



# Evaluating the Status of *Humulus Lupulus* Populations in Kazakhstan: Implications for Conservation, Sustainability, and Forest Ecosystem Management

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## Abstract

Environmental protection plays a key role in maintaining biodiversity and conserving ecosystems, including plant populations with high ecological potential. *Humulus lupulus* (*H. lupulus*), commonly known as hops, belongs to the Cannabaceae family and is a plant known for its rich phytochemical composition and wide range of bioactive properties. This study provides an ecological analysis and geobotanical assessment of *H. lupulus* populations in the southeastern part of Kazakhstan. Fieldwork conducted in July 2023 covered five regions: Almaty, Talgar, Enbekshikazakh, Sarkan, and Alakol. Plant identification was confirmed using herbarium resources, and geobotanical analysis was conducted using route surveys and the Drude scale. The floristic composition and age-related characteristics of each population were determined. The results identified five distinct populations, each characterized by unique ecological and phytocenotic features. Dense clonal groups were found in Almaty, while floristic composition varied in the Enbekshikazakh and Sarkan regions. Soil analysis revealed a wide range of humus content (from low to high), slightly alkaline pH, and significant variation in the concentrations of phosphorus (26–162 mg/kg), potassium (270–430 mg/kg), and zinc (3.8–57.3 mg/kg). The study emphasizes the remarkable adaptability of *H. lupulus* to diverse conditions and its susceptibility to anthropogenic pressure. This research underscores the significant impact of human activity on the environmental condition. To minimize the anthropogenic impact on the biosphere, it is essential to develop innovative approaches aimed at optimizing the use of natural resources, strengthening measures for biodiversity conservation, and restoring disrupted elements of ecological balance. Of particular importance in this context is the protection of *H. lupulus* populations as a critical component of ecosystem processes. A comprehensive approach to addressing these challenges will ensure long-term ecological sustainability and the preservation of natural heritage for future generations.

**Keywords:** *Humulus lupulus*; Cannabaceae; Ecosystem; Adaptation features; Geobotanical analysis; Plant populations; Environment.  
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## 1. Introduction

The protection of nature and the rational use of resources play a pivotal role in maintaining ecological balance and biodiversity in the face of global changes. In recent years, the scientific community's interest in biodiversity and sustainable use of natural resources has significantly increased. This is driven by the intensifying impact of anthropogenic factors and climate change, which have a considerable effect on

ecosystems and plants of great importance for both ecology and medicine. Special attention is given to the study of medicinal plants, such as hops, which are not only valuable raw materials for the pharmaceutical and food industries but also play a key role in maintaining local ecosystems. A comprehensive approach to the study of their properties and adaptive mechanisms becomes especially critical considering changing climatic conditions. Scientific study of hops and other species opens new opportunities for developing sustainable strategies for nature conservation, enhancing biodiversity, and optimizing ecological conditions.<sup>[1,2]</sup>

*Humulus lupulus* (*H. lupulus*) is an important plant, not only in terms of its economic value but also due to its ability to positively impact the environment. This plant is actively

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used in environmental protection activities and agriculture. One of the key ecological functions of hops is the support of biodiversity. It serves as a habitat for pollinators such as bees and butterflies, contributing to the maintenance of ecosystem balance. Hops vines are often found in both natural landscapes and anthropogenic environments, where they help connect ecosystems and enhance their resilience.<sup>[3]</sup>

Additionally, hops possess a unique root system that prevents soil erosion, improves soil structure, and helps retain moisture. This plant is effectively utilized for the remediation of contaminated soils due to its ability to absorb toxic substances, including heavy metals.<sup>[4]</sup>

Hops are also significant for organic agriculture and medicine, as their antimicrobial and antioxidant properties help reduce the reliance on chemical agents. Their high adaptability makes hops a promising candidate for cultivation in regions with challenging climatic conditions, such as the Mediterranean.<sup>[5,6]</sup>

In Kazakhstan, the Zhetysu and Almaty regions, with their diverse natural conditions and rich biodiversity, serve as key areas for the conservation and study of medicinal plants. Among them, hops stand out as a valuable plant not only in the pharmaceutical industry but also in folk medicine due to its sedative and anti-inflammatory properties. Hops are actively used for treating insomnia and anxiety, as well as serving as an antiseptic and a digestive aid. Given the plant's role in regional ecosystems and its medicinal potential, it is essential to preserve this species and manage natural resources wisely to ensure its sustainable existence and the retention of its beneficial components. Studies on the region's ecosystems confirm that hops can successfully adapt to various soil conditions, including those predominant in the Almaty region, facilitating its cultivation and expanding its use in medical practice. Therefore, it is essential to support sustainable ecological-economic methods of utilizing this resource, which will contribute to the preservation of the natural heritage and increase the effectiveness of medicinal raw materials.<sup>[7,8]</sup>

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Recently, there has been an increase in the use of natural products, medicinal preparations, and biologically active plant-derived substances in medicine. A significant portion of medicinal raw material comes from wild plants. Despite the high demand for medicinal plant materials, the technology for their collection and recovery in natural conditions requires substantial improvements. Medicinal plants are known for their mild and complex effects on the body, which makes them effective in treating various chronic diseases. However, the intensified anthropogenic impact on valuable plant populations has led to a reduction in raw material reserves. Consequently, the study of the chemical composition and biological properties of medicinal plants has become particularly important. *H. lupulus* (common hops) is a valuable plant widely used as an analgesic, a calming agent, and in the treatment of various sleep disorders, including nervous tension, insomnia, neuralgia, dysfunction of the autonomic nervous system, coronary artery spasms, tachycardia, and the early stages of hypertension. According to estimates on medicinal plant resources, *H. lupulus* is a species with a wide distribution but limited raw material reserves.<sup>[9-12]</sup>

*H. lupulus* is a perennial herbaceous vine, one of three species of *Humulus* in the Cannabaceae family. *H. lupulus* is a dioecious plant, meaning that male and female flowers typically develop on separate plants, although monoecious specimens can occasionally be found. The flowers are small, and pollination occurs via wind. Female plants produce strobiles (hop cones) ranging in length from 2.5 to 5 cm. These cones form shortly after pollination and consist of overlapping yellow-green bracts attached to the central axis. Each bract surrounds a small dry fruit that does not open upon maturation. Mature cones contain chemical compounds widely used in various industries, particularly in brewing. Male plants produce panicles for pollination, while female flowers are used in brewing. The seeds of *H. lupulus* are small, dense, and water-resistant, with a long dormancy period and slow germination. Female plants begin to form strobiles after several years. Most cultivated varieties are seedless, as seeds can affect the taste of beer.<sup>[13,14]</sup>

*H. lupulus* grows in river valleys, ravines, shrub thickets, and at the edges of forests and is also cultivated in gardens and vegetable plots. This plant is found in regions such as Tobyl-Yesil, Yertis, Semey, Kokshetau, Aktobe, Western and Eastern Kazakh Uplands, Altai, Tarbagatai, Zhetysu Alatau, Ile Alatau, and Karatal mountain ranges cover a vast geographical area, including regions such as Southern Europe, the Caucasus, Western Siberia, Western Europe, the Mediterranean, Asia Minor, and North America.<sup>[15]</sup>

The Almaty and Zhetysu regions are located in the southeastern part of Kazakhstan. The Almaty region includes the Ile Alatau mountain range, which borders Kyrgyzstan, China, as well as the Jambyl and Zhetysu regions. The Zhetysu region lies to the east and encompasses the Zhetysu Alatau mountains, as well as the surrounding areas near Lake

Balkhash. These areas are characterized by a diverse range of landscapes and climates, from continental conditions in the plains to colder mountain climates in the highlands.<sup>[16-18]</sup>

The Almaty and Zhetysu regions, along with the city of Almaty, are known for their natural beauty, cultural wealth, and economic development. The Almaty region includes the Talgar and Chilik districts, which are famous for their water resources, such as the Ile and Karatal rivers. This area features a variety of landscapes: forests, steppes, and deserts. Natural sites such as the Kolsay Lakes and Ile-Alatau National Park attract tourists and ecologists. Zhetysu region includes the Sarkan and Alakol districts, as well as the Zhetysu Alatau mountain range and the coastal territories of Balkhash. Special attention is drawn to Lake Alakol, known for its healing properties and natural beauty. The city of Almaty, located at the foot of the Ili Alatau mountains, is an important metropolis in the region and the country as a whole.<sup>[19,20]</sup>

In recent decades, the climate of the Almaty and Zhetysu regions has undergone significant changes linked to global warming and local environmental factors. The average annual temperature in Kazakhstan, including its southern regions, has increased by about 0.44 °C per decade, particularly manifesting during the summer. The frequency of extreme temperatures, such as days exceeding 35 °C, is increasing, while the number of freezing days is decreasing. Precipitation is also showing a decreasing trend, affecting droughts and water supply in the region. For instance, glacial melting is observed in the Zhetysu Alatau, which may lead to reduced river runoff and exacerbate water shortages in the future.<sup>[21]</sup>

The Almaty and Zhetysu regions are characterized by considerable temperature variation, which is a hallmark of a continental climate. During the summer, temperatures in these areas typically range from +25 °C to +35 °C on the plains, occasionally rising to as high as +40 °C during the hottest periods. In the mountain areas, summer temperatures typically range from +15 °C to +20 °C. In winter, the temperature in the plains drops from -5 °C to -15 °C, and during severe frosts, it may reach -30 °C. In mountain areas, winter temperatures are even lower, often below -20 °C, especially in the higher elevations. These temperature fluctuations, coupled with reduced precipitation, contribute to intensified drought conditions, creating challenges for agriculture and ecosystems in both regions.<sup>[22,23]</sup>

The Almaty and Zhetysu regions are characterized by a variety of soil and vegetation cover, influenced by their unique geographical location, climate, and relief. The soils and vegetation range from plain areas to mountainous regions, creating a variety of natural complexes. The plains are predominantly characterized by steppe ecosystems, semi-desert areas, and grazing lands, whereas the mountainous regions are marked by coniferous and deciduous forests, alpine meadows, and plant species adapted to high-altitude environments. These shifts in vegetation contribute to the formation of complex ecosystems that vary with altitude and climatic conditions, supporting a wide range of biodiversity.<sup>[24]</sup>

