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ORIGINAL ARTICLE

Impact of elevation and slope exposure on abundance of rare medicinal plant *Rhaponticum carthamoides* (Maral root)

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Rhaponticun carthamoides (Willd.) Iljin is a rare medicinal plant listed in the Red List of the Russian Federation. Spatial patterns of its reserves were studied for the monitoring and protection of wild populations at the Kuznetsk Alatau. The dependence of population abundance on environmental factors was revealed by geobotanical profiles. We derived the equation of nonlinear regression for rapid method of determining the weight of subsurface parts by counting the number of shoots. To assess rapidly and monitor the natural reserves we developed a mathematical model describing the abundance of *R. carthamoides* and its habitat altitude.
Key words: *Rhaponticun carthamoides*, conservation, environmental factors, abundance

Introduction

The exploitation of medicinal plant populations in wild without observing the mode of sustainable use is one of the threats to biodiversity (Schippmann, 1997, Schippmann et al. 2002). The information on natural resources and their spatial distribution is essential to protect rare medicinal species (Peters, 1996; On et al., 2001; Ghimire et al., 2005; Russell-Smith et al., 2006; Gaikwada et al., 2011; Rokaya et al., 2012).

Rhaponticum carthamoides (Willd.) Iljin (*Leuzea carthamoides* DC.), Maral root (Asteraceae) is the brand medicinal plant listed in the Red List of the Russian Federation. This species has a unique chemical composition and biological activity (Todorov et al. 2000; Plotnikov et al., 2008; Biskup & Lojkowska, 2009; Kokoska & Janovska, 2009; Gorelick-Feldman et al., 2010; Skopińska-Rózewska et al., 2010; Jurkštienė et al., 2011; Baranova et al., 2013) and the demand for its raw materials increases annually (Smelansky et al., 2009; Nekratova & Shurupova, 2014, 2015). Woody rhizomes and roots are gathered as raw materials of *R. carthamoides*, so its individuals die when harvesting. According to the classification of D. Rabinowitz (1981), this species is rare because it has a narrow geographic range bounded by the mountains of Southern Siberia, grows in specific habitats (subalpine meadows) and can form abundant populations. Although the resources of this species are quite large (Nekratova & Shurupova, 2014, 2016), massive poaching harvestings and depletion of wild populations gave rise to the inclusion of *R. carthamoides* in the Red List of the Russian Federation (Red Book…, 2008) and regional Red Lists (Red Book…, 2002, 2007, 2012). This species has been assigned the conservation category which has no analogues in the international conservation practice (IUCN, 2012) - "a rare species with resource value". This category allows the use of wild populations for industrial harvestings in certain regions.

Today the collection of the raw material of this species is prohibited only in the Kuznetsk Alatau representing only a small part of its range. However, the Red List did not become an obstacle for mass gathering even there due the lack of special controls for wildlife (Nekratova & Shurupova, 2015). It is obvious that as long as there is no way a directive to enforce the mode of sustainable use at the state level, the *R. carthamoides* must not be subjected to industrial harvesting of raw materials because it leads to destruction of strategically important natural resource. At present, two alternative ways of obtaining raw materials of this species are the cultivation in plantations (Skiba & Weglarz, 2000; Geszprych & Węglarz, 2002; Dzhurmanski, 2011) and the production of plant raw materials through tissue culture in vitro (Yuan et al, 2009; Zand et al., 2014; Skała et al., 2015). Wild resources of *R. carthamoides* should be regarded as sacrosanct strategic reserve and can only be used for collection of the propagation material (seed) and the needs of the local population.

The aim of our study is to identify the best habitat of *R. carthamoides* in terms of environmental factors where it forms abundant populations. Such are particularly valuable and in need of monitoring and protection. Based on the data of geobotanic profiles we analysed the influence of five environmental factors on the abundance of *R. carthamoides* among which were found determining. The model of the influence of the most important factor (altitude) to the number of aerial shoots of this species was developed. We have built the regression model linking the number of shoots with the weight of subsurface parts. This model is created for accurate determination of the potential reserves of raw materials by express method (without digging).

