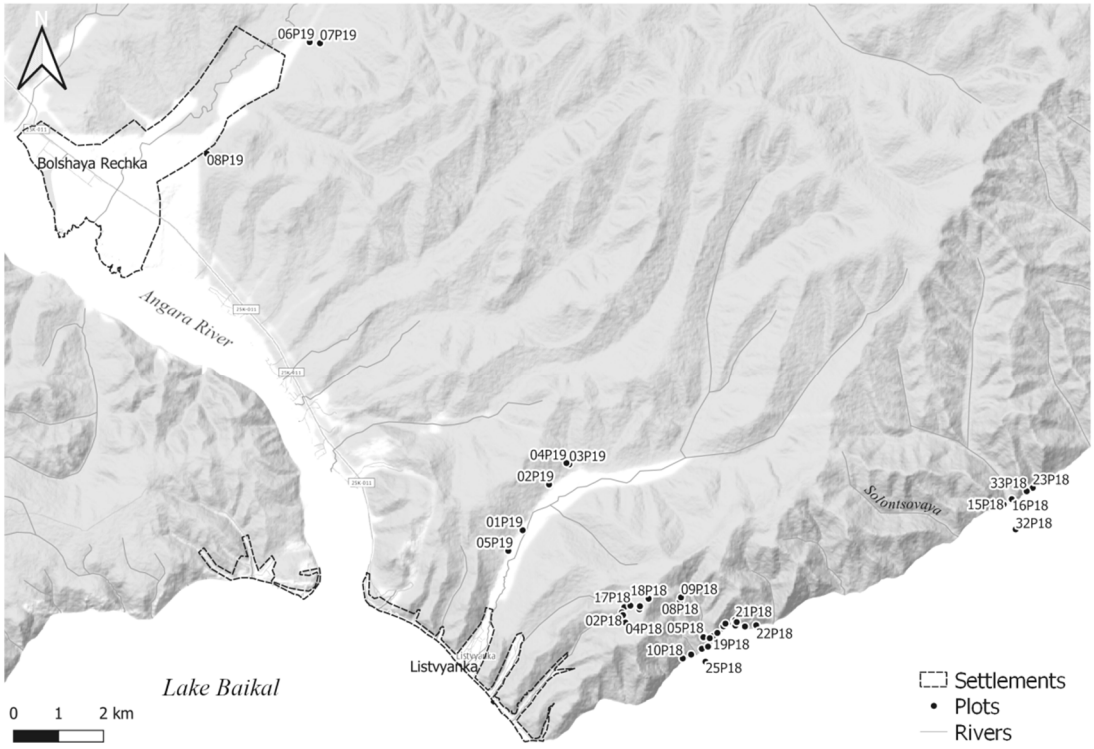

Figure 1. The location of the study area and test plots
(the background is "Stamen Terrain" http://maps.stamen.com/)

Mountain-taiga light-coniferous forests are widespread in the territory. The watersheds and near-watershed parts of the slopes are dominated by mountain-taiga dark coniferous, mainly cedar forests with the participation of fir, larch, and pine. Warmed by the sun, the slopes of the southern and southeastern exposure are occupied mainly by steppe larch and pine forests in combination with steppes. The valley bottoms are covered with meadows and swamps. Various stages of restorative successions are also common in the study area — young and middle-aged birch-aspen, aspen-birch, and larch-pine forests [13].

Experimental

The research included several stages: collecting information about the study areas (thematic maps, space images, etc.); field works (geographical and botanical descriptions of sample plots); the creation of GIS-projects and databases; classifications of geosystems using geosystem approach; delineation of the borders of landscape units using methods of GIS analysis and processing of remote sensing data; computer-based supervised classification of landscape units [14].

The input data were digital elevation models (SRTM with a resolution of 30 m), topographic maps (1:200,000), multispectral space images (Landsat-8 with a resolution of 30 m), the map of landscapes of the South of Eastern Siberia (1:1,500,000) [15], geological maps (1: 200,000) and other published thematic maps (landcover, land use, vegetation and soil units), literature data.