Chernozem and chestnut soils are the most common in the lowland and plain areas. These soils are considered some of the most fertile in Kazakhstan and are ideal for agriculture. In some places, saline soils-enriched with dissolved salts that are unsuitable for farming-are found. In the mountain regions, the soils are poorer and less fertile, consisting primarily of brown and gray soils that support mountain ecosystems. At higher elevations, in the alpine and subalpine zones, the soils are even more acidic, limiting agricultural opportunities but creating favorable conditions for the growth of mountain grasses and shrubs.<sup>[25]</sup>

As for the vegetation, the lowland and foothill regions are dominated by steppe plants. Typical steppe grasses such as feather grass, timothy, and sagebrush, as well as other shrubs, can be found here. These plants are well adapted to the dry climate and are commonly used for pastoral agriculture. In the foothills and mountain regions, conifer. As for the vegetation, in the plains and foothill areas, steppe vegetation predominates. Typical steppe grasses, such as feather grass and timothy, as well as wormwood and other shrubs, can be found here. These plants are well-suited to the arid environment and are commonly utilized for grazing purposes. In the foothills and mountainous areas, forests of coniferous and deciduous trees, including species such as pine, spruce, fir, birch, and aspen, are found. These forests are essential for the ecosystem, helping to regulate water systems and prevent soil erosion.<sup>[26]</sup>

At higher altitudes of around 2500-3000 meters, alpine and subalpine meadows are prevalent, supporting plant species like gentian, alfalfa, and violets, which are adapted to colder temperatures and shorter summer periods. In the southern regions, the flora shifts to semi-deserts and savannas. Here, plants such as saltwort, wormwood, various species of feather grass, and saxaul are resilient to the hot climate and drought.<sup>[27]</sup> Thus, the soils and vegetation of the Almaty and Zhetysu regions are diverse and depend on altitude, climate, and topography, which creates rich and varied ecosystems, making the region unique.<sup>[28,29]</sup>

The aim of the study is to conduct ecological monitoring and geobotanical assessment of the populations of *H. lupulus* in southeastern Kazakhstan, provide recommendations based on the analysis of population dynamics, ecological features, and their interaction with the surrounding environment in order to mitigate anthropogenic factors in various areas, such as Almaty, Talgar, Enbekshikazakh, Sarkan, and Alakol districts.

## 2. Materials and methodology

### 2.1 Preparation of the studied materials

Plant samples of *H. lupulus* were collected from five populations in the Almaty and Zhetysu regions in July 2023 during the fruiting period. The materials for this study were obtained from five locations: the Kazachka river valley near Almaty city, the second population in the Talgar region along the Almaty-Talgar highway, 220 meters south of the highway, the third population was selected in the foothill gently

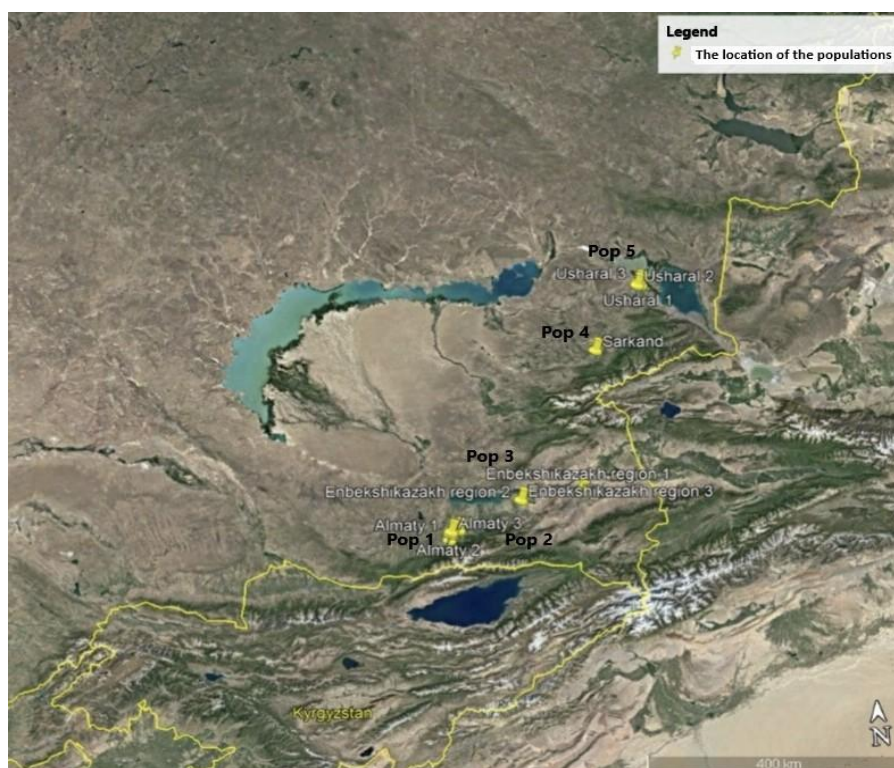


**Fig. 1:** Map of the location of the studied populations. Location 1: Almaty city, northeast side, elevation 500 m (Pop 1), location 2: Talgar district, southeast side, elevation 973 m (Pop 2), location 3: Enbekshikazakh district, southeast side, elevation 612 m (Pop 3), location 4: Sarkan district, southeast side, elevation 728 m (Pop 4), and location 5: Alakol district, southeast side, elevation 347 m (Pop 5).

undulating plains of the Enbekshikazakh district. Additionally, samples were taken from two populations in the Sarkan district in the foothill wavy plains, as well as in the Alakol region along the Tentek river valley. The collection and drying of herbarium samples were conducted according to the methodology described in Skvortsov's works.<sup>[30]</sup> This approach includes a meticulous selection of plants, proper labeling, and drying to preserve all characteristics for future research and herbarium purposes. The plant species collected during the field geobotanical expedition were confirmed using the "Illustrated Guide to the Identification of Plants of Kazakhstan".<sup>[31,32]</sup> The identification of plant families and genera was based on M. S. Baitenov's "Flora of Kazakhstan".<sup>[33]</sup> The taxonomy of species and higher taxa followed the classification system proposed by A. L. Takhtajan,<sup>[34]</sup> and the Latin names, along with any taxonomic updates, were verified through S. K. Cherepanov's references.<sup>[35]</sup> The identification of *H. lupulus* was carried out using the keys provided by Aigul Yedilova and described in the "Flora of Kazakhstan". The *H. lupulus* specimens have been archived in the herbarium at the Institute of Botany and Phytointroduction in Almaty, Kazakhstan. The herbarium specimen number is 0003575.

## 2.2 Study of populations and fieldwork

To evaluate the current condition of *H. lupulus* populations within its natural range, field research was carried out through

exploratory routes in the Almaty and Zhetysu regions. A total of six expeditions were conducted at various stages of the plant's growth cycle. The investigations primarily targeted the foothill and lower-mountain areas, covering sections of the Ile Alatau and Zhetysu Alatau mountain ranges. The degree of similarity between plant populations in the different areas was determined using the Jaccard index, as shown in Eq. (1).<sup>[36]</sup>

$$\frac{K_j=c}{a+b-c} \quad (1)$$

The abundance of species within the plant communities was measured using the Drude scale of abundance.<sup>[37]</sup> The species composition of plant communities and the vegetation cover were refined following established methodologies. The assessment of the plant condition within the populations and their characteristics was conducted according to the methods outlined by T. A. Rabotnov and A. A. Uranov.<sup>[38]</sup> To determine the age structure of the populations, the method proposed by A. A. Uranov was used. For studying the age structure, 20 m<sup>2</sup> transects were established at each study point. Population density was assessed based on the number of individuals per 20 m<sup>2</sup>. The GPS coordinates of the populations were determined using a "GARMIN GPS map 60CSx" navigator (Garmin Ltd., USA).

The approach used to evaluate the density and abundance of the target species followed protocols outlined in established population monitoring programs.<sup>[39]</sup> Studies on the *H. lupulus* populations, focusing on aspects such as plant morphology, ecological and community characteristics, age distribution,

seed output, as well as the vitality of populations and individual plants, were carried out using conventional methods.<sup>[40]</sup> Ecological stages, which reflect the species' environmental adaptations, were determined in situ in specific habitats.<sup>[41]</sup>

For the assessment of *H. lupulus* geographical distribution, the reconnaissance route method was employed, complemented by traditional techniques for analyzing plant morphology, community structures, and the species' ecological and biological attributes. Geobotanical mapping at a medium scale (1: 250,000) was performed, utilizing topographic maps and satellite imagery. Detailed landscape and route profiling were employed for this analysis. Contour maps were created using ArcGIS 10.8, based on SRTM satellite imagery with 90m resolution, cross-checked against topographic maps (Fig. 1).

Fieldwork followed protocols outlined by N. I. Rabotnov,<sup>[42]</sup> whose pioneering research on the Ile Alatau and Zhetysu Alatau served as the basis for the methodology used in this study. Herbarium samples from the Institute of Botany and Phytointroduction were also consulted. A systematic geobotanical analysis of the study area was developed, encompassing ecological and community classifications based on data processing, analysis, and systematization. A comprehensive assessment of plant communities and

ecological landscapes was conducted, with herbarium specimens collected alongside field vegetation studies.