Materials and methods

We studied ecological features of *R. carthamoides* in the Kuznetsk Alatau (Kemerovo region, the Republic of Khakassia) selected as a key area. This system of medium-high mountain ranges is located in the north-west of the Altai-Sayan Mountains and occupies about 38,000 km^2. To assess the impact of environmental factors on the abundance of *R. carthamoides* we laid 31 geobotanical profiles with total length of 41,800 m in different years. In order to reflect how the spatial patterns of *R. carthamoides* depend on the altitudinal zones, we made profiles through the valley of the rivers in the upper reaches and on the mountain slopes. The density i.e. the number of vegetative and generative shoots per 1 m^2 has been accepted as an abundance indicator. We counted shoots on linear transects with area of 2×10 m^2 throughout the length of the profile and calculated the number of aerial shoots per 1 m^2. We composed a relevé in each transect and recorded values of environmental factors (altitude, exposure and steepness of the slope, the presence of large-rocky substrate, and anthropogenic load), then counted the number of shoots. To determine the weight of the subsurface parts attributable to one shoot we laid 42 sample plots in different regions of the Kuznetsk Alatau where transects of varying length were laid, and the number of shoots was calculated to 1 m^2. We recorded the number of aerial shoots at each counting area, then dug up all the subsurface parts of *R. carthamoides*, weighed and calculated the weight of subsurface parts per 1 aerial shoot. Their shrinkage factor of Maral root's rhizomes and roots is 2.6 ± 0.1 (Nekratova & Shurupova, 2016). The weight of the subsurface parts is given to air-dry raw materials.

We evaluated the influence of environmental factors on the abundance of species based on the classical approach (Ramensky, 1930; Walter, 1960; Ellenberg, 1988). The principal methodological difference from the classical scheme of geobotanical data analysis was a rejection of ecological scales (Zazenkin, 1967) by the absolute values of environmental factors: altitude, exposure and steepness of slopes. Since the change of these values is reflected in the large-scale topographic maps, they associate abundance of species with a specific mountain area and get a more accurate picture of the spatial distribution of resources. In addition, we analysed the impact of large-rocky substrate and anthropogenic impact (grazing, billets, and mining). We analysed also an abundance of *R. carthamoides* in different types of vegetation. Based on data of 520 relevés made in the Altai-Sayan mountain region, we identified seven groups of fragments in *R. carthamoides* communities: subalpine meadows on the automorphic soils getting humidity from precipitation, subalpine meadows on hydromorphic soils getting humidity due to precipitation and groundwater (Sedelnikov, 1988), the alpine meadows, forest meadows, woodlands, thickets of shrubs, and tundra. To assess the impact of environmental factors on the abundance of *R. carthamoides* we calculated average (absolute) density, or the number of aerial shoots per 1 m^2 of the entire profile.

Statistical analysis was performed using Statistica v. 7.0 software. We used the discriminant analysis to identify the main factors that determine the value of the number of shoots per 1 m^2. We evaluated a statistical significance of the influence of particular environmental factors on the number of shoots normalized to the square plots using Kruskal-Wallis test. Statistical significance of differences between two independent samples was evaluated using the nonparametric Wald-Wolfowitz test. We assessed species and functional relationships of parameters between the studied traits by the "non-linear regression" (Rosenbrock and quasi-Newton methods). The degree of compliance with selected models of experimental data was evaluated by the value of the coefficient of determination R^2. We used the median as an average for the studied populations. The variation in the total sample is expressed through the variation range calculated after eliminating outliers.

Results and discussion

Altitude and exposure of the slope are two main factors that determine the density of *R. carthamoides* populations (Fig. 1). It is a reflection of the well-known pattern: these 2 complex factors due to the different conditions of temperature and moisture mode of habitats influence the formation of vegetation in mountain areas.