The main sources of information about the studied landscapes were field data. Between 2017 and 2020, 70 physical-geographical descriptions (look it on https://www.researchgate.net/publication/337944189_ Primorskij_hrebet) were completed on the study areas. Representative sample plots (15 to 15 m) characterizing the landscape diversity was laid in all major landforms.

At the stage of preliminary landscape mapping, an automatic classification of images from different seasons was carried out using the ISODATA method, then by using a digital elevation model, a classification of relief forms based on the index of the topographic position was conducted. According to the combination of classification parameters for the image and the relief form, each section is assigned to a certain type of landscape by the preliminary classification of geosystems [13]. As a result, we concluded that the use of remote sensing and GIS data is still impossible without carrying out field studies and manual correction of the contours and their parameters. The high fragmentation of the landscape contours obtained by this method (104,000) required generalization and editing based on the data of field complex studies and other above-

mentioned spatial data collected in the working project. In the range of scales 1:5,000 to 1:25,000, the contours were re-digitized using the QGIS program (their number was reduced by more than a hundred times). Work with spatial data was carried out in the geographic coordinate system WGS-84, in the universal transverse Mercator projection (UTM), zone 48N.

The legend to the map was improved: the facies groups were ordered according to the facies classes depending on their belonging to a certain factor-dynamic series [16], in which the root variant, which is closest to the zonal norm (or altitudinal belt), and serial facies groups, modified under the influence of a certain factor (lithomorphic, hydromorphic, cryomorphic, etc.) or a set of factors. The degree of influence of landscape-forming factors was determined from the data obtained during the processing of the DEM (landform, slopes, exposure of slopes, topographic moisture index), and from data on the type of vegetation [17].

Classification of geosystems was carried out for a number of geomers: examples of facies (the lowest hierarchical level), groups of facies, classes of facies, and geoms (highest hierarchical unit at the local level). To determine the factoral-dynamic series of facies and groups of facies, we performed ordination of test plots along the axes of three parameters as follows: the thickness of the humus horizon (field data), the topographic moisture index, and the slope calculated from DEM. The identified groups of sample plots were provided with the characteristics of the microrelief, vegetation, and soils. After that, they were ordered into typological units (groups of facies) [18].

Geoms were identified from their belonging to a particular belt, with similar structural characteristics of soil cover and vegetation. The class of facies is defined as the set of facies of one factorial-dynamical series and has its own primary variant (the primary group of facies), which are closest to the zonal norm, and serial groups of facies which are modified by a particular leading factor. In this case, the facies are connected by one equifinal state with a corresponding primary plant formation. Groups of facies are identified according to the degree of seriality (variability, reduction) and, hence, a decrease of the degree of correspondence to the zonal norm. They are separated according to the degree of modification into the following categories: primary (P) — facies in which the series of successions end with the establishment of a relative stability of biogeocenoses; pseudo-primary (PP) — facies characterized by the hypertrophied influence of one or several environmental factors which endows the biogeocenoses with a significant potential dynamism, additionally, serial (S) — facies where no stabilization of the structure and regimes of the biogeocenoses is reached because of the environmental conditions [17].