### 2.3 Microclimatic data

Fig. 2 displays the microclimatic information for the period 2023-2024 in the researched regions. The meteorological data were sourced from the official "Gismeteo" website. The data collected from meteorological stations located near the studied populations is presented in Fig. 2. The table includes climate information from various meteorological stations in Kazakhstan (Almaty city and Talgar, Enbekshikazakh, Sarkan, and Alakol districts), including the average air temperature, which ranges from 25.3 to 27.8 °C and soil temperature (31-34 °C), partial vapor pressure (3.41-4.49 hPa), relative humidity (73-83%), saturation deficit (1.40-1.60 hPa), atmospheric pressure (898.9-972.0 hPa), and precipitation (14.0-44.7 mm per day). These figures reflect the characteristics of a moderately continental climate with hot summers, moderate humidity, and significant variations in precipitation levels. The mountain regions (Almaty and Talgar district) show more humid conditions, while a dry climate with the lowest rainfall and humidity characterizes the Alakol region. In the Enbekshikazakh district, the average air temperature is 27.8 °C, while in the Talgar district, it reaches only 25.3 °C. Soil temperatures in the Enbekshikazakh district

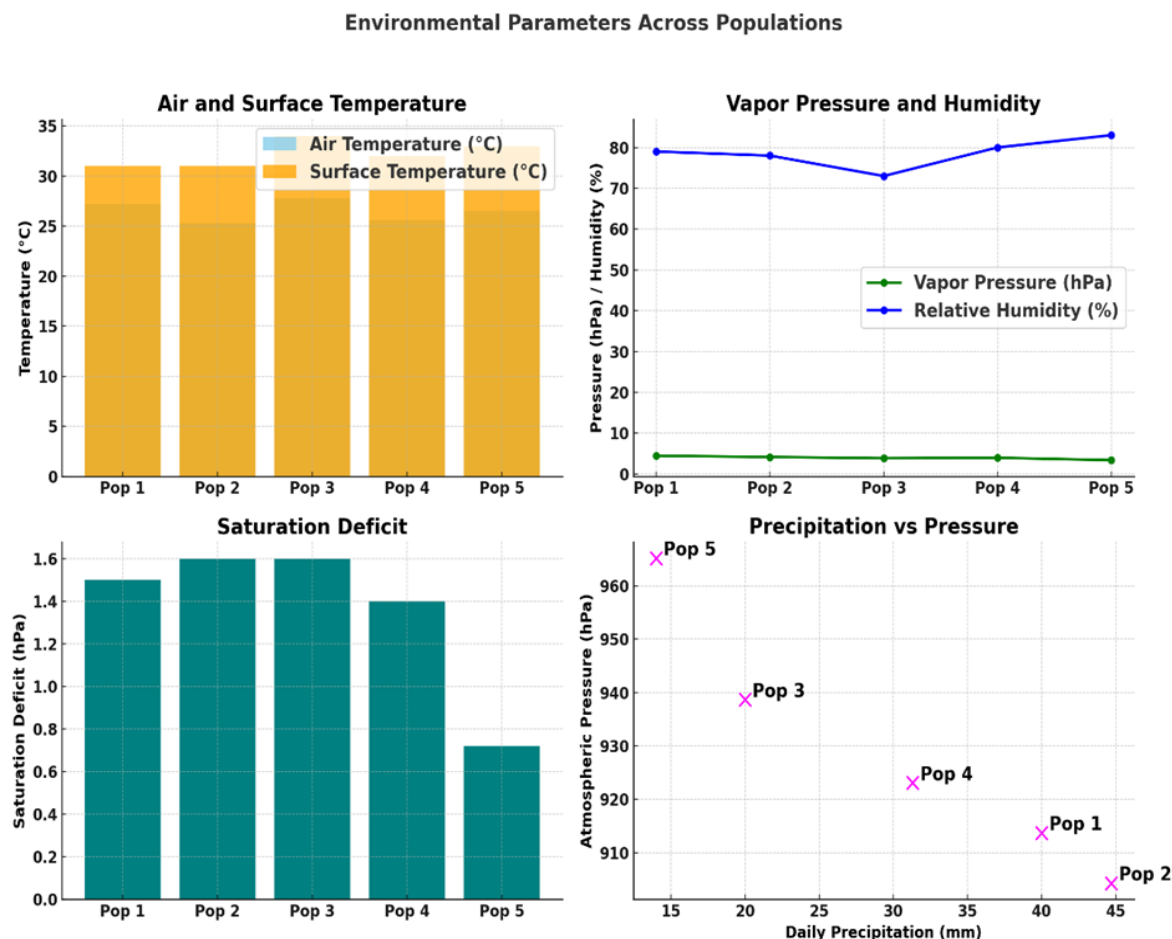


Fig. 2: Comparison of yearly data from weather stations.

can rise to 34 °C. The relative humidity in the Alakol district is 5.6% higher compared to other territories, and daily precipitation levels in the Talgar district surpass those in other regions by 69.8%. An analysis of these data indicates that the climate in the studied areas is continental, characterized by hot summers and cold winters, typical for the northern and eastern regions of the continent.

## 2.4 Soil evaluation

Both field and laboratory methods were used for the research. Fieldwork involved soil sample collection and the creation of soil profiles, while the laboratory phase focused on determining the chemical and mechanical properties of the soil.

Field research was conducted using the key transect method. During the field surveys, morphological techniques were applied to assess the characteristics of vegetation and soil.<sup>[43]</sup> The "envelope method" was used for sampling. A 4 × 5 m plot was established in a uniform area, with samples taken at the corners and the center of the plot. In accordance with GOST standards (state standard): 17.4.4.02-84 "Nature Protection. Soils. Methods of sampling and preparing samples for chemical, bacteriological, and helminthological analysis",<sup>[44-46]</sup> five soil samples were collected from each plot using a spade, to a depth of 30 cm. A uniform 4-5 cm thick layer of soil was then removed. The total humus content of the soil samples was determined using the Tyurin method.<sup>[47]</sup> The soil pH was also measured according to GOST,<sup>[48]</sup> and the mobile forms of phosphorus, potassium, zinc, manganese, and boron were determined.<sup>[49,50]</sup> The five point samples from one horizon (layer) were mixed in a special container, and an average composite sample was taken. The mass of the composite sample depended on the goals and type of analysis. For soil analysis, samples were packaged in double zip-lock polyethylene bags, accompanied by an identification slip indicating the location, date, sample number, depth, and name of the researcher. Fifteen samples were taken for physical-chemical analysis, each sample being analyzed in triplicate.

## 2.5 Field sampling

To evaluate the vegetation cover in the study area, sample plots measuring 20 m<sup>2</sup> were utilized, allowing for a comprehensive assessment of plant communities and the ecological characteristics of the territory. During fieldwork, GPS coordinates, altitude above sea level, data on topography, soil composition, and vegetation features were recorded. The life forms of plant species found on the southern slopes were classified according to standardized methodologies.<sup>[51]</sup>

The collected data were processed using statistical analysis methods with R (version 4.3.0). The Mann-Whitney U test was applied for comparing independent samples with a significance level of 5%, allowing for the analysis of non-parametric data. Additional calculations and result presentations were carried out using spreadsheet editors such as LibreOffice Calc and Google Sheets, which facilitated detailed data analysis and visualization.<sup>[52]</sup>

## 3. Results and discussion

### 3.1 Plant characteristics and geographic distribution

*H. lupulus* (common hop) can grow in a variety of natural zones within the region, including both mountainous areas (the eastern slopes of the Zhetysu Alatau and the southern foothills of the Tian Shan) as well as plains (Alakol, Sartkan districts). These plain areas are characterized by diverse soils and climates, which create favorable conditions for hop growth, particularly in coastal and foothill zones.

For the study of the medicinal species *H. lupulus*, an expedition was organized in 2023 in five districts of southeastern Kazakhstan, including Almaty and adjacent areas. The expedition was conducted in the summer to study hop populations in different ecosystems, such as forest and meadow zones. Transects were laid out in five different areas to investigate the age structure and ecological conditions affecting the distribution of this species.

To determine the age structure of *H. lupulus* populations in different areas, 20 m<sup>2</sup> transects were established. On each transect, the number of hop individuals was counted from the latent stage to the post-generative period. Measurement data allowed for the evaluation of population growth dynamics, life cycles, and the distribution and density of individuals at various stages of development. Geobotanical characterization was performed at the population level.

The climate in Almaty city, Almaty, and Zhetysu regions is characterized by sharp continental conditions with significant temperature fluctuations throughout the year. In northern regions, winter temperatures can drop to -14 °C, while in southern areas, they can reach -19 °C. Summer temperatures on the plains may rise to +30 °C, while in southern and eastern regions, they can reach +36 °C. Precipitation varies depending on the location: in steppe areas, it amounts to around 240 mm, whereas in mountainous regions, it is significantly higher, reaching 650-750 mm, due to unique climatic and geographical conditions. Mountain ranges like the Tian Shan and Alatau create distinct microclimates, where much more precipitation falls in the mountains compared to the lowlands.

The soils of Almaty region, Almaty, and Zhetysu regions are diverse and shaped by both climatic conditions and the local topography. The lowland and plain areas are predominantly covered by meadow chernozems, chestnut, and serozem soils, each with specific agronomic properties. Soils in the foothills of the Tian Shan and Zhetysu Alatau reflect the influence of mountainous terrain and vertical zonation. The humus content in light-serozem soils ranges from 1-1.5%, while dark-serozems can have 3-4%. These soils have favorable mineral compositions with adequate phosphorus and potassium reserves, creating optimal conditions for agriculture, including the cultivation of hops.

### 3.2 Floral characterization of *H. lupulus* populations

Five populations of *H. lupulus* were identified in the study area. This species is an important plant in agriculture and industry,

with various cultivars used in brewing and other sectors. The study area has a diverse and complex relief, consisting of both mountainous and flat areas. The varied terrain contributes to the diversity of the region's flora and fauna, as well as impacting agricultural development, water supply, and infrastructure. As a result of the expeditionary research, five main populations were distinguished, named after their geographic locations: (1) Almaty city, (2) Talgar (Almaty region), (3) Enbekshikazakh (Almaty region), (4) Sarkan (Zhetysu region), and (5) Alakol (Zhetysu region).

The distances between the studied populations range from 20 to 300 kilometers. The populations were classified based on the many individuals representing the same species. A key characteristic of a population is its ability to persist independently in the area through reproduction. The plants coexist in a specific area and are interconnected. These populations were found in different ecological-phytocenotic conditions, including steppe shrubs and grasses, lowland rocky slopes, and shrub vegetation.

The age structure of *H. lupulus* populations was analyzed at five sampling sites. The age structure can be described using a method similar to the one used for analyzing population density, the proportion of different age groups (vegetative and generative individuals), and the number of shoots. The age structure of the *H. lupulus* population in the studied areas of the Almaty region showed significant fluctuations in plant density and the proportion of different age groups. The population density of hops varied from 5 to 20 individuals per square meter, depending on the growth conditions. The proportion of vegetative individuals, *i.e.*, those forming shoots from the root system, varied from 60 to 80% of the total population. This is confirmed by the significant predominance of vegetative clones, which may contain from 8 to 15 shoots per plant. The number of generative individuals, *i.e.*, plants that produce flowers and cones, ranged from 10 to 30% of the total number of individuals in the population. These plants typically have less branched root systems and are less prone to producing additional shoots. The study of age structure showed that most hop populations in the studied areas consist mostly of plants in the vegetative growth stage, which is characteristic of perennial crops.