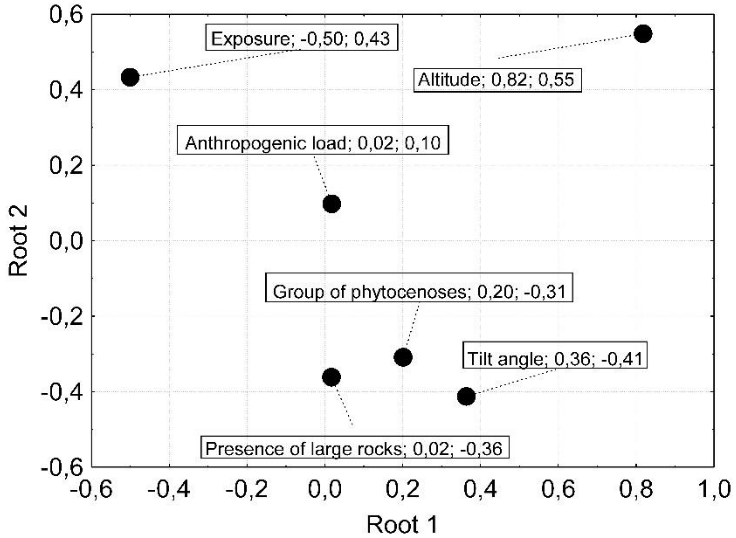

Fig. 1. Influence of environmental factors and plant communities on *R. carthamoides* average density

R. carthamoides was registered at altitudes of 800-1550 m while the highest occurrence observed in the range of 1100-1400 m a.s.l. (Fig. 2). There is a subalpine belt at these altitudes in the Kuznetsk Alatau where *R. carthamoides* is a characteristic species. The average population density varies greatly on the slopes of different exposures ($p<0.0001$) (Fig. 3). According to the number of shoots per 1 m^2 registered on slopes with different exposure populations of *R. carthamoides* are divided into 4 groups. The most favourable for the species is the northeastern, southeastern and western slopes where the number of aerial shoots averages 2.4-4.3 per 1 m^2. Populations on the eastern, northwestern, and southern slopes occupy an intermediate position with the 1-1.3 shoots per 1 m^2. The average shoots density is 0.3 per 1 m^2 in the south-western slopes, whereas *R. carthamoides* has not been ever registered on the northern slopes.

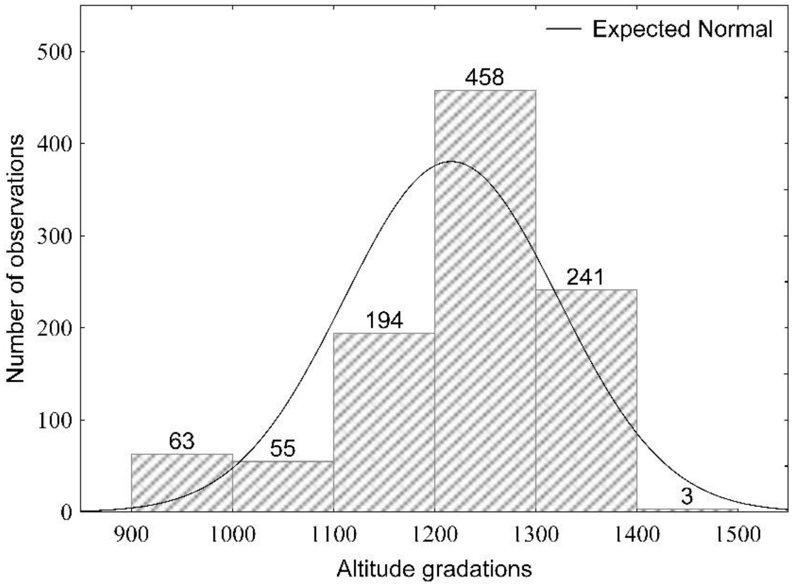

Fig. 2. Frequency of *R. carthamoides* occurrence at different altitudes

According to the scale of Walter (1960), the average density of *R. carthamoides* equals or exceeds 1 per 1 m^2 on medium-warmed slopes. The most and least warmed the slopes (south and north) are not suitable for this species. The absence of a direct dependence of the density of *R. carthamoides* from the radiation balance in the intermediate range between the southern and northern exposure is explained by mosaic of macrorelief.