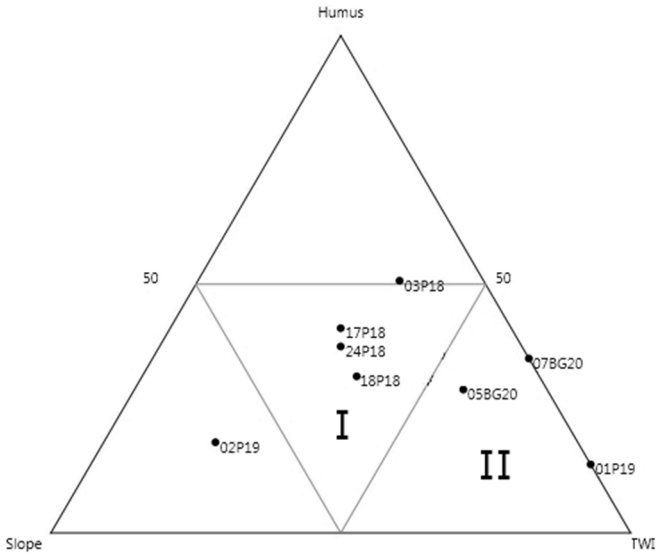

Figure 2. Ordination of plots belonging to two geomes: Mountain dark coniferous taiga and Cedar-larche taiga of intermountain basins and valleys (I — the facies close to the primary dynamic state, II — the facies close to the pseudo-primary state of subhydromorphic series) in the space of indicators of three factors: the thickness of the humus horizon, the topographic moisture index, the steepness of the slope

The ordination of the descriptions was carried out by constructing a ternary plot (Fig. 2). When constructing it, a triangular coordinate system on a plane is used to study the relationships between three

variables. As a result, the main factor series were identified — sublitomorphic (structural-denudation surfaces characterized by significant substrate skeletal structure), subhydromorphic (drainage depressions, valleys, and valleys, characterized by increased moisture) and subxerolithomorphic, formed under the influence of a complex of factors: arid conditions characteristic of slopes, in the rain shade, and the skeletal nature of the substrate. Classes of facies are grouped into geomes according to the zonal affiliation and similar structural features of the vegetation cover. The hierarchical levels above the geome are given following the legend of the map "Landscapes of the South of Eastern Siberia" [15].

As the result of landscape classification, the 5 geoms, 7 classes of facies and 14 groups of facies were identified on the study area (Tab. 1, Fig. 3). The calculation of the areas showed that the larch-pine forest with the admixture of aspen and rhododendron, red bilberry, small grasses, and often with Bergenia and green mosses on steep slopes (group of facies № 6, see Table 1 and Fig. 3) is most widespread in the study area. It covers 19 % of the territory. The group of facies № 2 (see Tab. 1 and Fig. 3) also occupies a large area (17 %).

Results and Discussion

Secondary mixed aspen-birch and birch-aspen forb grass forests (№ 4a, 7a, 9a) cover 5.7 % of the study area. Anthropogenically transformed landscapes occupy an insignificant area (3.4 %) and are represented mainly by several small villages.