At the same time, the proportion of generative individuals significantly increased in seasons with favorable growing and flowering conditions, especially in the foothills and plains, where the climate is milder and precipitation is more evenly distributed. The age structure of the populations in the study areas demonstrates moderate stability, with age indices fluctuating between 0.25 and 0.40. Generative individuals account for 25 to 35% of the population, with the highest proportion of generative plants observed in the virgin group, ranging from 37% to 58%. The proportion of juveniles (young and non-sexual plants) ranges from 10% to 30%, indicating a significant predominance of vegetative individuals, resulting in overall rejuvenation due to the formation of new vegetative shoots. Specifically, in population 1, the generative plants

account for 8 out of 47 (17%), and the juvenile proportion is 22%, in population 2, generative plants account for 14 out of 75 (19%), in population 3, for 17 out of 90 (19%), in population 4, for 20 out of 109 (18%), and in population 5, for 7 out of 57 (12%). All studied populations can be classified as homeostatic, indicating their high vitality and ability to regenerate. These populations maintain a stable proportion of age groups and can effectively adapt to changes in external conditions, indicating overall ecosystem stability.

For studying the age structure of populations, the size of the trial plots was 20 m<sup>2</sup> for each population. On average, no less than 10 trial plots were designated for each of the studied hop populations. This allowed for obtaining representative data on population density, age structure, and the dynamics of hop development in different ecological conditions.

### 3.3 Particular population information

#### 3.3.1 Population 1: Almaty city

The Almaty city population was located in Almaty city, Medeu district, Makataev street, 30 paces west of the Kazachka River. The terrain is the valley of the Kazachka River. Coordinates: 43°15.942' N, 076°58.029' E, at an elevation of 500 meters. This area was characterized by an herbaceous-grassland-plant diversity vegetation type. The populations of this species typically form dense, clonal groups due to their predominant mode of reproduction-vegetatively through rhizomes and shoots. This allows the plant to rapidly expand its territory, forming clonal families where individual plants, originating from a single root, can occupy large areas. The habitat of *H. lupulus* is diverse, encompassing both mountainous and lowland areas. The species prefers well-lit locations such as open glades, forest clearings, and riverbanks (Fig. 3), where the conditions for growth and reproduction are most favorable. In these habitats, the plant actively develops its vegetative biomass. In plant communities dominated by herbaceous plants, *H. lupulus* is often found in association with species such as nettle, plantain, and quack grass, as well as shrubs like currant and serviceberry. The vegetation in these habitats is predominantly herbaceous, constituting around 75% of the total cover, while shrub species account for no more than 15-20%. *H. lupulus* belongs to the herbaceous life form with a distinct vine-like growth form. Its shoots are capable of climbing supports, allowing the plant to occupy vertical space and effectively compete for light.

Additionally, *H. lupulus* reproduces vegetatively, shoots that emerge from the rhizomes generate new plants and form fast-growing, dense colonies. The populations of *H. lupulus* in these ecosystems exhibit high dynamism, as they can quickly colonize new areas in the absence of strong competition from other plants. However, in highly competitive plant communities, where species such as grasses may dominate a large portion of the plant cover, *H. lupulus* may experience significant limitations in growth and spread. The plant's high ability to clone through rhizomes and shoots results in dense ground cover. Based on the description of ranks, methodology

for accounting, and the provided data, the plant populations of the region can be classified as follows (Table 1).



**Fig. 3:** *H. lupulus* in the Almaty population. Natural habitats: the relief of the Kazachka River valley.

**Table 1:** Distribution of plant families in the population 1.

| Family         | Percentage (%) | Dominant species                                                                           |
|----------------|----------------|--------------------------------------------------------------------------------------------|
| Poaceae        | 34             | <i>Polygonum aviculare</i> L., <i>Poa pratensis</i> L., <i>Polygonum lapathifolia</i> L.   |
| Asteraceae     | 16             | <i>Taraxacum officinale</i> L., <i>Cichorium intybus</i> L., <i>Xanthium strumarium</i> L. |
| Fabaceae       | 9              | <i>Trifolium pratense</i> L., <i>Glycyrrhiza glabra</i> L.                                 |
| Polygonaceae   | 6              | <i>Polygonum aviculare</i> L., <i>Atriplex tatarica</i> L.                                 |
| Rosaceae       | 7              | <i>Rubus caesius</i> L.                                                                    |
| Ulmaceae       | 5              | <i>Ulmus pumila</i> L., <i>Ulmus laevis</i> Pall.                                          |
| Caprifoliaceae | 4              | <i>Lonicera tatarica</i> L.                                                                |

### 3.3.2 Population 2: Talgar district

The Talgar population is located along the Almaty-Talgar highway, approximately 220 paces south of the road. Coordinates: 43° 18.500' N, 077° 06.919 E, at an elevation of 973 meters. The terrain is a gently undulating foothill plain with a dry riverbed valley. The *H. lupulus* population in Talgar is situated in the foothill area at an elevation of approximately 973 meters above sea level. The territory is characterized by a woody-shrub-grass-diverse plant type, with hops included. The following plant community types were identified: woody-grass-diverse, grass-diverse-weedy, and shrub-diverse-grassy. The projective cover reached 80%. These areas are typical of both lowland and mountainous regions, where hops are found in mixed communities, including both steppe and forest in

phytocenoses. The hops population primarily grows along rivers, where soil and air humidity remain high, creating ideal conditions for plant growth. The vegetation in these communities is characterized by mesophytic and mesoxerophytic conditions, which are ideal for hops, as they require moderate moisture and sheltered areas for growth. Hops habitats in the Talgar population include slightly sloped foothill areas covered by a variety of herbaceous vegetation. This population of *H. lupulus* is characterized by high density in certain spots, especially along water bodies where humidity remains stable throughout the year. Vegetative forms predominate, with generative plants making up a smaller proportion of the population, indicating a high level of vegetative reproduction in these conditions. This description takes into account the ecological features of the Talgar district, such as the typical habitats of hops, climatic conditions, the specific vegetation, and the role of hops in these communities (Fig. 4).



**Fig. 4:** *H. lupulus* in the Talgar district population.

The vegetation cover of the region is characterized by high diversity, with more than 75 species present. These communities are dominated by herbaceous plants, among which the following families stand out, as indicated in Table 2.

In the Talgar district, herbaceous species make up 77% of the phytocenosis, with grasses and nettles being the dominant families. Shrubs constitute a small portion, accounting for 5%, and the ecological composition of the phytocenoses is characterized by the predominance of both mesophytic and mesoxerophytic species in accordance with the region's climatic and soil conditions. The degree of synanthropization, which reflects the impact of anthropogenic factors, is 30%, indicating frequent human interventions in the region's ecosystem.

### 3.3.3 Population 3: Enbekshikazakh district

The Enbekshikazakh population is located in the Almaty region, on Tselynnaya Street, between Bijanova and Vinogradnaya Streets, near a small stream. Coordinates: 43°35.239' N, 078°14.962' E. The terrain was characterized by a gently undulating foothill plain (Fig. 5).

**Table 2:** Distribution of plant families in the population 2.

| Family        | Percentage (%) | Dominant species                                                                          |
|---------------|----------------|-------------------------------------------------------------------------------------------|
| Poaceae       | 35             | <i>Poa pratensis</i> L., <i>Elymus repens</i> L., <i>Alopecurus pratensis</i> L.          |
| Asteraceae    | 20             | <i>Taraxacum officinale</i> L., <i>Cichorium intybus</i> L., <i>Galatella punctata</i> L. |
| Fabaceae      | 10             | <i>Trifolium pratense</i> L., <i>Daucus carota</i> L.                                     |
| Cannabaceae   | 8              | <i>H. lupulus</i> L., <i>Cannabis ruderalis</i> L.                                        |
| Rosaceae      | 7              | <i>Rubus idaeus</i> L., <i>Rubus</i> L.                                                   |
| Ulmaceae      | 6              | <i>Ulmus</i> L.                                                                           |
| Polygonaceae  | 5              | <i>Polygonum aviculare</i> L.                                                             |
| Apiaceae      | 4              | <i>Daucus carota</i> L.                                                                   |
| Urticaceae    | 3              | <i>Urtica urens</i> L.                                                                    |
| Ranunculaceae | 2              | <i>Thalictrum</i> L.                                                                      |

**Fig. 5:** *H. lupulus* in the population of the Enbekshikazakh district.

The *H. lupulus* populations in the region are typically found on herbaceous meadow slopes, representing wetland ecosystems. These areas feature a diverse flora comprising herbaceous and shrub species. The dominant vegetation type in the studied area was a weed-grass-woody-shrub-sagebrush type, with a projective cover of 65%. The habitat of *H. lupulus* in the Enbekshikazakh district of Kazakhstan is typical of the foothills of the Ile Alatau and the river valleys, such as the Chilik River and other bodies of water in the region. In these areas, hops are found along floodplains and watershed areas, in forest and shrub zones, as well as in places with moist soils and adequate sunlight. These conditions are favorable for the growth of hops, as the plant prefers moderately moist soils with good drainage, as well as protection from strong winds and extreme temperatures. The common hop can be found in

herbaceous and shrub communities, often as part of phytocenoses that include grasses, legumes, and other perennial herbs (Table 3). Generative hop plants typically feature both male and female flowers on separate individuals. In this district, hops usually grow as tall vines along water bodies, climbing on supports and shrubs. *H. lupulus* often grows in mixed phytocenoses with other herbaceous plants (Table 4), such as grasses and asters.

### 3.3.4 Population 4: Sarkan district

The *H. lupulus* population № 4 in the Sarkan district is located in the foothills, at an altitude of approximately 728 paces above sea level (Zhetysu region, Sarkan district, the village of Sarkan). The terrain is a gently undulating foothill plain. Coordinates: 45°24.327' N, 079°54.830' E. (Fig. 6)

These areas are characterized by gently rolling terrain and diverse natural conditions, where hops are found in mixed phytocenoses combining steppe and meadow species. These areas often experience full or diffuse sunlight, which favorably influences the photosynthetic processes of hops, ensuring good growth. The vegetation in these communities exhibits mesophytic and mesoxerophytic characteristics, enabling hops to thrive in moderate humidity conditions. The vegetation cover involving *H. lupulus* in this area includes grass and herbaceous associations, as well as woody and shrub growths. The projective cover reaches 65%.

The habitats of *H. lupulus* in the Sarkan district include gently sloping grassy hills covered with diverse vegetation, including both herbaceous species and shrubs. In this region, vegetative forms of hops dominate, which suggests a high level of vegetative reproduction. Generative plants are encountered less frequently, which may indicate specific

**Table 3:** Distribution of plant families in the population 3.

| Family       | Percentage (%) | Dominant species                                              |
|--------------|----------------|---------------------------------------------------------------|
| Cannabaceae  | 20             | <i>H. lupulus</i> L., <i>Cannabis ruderalis</i> L.            |
| Poaceae      | 15             | <i>Agropyron repens</i> L., <i>Calamagrostis epigejos</i> L.  |
| Ulmaceae     | 12             | <i>Ulmus pumila</i> L., <i>Ulmus parvifolia</i> L.            |
| Asteraceae   | 10             | <i>Artemisia terrae-albae</i> , <i>Xanthium strumarium</i> L. |
| Polygonaceae | 8              | <i>Atriplex cana</i> L.                                       |
| Rosaceae     | 8              | <i>Malus sieversii</i> L.                                     |
| Aceraceae    | 6              | <i>Acer saccharum</i> L.                                      |
| Salicaceae   | 5              | <i>Salix starceana</i> L.                                     |
| Asteraceae   | 4              | <i>Arctium lappa</i> L.                                       |

**Table 4:** *H. lupulus* population and its ecological characteristics.

| Ecological groups of plants | The total number of, % |
|-----------------------------|------------------------|
| Mesophytes                  | 57                     |
| Xerophytes                  | 14                     |
| Mesoxerophytes              | 17                     |
| Heromesophytes              | 6                      |
| Mesohygrophytes             | 6                      |

conditions for their growth and reproduction. This could be due to a limited area for generative reproduction or the dominance of vegetative spread, characteristic of most hop populations in these climatic conditions. Thus, the populations of hops in the Sarkan district are characterized by high ecological resilience and dense vegetation, creating ideal conditions for the sustainable growth and reproduction of the plant.

**Fig. 6:** *H. lupulus* in the Sarkan district population.

The vegetation cover of the Sarkan district, where *H. lupulus* is found, is characterized by high floristic diversity and includes over 36 plant species. These communities are dominated by herbaceous plants, among which the most significant families are listed in Table 5. In these communities, *H. lupulus* is found in association with numerous herbaceous species, as well as shrubs, making it part of relatively stable ecosystems with high biodiversity.

In the Sarkan district, herbaceous species make up about 80% of the phytocoenosis, with grasses and nettles, such as Poaceae and Urticaceae, dominating, providing the basis for *H. lupulus* habitat in this region. Shrubs constitute about 6%, and trees about 4%. The ecological composition of the region's phytocoenoses is characterized by the predominance of mesophytes, as well as xerophytes and mesoxerophytes, reflecting the moderate climatic and soil conditions typical of the Sarkan district. These conditions provide optimal growth conditions for *H. lupulus*, which prefers moderate humidity and sheltered areas.

The synanthropization index in the Sarkan district is about 28%, indicating significant anthropogenic influence on the ecosystem. This suggests relatively frequent human interventions, such as agricultural activities and deforestation, which may have both positive and negative impacts on the stability of *H. lupulus* populations in the region.

**Table 5:** Distribution of plant families in the population 4.

| Family      | Percentage (%) | Dominant species                                                                       |
|-------------|----------------|----------------------------------------------------------------------------------------|
| Poaceae     | 35             | <i>Agropyron repens</i> L., <i>Phleum pratense</i> L.,<br><i>Dactylis glomerata</i> L. |
| Cannabaceae | 15             | <i>H. lupulus</i> L.                                                                   |
| Asteraceae  | 12             | <i>Achillea millefolium</i> L., <i>Taraxacum officinale</i> L.                         |
| Fabaceae    | 10             | <i>Trifolium pratense</i> L.                                                           |
| Ulmaceae    | 8              | <i>Ulmus laevis</i> Pall.                                                              |
| Rosaceae    | 8              | <i>Rubus vulgaris</i> L.                                                               |
| Asteraceae  | 6              | <i>Chichorium intybus</i> L.                                                           |

### 3.3.5 Population 5: Alakol population

The Alakol population is located in the Zhetysu Region, Alakol District, near the village of Usharal, 100 paces west of the highway. Its coordinates are 46°10.241' N, 080°52.113' E, at an elevation of 347 meters. Relief: the valley of the Tentek river. The *H. lupulus* population in the Alakol district is located in the foothills, at about 347 meters above sea level. These areas are characterized by gentle rolling relief and a variety of natural conditions, creating favorable conditions for the growth of hops (Fig. 7). The vegetation cover with *H. lupulus* participation in this area is represented by tree-shrub-grass associations, with a projected cover of 70%. *H. lupulus* in this region is found in mixed phytocoenoses, combining steppe and meadow plant species. These areas are usually subject to full or diffuse sunlight, which positively influences the photosynthetic activity of hops, ensuring their normal growth and development.

The vegetation in these communities has characteristic mesophytic and mesoxerophytic traits, allowing hops to thrive in moderate moisture and warmth. Soils in the Alakol district are diverse, ranging from meadow soils to drier, more stony areas, supporting the successful growth of hops, as it prefers fertile but not overly moist soils. The annual precipitation varies from 400 to 550 mm, with peaks during the spring and autumn periods, maintaining stable soil moisture and creating favorable conditions for plant growth, including hops.

The habitats of *H. lupulus* in the Alakol district include gentle grassy slopes and riverbanks, where the vegetation is diverse, including both herbaceous species and shrubs. In these communities, vegetative forms of hops dominate, indicating a high level of vegetative reproduction. Generative plants are less common, which may be associated with specific ecological conditions for their growth and reproduction.

The plant cover of the Alakol district is distinguished by a high level of floristic diversity, with over 23 species of plants. These reports are dominated by herbaceous species, including representatives of the families presented in Table 6. Moreover, other families such as Lamiaceae, Polygonaceae,

Ranunculaceae, and others, comprising the remaining 11%, can also be encountered within the community. The analysis of all five populations revealed that Poaceae and Cannabaceae dominate with high abundance (29.83%) and stability, playing a crucial role in the ecosystems.

**Fig. 7:** *H. lupulus* in the population of the Alakol district.

Vegetative forms of plants in the Alakol region are predominantly mesophytes and mesoxerophytes, which corresponds to the moderately humid conditions of the region. The flora and vegetation composition, along with the climatic features, make this area ideal for the growth of plants such as *H. lupulus*, which dominates these communities.

The species composition similarities between populations suggest that they all predominantly include plants from large and widespread families such as Poaceae, Asteraceae, and Fabaceae. Moreover, many populations contain species from the Rosaceae and Caryophyllaceae families, indicating common ecological conditions and similar plant communities.

The analysis and calculation of floristic similarity indices for populations in Almaty, Talgar, Enbekshikazakh, Sarkan, and Alakol districts confirm the high ecological plasticity of vegetation across the studied regions. The recorded floristic

**Table 6:** Distribution of plant families in the population 5.

| Family       | Percentage (%) | Dominant species                                                                                                                                 |
|--------------|----------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| Poaceae      | 35             | <i>Agropyron repens</i> L., <i>Calamagrostis epigejos</i> L., <i>Elymus repens</i> L., <i>Phragmites australis</i> .                             |
| Cannabaceae  | 15             | <i>H. lupulus</i> L.                                                                                                                             |
| Asteraceae   | 10             | <i>Achillea millefolium</i> L., <i>Arctium lappa</i> L., <i>Cirsium vulgare</i> L.                                                               |
| Fabaceae     | 10             | <i>Medicago falcata</i> L., <i>Medicago romanica</i> Prod., <i>Trifolium dentatum</i> Waldst. & Kit., <i>Glycyrrhiza uralensis</i> Fisch. ex DC. |
| Elaeagnaceae | 8              | <i>Elaeagnus oxycarpa</i> L.                                                                                                                     |
| Ulmaceae     | 8              | <i>Ulmus laevis</i> Pall.                                                                                                                        |
| Rosaceae     | 6              | <i>Rubus vulgaris</i> L.                                                                                                                         |
| Cyperaceae   | 5              | <i>Carex songorica</i> L.                                                                                                                        |
| Tamaricaceae | 3              | <i>Tamarix ramosissima</i>                                                                                                                       |

similarities between the specific populations, despite geographical and microclimatic differences, reflect the ability of plant communities to adapt to changing ecological factors, such as climate, soils, and topography. This data confirms that plant species can maintain viability across different phytocenoses (plant communities), where various ecological factors interact.

The analysis of floristic similarity between *H. lupulus* populations based on the Jaccard index demonstrated a moderate level of species overlap. The highest floristic similarity was observed between Population 1 and Population 2 (12.1%), which may reflect similar ecotopes and anthropogenic influences. The lowest index value was recorded between Population 2 and Population 3 (6.1%), indicating different successional dynamics or variations in edaphic continuum conditions. The similarity between other pairs ranged from 6.3% to 10%, showing differentiation of phytocenoses. These results underline the importance of further studying the structural and ecological dynamics of *H. lupulus* communities, as well as a detailed evaluation of the interaction of biotic and abiotic factors, including the impact of climate, soil composition, and local habitat conditions, which shape unique plant communities and their resilience.

Thus, the observed floristic variability and the persistence of common species and families in different populations confirm the high ecological flexibility of the studied species, allowing them to maintain viability in various ecosystems. This also indicates the capacity of plant communities to adapt and form stable phytocenoses in diverse natural zones with changing climatic, edaphic, and anthropogenic factors. Plants can actively respond to changes in environmental factors, which is an essential aspect of ecological dynamics and population ecology.