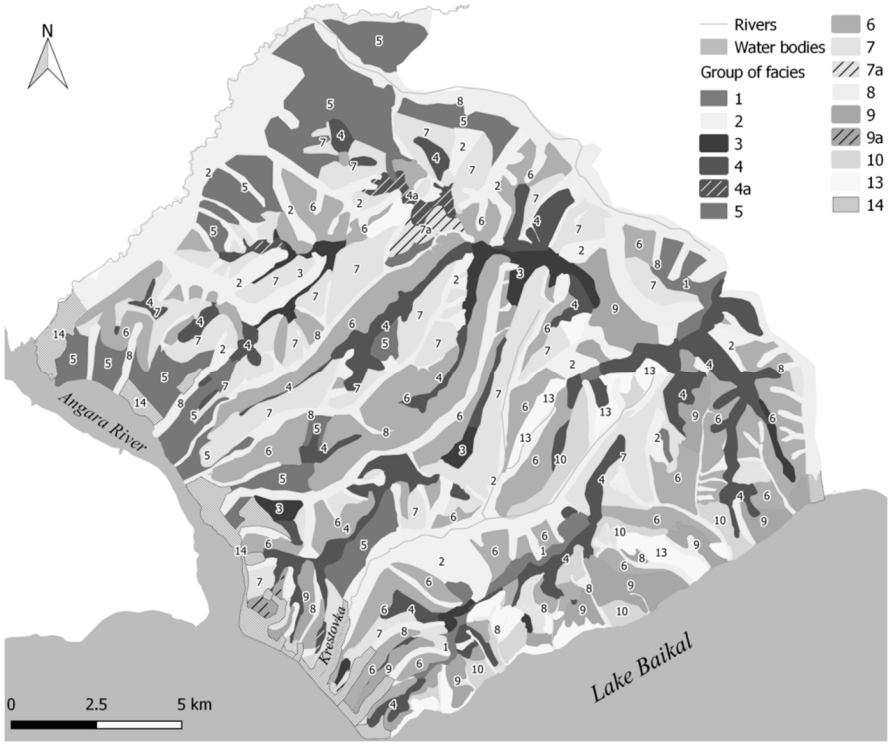

Figure 3. Geosystems of the southern part of the Primorsky ridge

Table 1

The fragment of legend to the map "Geosystems of the southern part of the Primorsky ridge"

№	Group of facies	Dynamic state of geosystem*
NORTH ASIA TAIGA		
Class of geoms "Mountain taiga of South Siberia"		
Geom "Mountain dark coniferous taiga"		
Class of sublithomorphic facies		
1	Fir *(Abies sibirica* Ledeb.) — Siberian cedar (*Pinus sibirica* Du Tour) forest with shrubs (*Duschekia fruticose* (Rupr.) Pouzar, *Sorbus sibirica* Hedl.) and Bergenia (*Bergenia crassifolia* (L.) Fritsch) on narrow watersheds and near-watershed slopes (03P18, 17P18, 18P18, 24P18)**	P