*H. lupulus* in the studied populations exhibits a

mesophytic-hygrophytic type of ecological and biological adaptation, indicating its preference for moist and moderately moist habitats, such as river valleys, floodplains, and wet forest ecosystems. However, its ability to withstand brief periods of drought also suggests a degree of xerophytic plasticity.

The main factors limiting the spread of *H. lupulus* are soil moisture, temperature conditions, soil type, competition with other plants, biotic influences (pests and diseases), and anthropogenic changes in the environment. These factors collectively determine where the plant can successfully grow, and where its spread is constrained.

The analysis of field data for *H. lupulus* in various populations of Kazakhstan (Almaty, Talgar district, Enbekshikazakh district, Sarkan district, and Alakol district) leads to the conclusion of a high ecological and biological plasticity of this species. The common hop demonstrates the ability to adapt successfully to diverse growing conditions, enabling its widespread presence in various phytocenoses. Despite the similar floristic composition, each growing site has its own specificities, determined by ecological factors such as humidity, soil type, climate, and other conditions.

*H. lupulus* is found in various phytocenoses, including meadow, valley, and steppe communities, indicating its versatility and ability to adapt to more humid and arid conditions. In the habitats where hops occur, several plant families are prominent, particularly Poaceae, Fabaceae, Asteraceae, and Caryophyllaceae, which often form the basis of the flora. This suggests that hops frequently coexist in communities with other herbaceous plants, contributing to resilient ecosystems.

This is further supported by the fact that hops in different populations exhibit similar morphological traits, such as leaf size, stem height, and flowering duration, but with variations

**Table 7:** Comparative characteristics of the morphological traits of *H. lupulus* plants.

| Name         | Total number | Juvenile (j) | Immature (i) | Virginal (v) | Generative (g) |
|--------------|--------------|--------------|--------------|--------------|----------------|
| Population 1 | 47           | 7            | 15           | 17           | 8              |
| Population 2 | 75           | 16           | 19           | 26           | 14             |
| Population 3 | 90           | 19           | 25           | 29           | 17             |
| Population 4 | 109          | 22           | 29           | 38           | 20             |
| Population 5 | 57           | 5            | 22           | 23           | 7              |

typical for the specific growing conditions (Table 7). Thus, it can be concluded that *H. lupulus* has high ecological and biological flexibility. This enables it to maintain its viability in various phytocenoses, regardless of changes in climatic and soil conditions. These results confirm that hops can effectively develop and bear fruit in both wetter valleys and floodplains, as well as in drier steppes and mountainous regions, where growing conditions can vary significantly. To gain a deeper understanding of the ecological plasticity of hops, further study of its adaptive mechanisms in different ecological settings is necessary.

This conclusion reflects a comprehensive approach to the study of *H. lupulus*, considering its adaptive capacities and the variation of morphological traits based on growing conditions. From the analysis of the flora of the *H. lupulus* populations in five districts (Almaty, Talgar district, Enbekshikazakh district, Sarkan district, and Alakol district), several important observations can be made. The Asteraceae family is also represented by a significant number of species, which is explained by the nature of the hop habitats, often found in meadows and grassland phytocenoses. This family ranks second in species richness, following Poaceae.

Therefore, it can be concluded that the Poaceae and Asteraceae families are the most important and diverse in the flora of *H. lupulus* populations, emphasizing their role in shaping the ecosystems where hops grow. These families also reflect the biogeographical characteristics of the region in which hops adapt, combining influences from both Mediterranean and boreal zones.

The populations of *H. lupulus* in Almaty, Almaty Region, as well as in the Zhetysu Region, exhibit high plant species diversity, encompassing numerous plant species that play a key role in regional ecosystems and hold significant economic value. The mountain ridge area is home to such plants as *Salvia officinalis* L., *Melissa officinalis* L., *Leonurus cardiaca* L., *Thymus vulgaris* L., *Matricaria chamomilla* L., *Lavandula angustifolia* Mill., *Inula helenium* L. and *Chrysanthemum cinerariaefolium* (Trevir.) Vis. These plants are widely used in medicine, perfumery, and agriculture. Local residents also highly value berries like cranberry, blueberry, and raspberry, as well as herbs commonly used in agriculture and folk medicine. All these plants contribute to a rich ecosystem that supports the economic development of the region.

The flora of the *H. lupulus* populations in Almaty city, Almaty Region, and the Zhetysu Region is characterized by a high level of biodiversity, containing species from the Fabaceae family, like *Trifolium* spp. and *Medicago sativa* L., as well as from the Caryophyllaceae family, including *Cerastium* spp., are present. Medicinal plants from the Lamiaceae family, such as *Melissa officinalis* L., and members of the Hypericaceae family, like *Hypericum perforatum* L., also play a significant role.

The largest group in the flora of *H. lupulus* populations in Almaty, Almaty Region, and the Zhetysu Region is the Poaceae (Table 8), which consists of variety of species. Grasses play a central role in the region's ecosystems, providing forage for livestock and forming critical components of grassland communities. Grasses make up about 20-25% of the total flora in these areas, with species such as *Poa* spp., *Festuca* spp., and *Agropyron* spp., forming the dominant vegetation on pastures and meadows.<sup>[53]</sup>

**Table 8:** Taxonomic composition of dominant families in the *H. lupulus* population.

| Families                   | The total number of, % |
|----------------------------|------------------------|
| <i>Poaceae</i> Juss.       | 30.8                   |
| <i>Asteraceae</i> Giseke.  | 13.6                   |
| <i>Fabaceae</i> Lindl.     | 9.8                    |
| <i>Ulmaceae</i> Mirb       | 7.8                    |
| <i>Rosaceae</i> Juss.      | 7.2                    |
| <i>Polygonaceae</i> Lindl. | 3.8                    |
| The other 20 families      | 27                     |

In communities with *H. lupulus* (common hop), various aromatic plants from the Asteraceae family, such as *Bidens tripartita* L., *Matricaria chamomilla* L. and *Tussilago farfara* L., as well as species from the Lamiaceae family like *Melissa officinalis* L., *Lavandula angustifolia* Mill., *Salvia officinalis* L., and *Mentha* spp., are frequently encountered. These plants prefer moist soils rich in organic matter, facilitating their coexistence with hops in natural ecosystems.

The most valuable plants in the communities with *H. lupulus* include *Melissa officinalis*, *Salvia officinalis*, and *Matricaria chamomilla*. *Melissa officinalis* is known for its calming properties, helping to alleviate stress, improve sleep, and even providing antiviral effects. *Salvia officinalis* is valued for its antiseptic and anti-inflammatory properties, often used in treating colds and inflammation (Table 9). *Matricaria chamomilla* is recognized for its antiseptic and calming effects and is used for treating skin conditions and stomach issues. These plants are widely used in medicine and cosmetology for their beneficial properties.

Plant tiers or layers are essential for maintaining water quality, reducing erosion, and promoting biodiversity. In our Stream Wise property assessments, we classify these layers as canopy, understory, shrubs, groundcover, and duff. Each tier, from the canopy to the duff layer, supports a distinct plant community that contributes to the overall health of the ecosystem. The populations of *H. lupulus* in the studied regions can be divided into three tiers (Table 10).

**Table 9:** Economically important plant groups in the *H. lupulus* population.

| Plant groups           | The total number of, % |
|------------------------|------------------------|
| Weeds                  | 11.5                   |
| Food plants            | 6.7                    |
| Medicinal plants       | 6.0                    |
| Honey-bearing plants   | 14.3                   |
| Essential oil plants   | 5.9                    |
| Fodder plants          | 13.7                   |
| Ornamental plants      | 12.7                   |
| Dye plants             | 5.3                    |
| Vitamin-bearing plants | 6.5                    |
| Tehnical plants        | 17.4                   |

**Table 10:** Plant tier classification and associated species in *H. lupulus* habitats.

| Plant tier | Associated species                                                                                                                                                                                                                                                                                                                   |
|------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| I          | <i>Ulmus pumila</i> L., <i>Ulmus laevis</i> Pall., <i>Ulmus parvifolia</i> L., <i>Salix starceana</i> L., <i>Acer saccharum</i> L.                                                                                                                                                                                                   |
| II         | <i>Rubus caesius</i> L., <i>Rubus idaeus</i> L., <i>Rubus vulgaris</i> L., <i>Trifolium pratense</i> L., <i>H. lupulus</i> L., <i>Cannabis ruderalis</i> L.                                                                                                                                                                          |
| III        | <i>Poa pratensis</i> L., <i>Phragmites australis</i> , <i>Agropyron repens</i> L., <i>Alopecurus pratensis</i> L., <i>Calamagrostis epigejos</i> L., <i>Taraxacum officinale</i> L., <i>Cichorium intybus</i> L., <i>Xanthium strumarium</i> L., <i>Arctium lappa</i> L., <i>Polygonum aviculare</i> L., <i>Atriplex tatarica</i> L. |

In these populations, various useful plant species are encountered, such as forage, medicinal, vitamin-rich, food, and technical plants used for fiber production, as well as ornamental species that provide aesthetic value to the ecosystems. These plants contribute to biological diversity and support the resilience of *H. lupulus* populations.

As shown by the calculations, the flora of the *H. lupulus* populations demonstrates varying levels of similarity. Using the Jaccard index (Fig. 8), the highest floristic similarity is observed between populations 1 and 2, which indicates similar ecosystems and comparable soil-climatic conditions in these populations. Populations 1 and 3 also show a high similarity (10.3%), further confirming their species likeness. On the other hand, populations 2 and 3 have the least similarity (6.1%), which may be related to differences in environmental conditions. The Jaccard index ranges from 0 to 1, with values close to 1 indicating greater floristic similarity. The floristic similarity among the surveyed populations ranges from 6.1% to 12.1%. The species composition similarity is shown in Table 11.

**Table 11:** The species composition similarity of diferent populations.

| Populations (Pops.) | Jaccard index (%) |
|---------------------|-------------------|
| Pops. 1 and 2       | 12.1              |
| Pops. 1 and 3       | 10.3              |
| Pops. 1 and 4       | 6.9               |
| Pops. 1 and 5       | 10.0              |
| Pops. 2 and 3       | 6.1               |
| Pops. 2 and 4       | 6.3               |
| Pops. 2 and 5       | 9.1               |
| Pops. 3 and 4       | 7.4               |
| Pops. 3 and 5       | 6.9               |
| Pops. 4 and 5       | 7.1               |

The lowest similarity is observed between the floras of the first and third, as well as the second and third *H. lupulus* populations. This is likely explained by the geographic distance between these populations and differences in soil-climatic conditions. Furthermore, the flora of the third population contains a significant number of species characteristic of other ecological zones, which also influences the degree of similarity with other populations.