Continuation of Table 1

Geom “Siberian cedar-larch taiga of intermountain basins and valleys”		
Class of subhydromorphic facies		
2	Siberian cedar–larch (*Larix sibirica* Ledeb.) with the admixture of spruce (*Picea obovate* Ledeb.) and birch (*Betula spp.*) shrubby (*Rhododendron dauricum* L.*, Spiraea media* Schmidt) forest with red bilberry (*Vaccinium vitis-idaea* L.), small grasses (*Lycopodium annotinum* L.*, Maianthemum bifolium* (L.) F.W. Schmidt) and green mosses *(Pleurozium schreberi* (Brid.) Mitt.) (02P19, 05P19, 05BG20) combined with birch — spruce shrubby (*Duschekia fruticosa, Chamaedaphne calyculata* (L.) Moench) forest with sedge and sphagnum in intermountain basins and valleys (01P19, 07BG20)	PP
Geom “Mountain light coniferous taiga”		
Class of sublithomorphic facies		
3	Larch–pine (*Pinus sylvestris* L.) with Siberian cedar undergrowth and rhododendron (*Rhododendron dauricum*) suffruticose (*Linnaea borealis* L.*, Vaccinium vitis-idaea*) forest with green mosses on watersheds and near-watershed slopes (03BG20, 03БГ18)	P
4	Pine forest with larch, forb (*Chrysanthemum zawadskii* Herbich), and legume grasses (*Lathyrus humilis* (Ser.) Spreng., *Vicia cracca* L.) on watersheds and near-watershed slopes with rocks (01BG18)	S
4a	Secondary mixed aspen (*Populus tremula* L.) — birch (*Betula spp.*) and birch-aspen forb grass forests	
5	Larch-pine shrubby (*Ledum palustre* L.*, Rhododendron dauricum, Duschekia fruticosa*) forest with Siberian pine undergrowth, red bilberry and small grasses (*Maianthemum bifolium*, *Linnaea borealis*) combined with sedge (*Carex sabynensis* Less. ex Kunth) and green mosses (*Pleurozium schreberi, Polytrichum commune* Hedw.) on gentle slopes and piedmont plains (03P19, 04P19, 06P19, 07P19)	PP
6	Larch-pine with the admixture of aspen forest with rhododendron (*Rhododendron dauricum),* red bilberry, small grasses, and often with Bergenia and green mosses on steep slopes (08P18, 08P19, 09P18, 03БГ17, 04БГ20)	S
7	Larch-pine with the admixture of aspen and birch forest with small grasses (*Maianthemum bifolium Galium boreale* L.), legume grasses (*Vicia baicalensis* (Turcz.) B. Fedtsch.*, Vicia amoena* Fisch.), and graminoids (*Calamagrostis arundinacea* (L.) Roth*, Brachypodium pinnatum* (L.) Beauv.*)* mostly on steep slopes (01P18, 02P18, 04P18, 11P18)	S
7a	Secondary mixed aspen-birch and birch-aspen forb grass forests	
Class of subhydromorphic facies		
8	Birch-larch with Siberian cedar and pine shrubby (*Rosa acicularis* Lindl.*, Spiraea spp.)* forest with sedge (*Carex macroura* Meinsh.) and forb grasses *(Allium microdictyon* Prokh.*, Rubus saxatilis* L.) (05P18, 02BG20, 01BG20), sometimes replaced by small grasses (*Trientalis europaea* L.*, Maianthemum bifolium*) and shavegrass (*Equisetum spp.*) (16P18) combine with shrubby (*Padus avium* Mill.*, Spiraea flexuosa* Fisch. ex Cambess.) meadows with tall grasses (*Cardamine macrophylla* Willd.*, Aconitum septentrionale* Koelle) and fern (*Matteuccia struthiopteris* (L.) Tod.) in valleys (06P18, 07P18)	S
Geom «Piedmont light-coniferous subtaiga»		
Class of sublithomorphic facies		
9	Larch-pine shrubby (*Spiraea media, Rhododendron dauricum, Rosa acicularis*) forest with legume grasses (*Vicia unijuga* A. Braun*, Vicia nervata* Sipliv.*, Lathyrus humilis)* and graminoids (*Calamagrostis arundinacea, Poa sergievskajae* Prob*)* often with forb (*Pulsatilla patens* (L.) Mill.*, Iris ruthenica* Ker Gawl.*, Chrysanthemum zawadskii* Herbich) on steep slopes, mainly of southern and southeastern aspect (19P18, 20P18, 21P18, 22P18, 26P18, 27P18, 29P18, 30P18, 31P18, 06BG20, 04BG18)	S
9a	Secondary mixed aspen-birch and birch-aspen forb grass forests	
Class of subxerolithomorphic facies		
10	Steppificated pine forest with cotoneaster (*Cotoneaster melanocarpus* Fisch. ex Blytt*, Cotoneaster lucidus* Schltdl.), sedge (*Carex korshinskyi* Kom.), graminoids (*Koeleria cristata* (L.) Pers.*, Agropyron distichum* (Georgi) Peschkova), and forb (*Rhaponticum uniflorum* (L.) DC.*, Kitagawia baicalensis* (I. Redowsky ex Willd.) Pimenov*, Artemisia gmelinii* Weber ex Stechm.) on steep slopes, mainly of southern aspect (10P18, 13P18, 01BG17, 02BG18, 23P18, 33P18)	S

Continuation of Table 1

CENTRAL ASIAN STEPPE		
Class of geoms “Mountain Western Baikal steppes”		
Geom “Piedmont steppes”		
Class of subxerolithomorphic facies		
13	Steppes (*Agropyron cristatum* (L.) Gaertn., *Koeleria cristata, Tephroseris integrifolia* (L.) Holub, *Thymus baicalensis* Serg., *Carex pediformis* C.A. Mey., *Poa sibirica* Roshev.) often with cotoneaster (*Cotoneaster melanocarpus*) and single pines and larch on steep slopes with rocks, mainly of southern aspect (12P18, 15P18)	S
Anthropogenically transformed geosystems		
14	Settlements and infrastructure	

Notes: * Dynamic state of geosystem: P — Primary, PP — Pseudo-primary, S — Serial; ** In parentheses the plots numbers are indicated, see Fig. 1.

As noted by D.V. Zolotov and D.V. Chernykh [19], in addition to constructing factorial-time series, other principles of systematization of geosystems at the topological level have been developed, for example, the classification of elementary landscape areas by L.G. Ramenskiy, geochemical classification of elementary landscapes, universal typological classification of facies by Prokaev et al. [20], etc. However, it is the factorial-dynamic approach of A.A. Krauklis “takes into account the lateral connections that go beyond the gravity conjugation of locations and, despite the functional-dynamic basis, makes it possible to judge the genesis of the landscape structure” [16]. The resulting model of factorial-dynamic series, built-in with a hierarchical classification, links local data with the region as a whole and makes it possible to trace the dynamics of geosystems, taking into account their genesis. This approach allows to identify the relationships between geosystems, which are considered as stable systems but subject to continuous changes under the influence of various factors. In this case, the structure is understood as an invariant (unchanging) aspect of the system, and the dynamics are a rhythmic change in the states of the geosystem under the influence of internal and external factors within a certain time interval, which does not lead to a change in its structure [21]. Field landscape mapping, despite the development of remote sensing methods, remains relevant. Without these soil descriptions, it is difficult to accurately determine the root state of areas of the territory that are in the stages of restorative succession.

Conclusions

The main features of the landscape structure of the southern part of the Primorsky Ridge are identified based on the analysis of the results of geosystem classification and mapping. Geosystems of the study area are represented by a combination of four types of mountain taiga geoms (correlated with high-altitude zones) and one steppe geom. Such a contrast in a relatively small area is due to the influence of the barrier effect under conditions of high-altitude zonation. Steppe landscapes are formed on the slopes of the southern and southeastern exposure in conditions of a rain shadow.

The seven classes of facies formed under the influence of local environmental factors are represented by the following dynamic series: sublithomorphic, subhydromorphic, and subxerolithomorphic. Factoral-dynamic analysis of the geosystems showed that deep ruggedness of the relief and significant distribution of steep slopes have the greatest impact on the formation of geosystems at the local level. The study area is mostly occupied by landscapes of the sublitomorphic series (66 %) also 29 % of the territory is covered with landscapes of the subhydromorphic series, and 5 % — subxerolithomorphic. Only 5 % of the study area is occupied by landscapes in a primary dynamic state.

The modeling landscape structure in the framework of the geosystem approach using factoral-dynamical series of groups of facies allows considering both regional and local factors of landscape forming. This can be of great practical importance for predict changes in the landscape structure under the influence of both natural and anthropogenic factors, ecological monitoring, assessing the resource potential of the territory and landscape functions, landscape planning, and other applied tasks.

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Приморск жотасының геожүйелері (Байкал аймағы)
Жіктеу және картаға түсіру

Мақалада Приморск жотасының (Байкал аймағы) ландшафттары мысалында геожүйелерді жіктеу және картаға түсіру үшін ландшафт тәсілін қолдану қарастырылған. Ауданның ландшафттық құрылымының моделін зерттеу үшін В. Сочава құрастырған геожүйе тұжырымдамасы және А. Крауклис әзірлеген фациялардың факторлық-динамикалық қатарлар әдісі қолданылған. Геожүйелердің иерархиялық классификациясын әзірлеуге 70 учаскедегі дала жұмыстарының деректері негіз болды. Графиктерді үш параметр бойынша үйлестіру (топографиялық ылғалдылық индексі, еңіс тіктігі және қарашіріктің қалыңдығы) геожүйелерді сыныптар бойынша топтастыру және олардың динамикалық жай-күйін анықтау үшін үшбірлік графиктер әдісімен жүргізілді. Ландшафттық карта далалық жұмыстар, DEM және қашықтықтан зондтау деректері негізінде жергілікті машстабта (1:50 000) құрастырылды. Нәтижесінде зерттелетін аймақта фациялардың 14 тобы анықталды. Олар шарықтау шегі мен сабақтастық кезеңдерімен де, антропогендік модификациялармен де ұсынылған. Жергілікті қоршаған орта факторларының әсерінен пайда болатын фациялардың негізгі кластары факторлық-динамикалық талдау көмегімен анықталады. Олар мына динамикалық қатарлармен ұсынылған: сублитоморфты, субгидроморфты және субсеролитоморфты. Зерттеу алаңының 66 % — ын сублитоморфты қатардың ландшафттары алып жатыр.