### 3.4 Chemical characteristics of the analyzed soils

Soil, as a multifaceted system, has a significant ability to absorb and retain water, which plays a key role in providing plants with the necessary conditions for growth. Soil constantly maintains a certain level of moisture, which supports plant life and development. Water enters the soil from various sources, including precipitation, groundwater, condensation of atmospheric water vapors, and irrigation. This

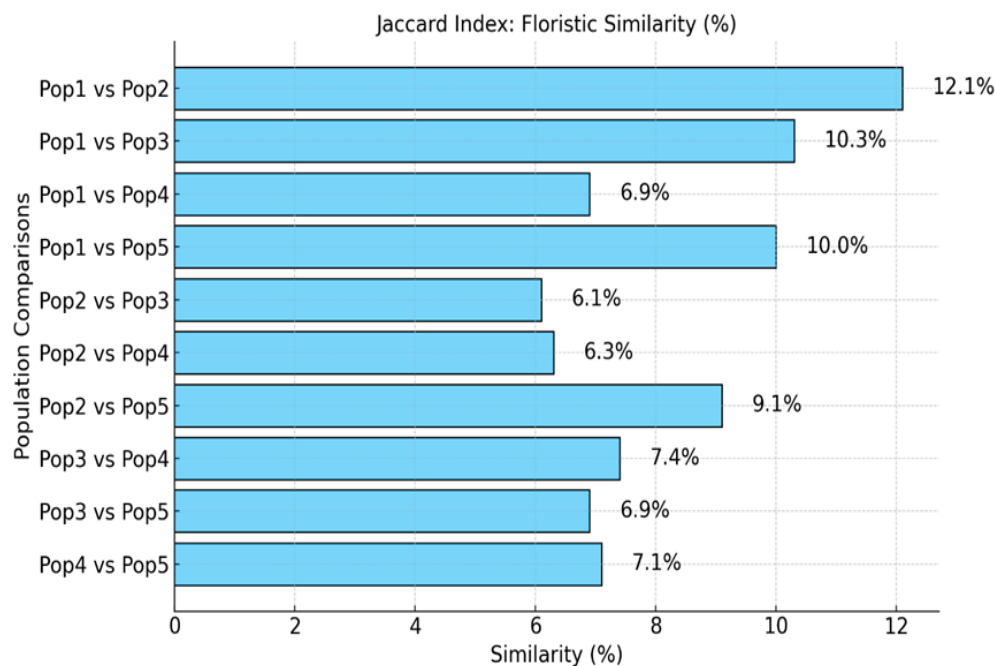


**Fig. 8:** Floristic similarity index of the studied *H. lupulus* populations, calculated using the Jaccard formula.

ability of soil to retain water is crucial for *H. lupulus* since it requires sufficient moisture for proper growth, especially during periods of active vegetative development.<sup>[54]</sup>

#### Population 1

Soil Type: typical serozem

The soil cover in the studied area is represented by serozem soils with a clayey mechanical composition.

Dark brown in color, rich in plant roots, with dry crusts and many small stones, slightly compacted with a clear boundary to the next horizon. The texture is granular with high moisture. Water permeability is average. The mechanical composition is medium clay (closer to heavy), forming a dense crust when irrigated. Nutrient content is low, so regular organic-mineral fertilization is necessary. In the soil degradation zone, there are meadow gray soils and meadow soils with heavy clay. A dense, cemented carbonate horizon is found at about one-meter depth and deeper. Saline and salty sections occur among these soils.

#### Population 2

Soil Type: meadow serozems are ordinary loamy

Morphogenetic characteristics of the soil in the second population area.

Gray with a dark brown tint, slightly compacted, weakly scaly, powdery, with no bubbling process observed, with a well-defined transition to the next layer. High moisture content and light clay texture.

These soils have a good structure characterized by layering and a fairly high organic matter content. The upper layer is dark in color and contains large amounts of organic substances, contributing to high fertility. The structure is loose and porous, which ensures good water exchange and aeration, positively affecting the root system development of plants.

#### Population 3

Soil Type: typical serozem

Morphogenetic characteristics of the soil in the third population area.

Grayish with a dark brown hue, slightly compacted, weakly scaly, powdery, and without observable bubbling. In the Enbekshikazakh district of Kazakhstan, typical gray soils are formed under ephemeral-rush vegetation on proluvial deposits. Soils are characterized by normal water permeability but form a dense crust on the surface when irrigated.

#### Population 4

Soil Type: serozem

Morphogenetic characteristics of the soil in the fourth population area.

Dark gray soil with a large amount of plant residues and loose microstructure. The soil is highly varied in color, with discolored patches standing out against the dark shade. The microstructure is denser, with a significant amount of fresh plant residues and considerably higher humus content.

#### Population 5

Soil Type: northern typical serozem

Morphogenetic characteristics of the soil in the fifth population area.

Gray-brown soil with vegetation, slightly moist, compacted, and of heavy clayey composition. Soils in the Alakol district are characterized by low humus content, which limits the availability of certain micronutrients, such as zinc and iron. These soils have a medium or fine-grained structure, good water permeability, and aeration, but they are susceptible to rapid moisture evaporation, requiring careful water management, especially in dry years.

Humus is the most important component of soil organic matter, playing a crucial role in the successful cultivation of hops. It not only improves the physical properties of the soil,

including its structure and moisture-holding capacity, but also provides essential nutrients such as nitrogen, phosphorus, and potassium to plants. Humus ensures a balanced nutrient supply to plants, promoting their stable growth and development. To achieve high hop yields, it is recommended to maintain stable humus content to improve root system activity and enhance nutrient bioavailability. Regular use of organic fertilizers can contribute to increased humus levels and improved soil quality.<sup>[55,56]</sup>

**Table 12:** Humus content.

| Population (Pop.) | Total Humus (%) |
|-------------------|-----------------|
| Pop. 1            | 1.46            |
| Pop. 2            | 2.88            |
| Pop. 3            | 2.99            |
| Pop. 4            | 3.45            |
| Pop. 5            | 2.68            |

The analysis revealed significant variation in humus levels among the soils of *H. lupulus* populations (Table 12). The humus proportion ranged from a minimum of 1.46% in Population 1 to a maximum of 3.45% in Population 4, with moderate values observed in populations 2, 3, and 5 (2.68%–2.99%).

This variation indicates diverse ecological conditions that could influence the growth and productivity of hops. The high

humus content in Population 4 highlights improved cultivation conditions, such as enhanced soil fertility, greater water-holding capacity, and better nutrient availability. On the other hand, population 1, with the lowest humus level, requires particular attention to improve soil quality, such as applying organic amendments or other fertility enhancement measures.

The optimal pH range for soil supporting the cultivation of *H. lupulus* lies between 5.7 and 7.5. Within this interval, plants can access essential nutrients in the most bioavailable forms, promoting healthy growth and development. Deviations from this range, whether toward more acidic or alkaline conditions, can lead to nutrient deficiencies or toxicities and indirectly contribute to the prevalence of plant diseases. The chemical properties of soils hosting populations of *H. lupulus* were analyzed, revealing significant variation, particularly in pH levels. This variation reflects the species' adaptability to diverse edaphic and ecological conditions, emphasizing its ecological plasticity and importance in preserving natural ecosystems (Fig. 9).

The study identified a soil pH range from neutral to strongly alkaline (7.60–8.75). The highest pH values were recorded in Population 5 (8.55), indicating its resilience to carbonate soils with elevated alkalinity. Populations 1, 2, and 3 exhibited similar pH values (8.53, 8.24, and 8.17, respectively), indicating their adaptation to moderately alkaline conditions. Conversely, the lowest pH values (7.60–7.69) were observed in Population 4, likely attributable to the geological characteristics of the region and higher organic matter content, which can influence soil acidity (Table 13).

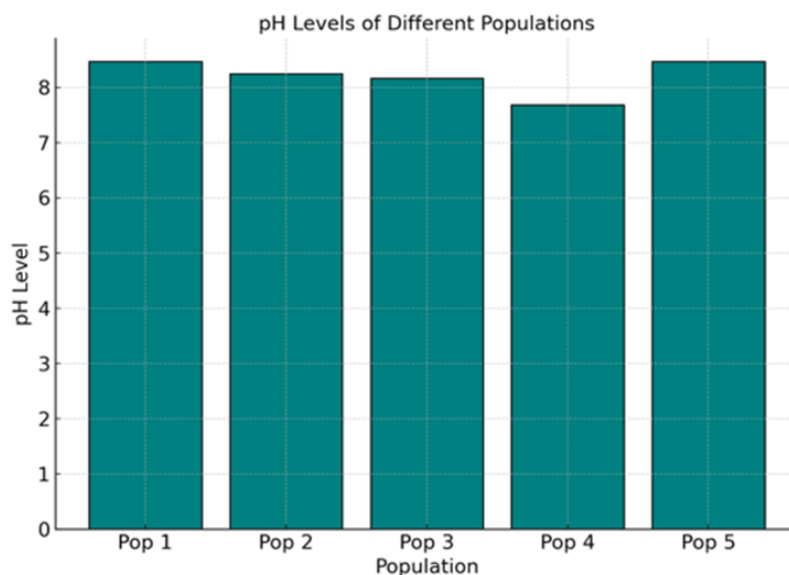


**Fig. 9:** Soil pH content.

Soil pH levels approaching or exceeding 7.6 to 8.7 fall outside the optimal range for *H. lupulus*, potentially compromising plant growth and vitality. High alkalinity reduces the availability of key micronutrients, including iron, manganese, zinc, and boron, often resulting in chlorosis (leaf yellowing) and stunted growth. To mitigate the effects of high

alkalinity, soil amendments such as sulfur or acidic organic materials, like peat, are recommended to adjust the pH. Regular soil testing is essential for addressing imbalances promptly and maintaining plant productivity. These findings highlight the capacity of *H. lupulus* to tolerate a wide spectrum of soil and climatic conditions, making it a promising crop for

cultivation in regions with variable soil composition. However, neutral to slightly alkaline soils rich in organic matter provide the most favorable conditions for growth.

*H. lupulus* is a high-yield crop that produces significant biomass, including shoots, leaves, and cones. Its successful cultivation depends on balanced nutrient availability, ensuring that the plants receive adequate levels of macro- and micronutrients. Often, deficiencies or excesses in specific nutrients fail to meet the plant's physiological needs, affecting growth and productivity. Optimal nutrient management plays a crucial role in supporting plant health and achieving high yields.<sup>[57,58]</sup>

The chemical composition of soils across the *H. lupulus* populations showed substantial variability in nutrient content. Phosphorus concentrations ranged from 26 to 162 mg/kg, potassium from 270 to 430 mg/kg, zinc from 3.80 to 57.3 mg/kg, manganese from 89.0 to 171.8 mg/kg, and boron from 4.16 to 15.68 mg/kg. Such differences underscore the plant's adaptive plasticity, allowing it to thrive in a variety of soil conditions. However, deficiencies in certain nutrients, such as zinc in population 1 (3.80 mg/kg) and boron in population 2 (4.16 mg/kg), highlight the need for agrochemical interventions to optimize nutrient availability.

Phosphorus and potassium levels also require regulation, particularly in excessive concentrations. For example, population 4 exhibited the highest phosphorus levels (162 mg/kg), while population 3 recorded elevated potassium levels (430 mg/kg). Such imbalances may reduce nutrient efficiency due to antagonistic interactions among soil nutrients. Regular soil assessments and tailored fertilization strategies are vital for mitigating these imbalances and improving the yield and quality of *H. lupulus*.

Key macronutrients essential for *H. lupulus* include phosphorus, potassium, and magnesium. Their requirements vary throughout the growth cycle. Phosphorus, for instance, is

crucial for root development during early spring, while potassium becomes critical during vegetative growth for leaf and cone formation. Deficiencies manifest as visible symptoms; potassium deficiency, for example, results in leaf discoloration and marginal browning resembling burn damage, whereas phosphorus deficiency is characterized by small, dark green leaves with brownish tones.

Micronutrients such as zinc and boron also play vital roles in the healthy development of *H. lupulus*. Elevated soil pH, often associated with excessive phosphate content, can exacerbate zinc deficiency by reducing its bioavailability. This deficiency commonly manifests as stunted growth and diminished overall vigor, making zinc an essential focus in high-pH soils. Addressing the delicate balance between macro- and micronutrient levels, particularly considering soil chemical properties and the demands of specific growth stages, is crucial for maximizing the growth potential of *H. lupulus*.

Table 13 presents the concentration of bioavailable nutrients in the soils studied, illustrating significant differences in phosphorus, potassium, and essential trace elements like boron and zinc. Soils in the first and second populations exhibit low levels of zinc and boron, which could limit hop growth during the early stages of development. Conversely, the third and fourth populations are characterized by the highest concentrations of micronutrients, making their soils more nutrient-rich and supportive of the plant during active growth phases. In population 5, a decrease in the content of most elements, particularly potassium, was observed, potentially undermining plant resilience. Regular soil monitoring, micronutrient analysis, and environmental condition adjustments are essential to provide hops with adequate nutrients. This integrated cultivation approach, considering both soil chemical composition and environmental factors, helps minimize stress impacts and fosters the development of resilient, high-yielding populations.

**Table 13:** Available forms of soil nutrients.

| Population | Phosphorus<br>(mg/kg) | Potassium<br>(mg/kg) | Zinc<br>(mg/kg) | Manganese<br>(mg/kg) | Boron<br>(mg/kg) |
|------------|-----------------------|----------------------|-----------------|----------------------|------------------|
| Pop. 1     | 37                    | 350                  | 3.80            | 89.0                 | 5.35             |
| Pop. 2     | 26                    | 360                  | 5.40            | 171.8                | 4.16             |
| Pop. 3     | 126                   | 430                  | 29.0            | 154.6                | 15.68            |
| Pop. 4     | 162                   | 370                  | 57.3            | 115.2                | 14.87            |
| Pop. 5     | 26                    | 270                  | 7.40            | 129.9                | 6.69             |

#### 4. Conclusions and perspectives

The research results identified five main populations of *H. lupulus*, each distinguished by unique phytocoenotic and ecological conditions. The Jaccard Index was employed to quantitatively assess the degree of floristic similarity among

*H. lupulus* populations based on their species composition. Analysis of the five populations revealed significant variations in floristic commonality levels, influenced by soil-climatic features and geographical location. The highest similarity index (12.1%) was observed between populations 1 and 2, as

well as between populations 1 and 3, indicating similar environmental conditions in these areas. Conversely, the lowest similarity (6.1%) was recorded between populations 2 and 3, reflecting divergent habitat conditions and localized plant adaptations. These findings confirm the substantial influence of environmental factors on floristic diversity and the degree of ecosystem similarity among the populations.

The abundance of species within the phytocoenoses was evaluated using Drude's abundance scale, providing a detailed analysis of the floristic diversity of *H. lupulus* populations in Almaty and neighboring regions. The data indicate that floristic similarity between populations of hops ranges from 6.1% to 12.1%, highlighting variations in vegetation and environmental impacts. Common hops, owing to their vegetative reproduction, form dense clonal groups that facilitate their expansion across various ecosystems, including those dominated by families such as Poaceae, Asteraceae, Fabaceae, and Rosaceae. Additionally, Drude's scale demonstrated a high level of synanthropization (up to 35%) in certain areas, such as Talgar and Sarkan, underscoring significant anthropogenic influences. These effects can either stimulate or constrain the growth of hop populations, particularly in agricultural lands where hops compete with cultivated crops. Thus, applying Drude's abundance scale allows for an assessment of floristic diversity and natural and anthropogenic impacts on vegetation structure, improving our understanding of the mechanisms governing the spread of this plant across different ecosystems.

Research into *H. lupulus* populations in five regions of southeastern Kazakhstan involved transects to determine the age structure of individuals. Distinct age groups were identified in each population: juvenile, immature, virginile, and generative individuals. This facilitated a scientifically grounded assessment of the populations' health in each region. The findings revealed that vegetative reproduction through rhizomes was the primary reproductive mechanism in all five populations, leading to dense clonal groups. However, seed-based reproduction, albeit limited, also plays a role.

Natural soil conditions were analyzed in Almaty City, Talgar, Enbekshikazakh, Sarkan, and Alakol districts of the Almaty region. The study identified the morphological characteristics and types of soils in each area. For instance, Almaty city soils were classified as ordinary gray soils, Talgar soils as ordinary meadow gray loamy soils, Enbekshikazakh soils as ordinary gray soils, Sarkan soils as gray soils, and Alakol soils as northern gray soils. Additionally, humus content in these soils was measured, ranging from low to high levels depending on the population. The elemental composition of hop soils revealed significant differences in levels of phosphorus, potassium, zinc, manganese, and boron, emphasizing the species' resilience to diverse ecological settings.

The study highlights a link between soil nutrient balance and the vitality of *H. lupulus* populations, where nutrient concentration directly influences growth and development.

Populations 3 and 4 demonstrated optimal growth conditions attributed to high levels of phosphorus, potassium, and zinc, which are crucial for photosynthesis, stress resistance, and root system development. Elevated levels of these nutrients promote intensive growth, better metabolism, and enhanced generative activity, leading to higher proportions of mature individuals and increased overall population size. These populations exemplify *H. lupulus* adaptation to favorable soil conditions. Conversely, reduced growth was observed primarily in population 1, where deficiencies in essential elements such as zinc and potassium slowed metabolic processes and hindered development. This slower growth adversely affected the distribution and reproduction of hops, as reflected in the lower numbers of mature individuals. A similar trend was seen in population 2, which exhibited potassium and micronutrient deficiencies despite relatively normal phosphorus levels. As soil composition declined further, growth inhibition became more pronounced, as evidenced in population 5, where boron and potassium deficiencies significantly affected hop productivity. In this population, reduced photosynthetic activity and fewer mature individuals were observed.

These findings highlight that the correlation between soil micro- and macronutrient levels and the condition of *H. lupulus* populations demonstrates that deficiencies in key nutrients phosphorus, potassium, zinc, and boron - lead to significantly slowed growth and reduced numbers of healthy individuals. Populations in soils with balanced nutrient composition, such as populations 3 and 4, exhibit higher productivity and generative activity, reinforcing the notion that optimal soil conditions enhance development and stability. The study underscores the importance of conserving natural hop populations and managing soil resources sustainably. The results are applicable to developing agricultural strategies and conservation efforts to maintain biodiversity.

The study revealed that humus levels and soil pH significantly impact plant community composition and the productivity of *H. lupulus* populations. The highest number of mature and generative individuals was observed in populations 3 and 4, where humus content ranged from 2.5% to 4.2%, and soil pH varied between 6.5 and 7.2, indicating a slightly alkaline to neutral environment. These conditions promoted optimal root development, sufficient moisture retention, and adequate aeration, facilitating vigorous vegetative growth and high generative activity in hops.

In contrast, population 1 exhibited low humus content (below 2%) and a pH below 6.0, negatively affecting plant growth. Acidic conditions contributed to the leaching of essential nutrients such as potassium, calcium, and magnesium, hindering growth rates and increasing competition pressure from other plant species. A similar trend was observed in population 5, where humus levels were 1.8%, and soil pH was approximately 5.8. The deficiency of organic matter and elevated acidity limited the capacity for vegetative propagation, reducing the number of mature individuals. Thus,

the optimal balance of humus content and soil pH plays a crucial role in maintaining stable *H. lupulus* populations. Soils with moderate humus levels and a neutral pH provide essential macro- and micronutrients, supporting sustained growth, active reproduction, and successful population expansion of hops.

In conclusion, *H. lupulus* represents a valuable resource for the national economy but also a key element of ecosystems with high adaptive potential and relevance for ecological and geobotanical studies. Therefore, conducting phytochemical analyses to assess the effects of these factors on the concentration of biologically active compounds in the plant is essential for improving cultivation methods in the context of contemporary environmental changes.

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### Conflict of Interest

There is no conflict of interest.

### Supporting Information

Not applicable.

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