Кілт сөздер: фациялардың факторлық-динамикалық қатары, ландшафтық тәсіл, геожүйенің құрылымы, иерархиялық жіктеу, ландшафттық типологиялық карта, спутниктік бейнелер, биіктіктің сандық моделі, ординация.

С.В. Солодянкина, Ю.В. Вантеева

Геосистемы Приморского хребта (Байкальский регион)
Классификация и картирование

В статье обсуждено применение ландшафтного подхода для классификации и картирования геосистем на примере ландшафтов Приморского хребта (Байкальский регион). Для моделирования ландшафтной структуры района исследования использованы концепция геосистемы, сформулированная В. Сочавой, и метод факторально-динамических рядов фаций, разработанный А. Крауклисом. Основой для разработки иерархической классификации геосистем послужили данные полевых работ на 70-ти участках. Ординация графиков по трем параметрам (индекс топографической влажности, крутизна склона и толщина гумуса) проводилась методом тернарных графиков для группирования геосистем по классам и определения их динамического состояния. Ландшафтная карта была составлена в локальном масштабе (1:50 000) на основе данных полевых работ, DEM и дистанционного зондирования. В результате в районе исследования было выявлено 14 групп фаций. Они представлены как климаксовыми и сукцессионными стадиями, так и антропогенными модификациями. Основные классы фаций, образующиеся под воздействием локальных факторов окружающей среды, выявлены с помощью факторно-динамического анализа. Представлены они следующими динамическими рядами: сублитоморфными, субгидроморфными и субксеролитоморфными. 66 % площади исследования занимают ландшафты сублитоморфного ряда.

Ключевые слова: факторально-динамический ряд фаций, ландшафтный подход, структура геосистемы, иерархическая классификация, ландшафтная типологическая карта, спутниковые изображения, цифровая модель рельефа, ординация.

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Республиканская научно-практическая конференция «Современное состояние биоразнообразия РГУ «ГНПП «Буйратау» и его роль в экотуризме», посвященная 10-летию РГУ «Государственный национальный природный парк «Буйратау»

К 10-летнему юбилею организации Государственного национального природного парка «Буйратау» (11.03.2011 г.) была организована Республиканская научно-практическая конференция «Современное состояние биоразнообразия РГУ «ГНПП «Буйратау» и его роль в экотуризме», по итогам которой был издан сборник материалов.

В конференции приняли участие более 40 сотрудников национальных парков, ученых, преподавателей университетов.

В рамках конференции были рассмотрены вопросы мониторинга, сохранения и возобновления биологического разнообразия, охраны и рационального использования природных ресурсов, исследования в области повышения продуктивности растений и животных.

Материалы конференции охватывают итоги анализа состояния популяций редких и исчезающих видов растений и животных ГНПП «Буйратау», Сайрам-Угамского, Кокшетауского, Иле-Алатауского и Баянаульского ГНПП, резерватов Акжайык, Ыргыз-Торгайский. Предложены меры по сохранению популяций лекарственных растений, эндемиков, увеличению видового состава охотничьих животных; ограничений проникновения чужеродных видов в природные популяции и защите от фитопатогенов. В рамках конференции проведен обмен научным и производственным опытом, методической базой, намечены дальнейшие мероприятия по развитию научной деятельности в особо охраняемых природных территориях.

Сборник материалов конференции, объемом 7,5 печатных листов, будет представлять интерес для ученых, сотрудников особо охраняемых природных территорий, преподавателей вузов и колледжей, студентов, магистрантов и докторантов PhD по биологическим и сельскохозяйственным направлениям.

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