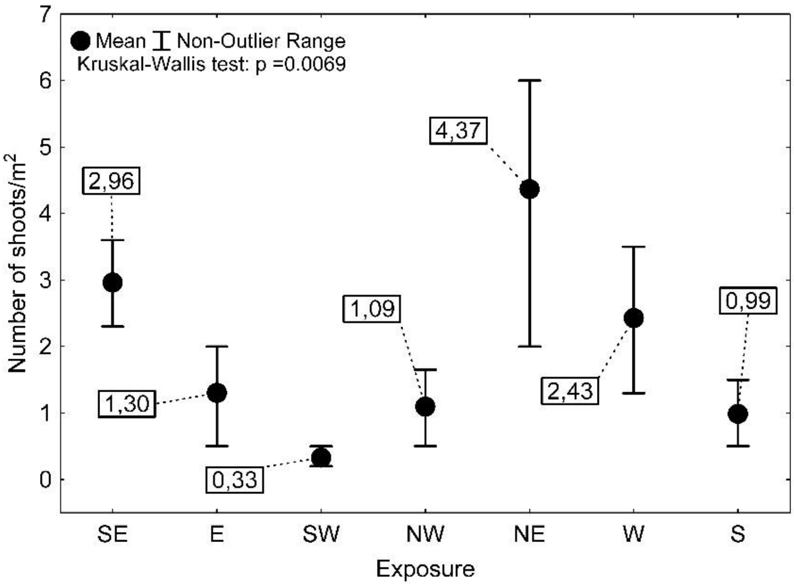

Fig. 3. Dependence of the abundance of *R. carthamoides* populations on slope exposures. Exposure: SE – South-East, E – East, SW – South-West, NW – North-West, NE – North-East, W – West, S – South.

The frequency of occurrence and abundance of *R. carthamoides* depend on the steepness of the slopes (Fig. 4). This species is more common in the sloping habitats (4-10 °), and the number of shoots in the population ups to 40 per m^2 with the largest frequency of occurrence registered with a slope equal to 5 °. *R. carthamoides* grows in the Kuznetsk Alatau mostly in middle mountainous areas where the landforms are represented by ancient planation surfaces: the Spassky Mountains, the Sargaya ridge, the upper reaches of the Pihterek. The frequency of occurrence and population density of this species decrease on the steeper slopes. *R. carthamoides* grows very rarely both on steep (more than 30 °) and very gentle slopes (less than 3°).

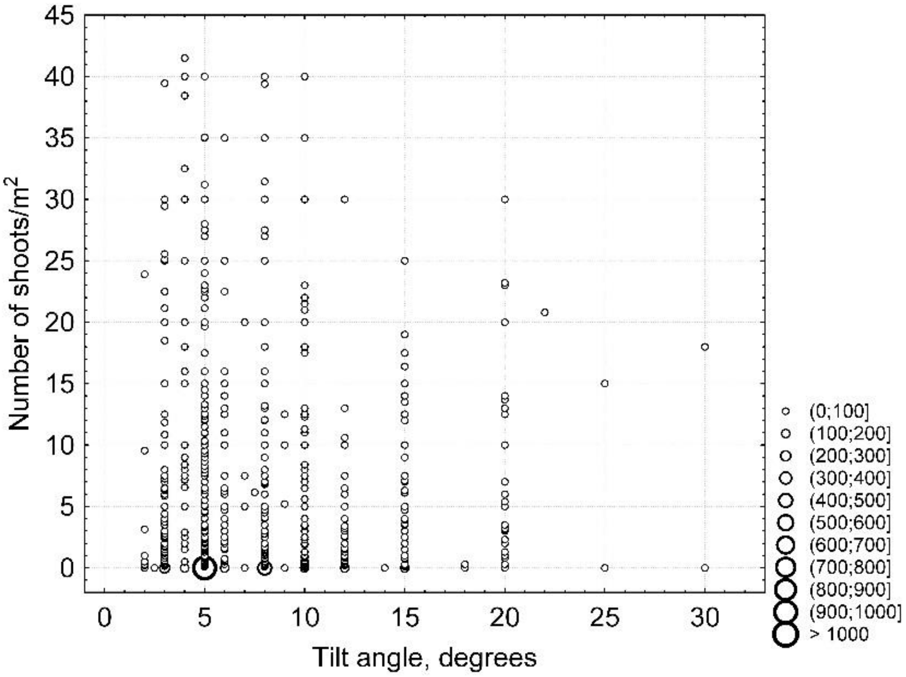

Fig. 4. Occurrence and abundance of *R. carthamoides* at slopes with different steepness

R. carthamoides prefers subalpine meadow soil so the average density of its populations is substantially limited by the large-rocky substrate represented by clastic rock material (Fig. 5). The number of shoots per 1 m^2 while growing on the large-rocky substrate ceteris paribus on average is less than about 2 times. Probably, *R. carthamoides* loses benefits over competing with him subalpine species (*Saussurea frolowii* Ledeb., *S. latifolia* Ledeb. et al.) in such habitats as large stones to limit the opportunities for growing roots in the territory by vegetative propagation.

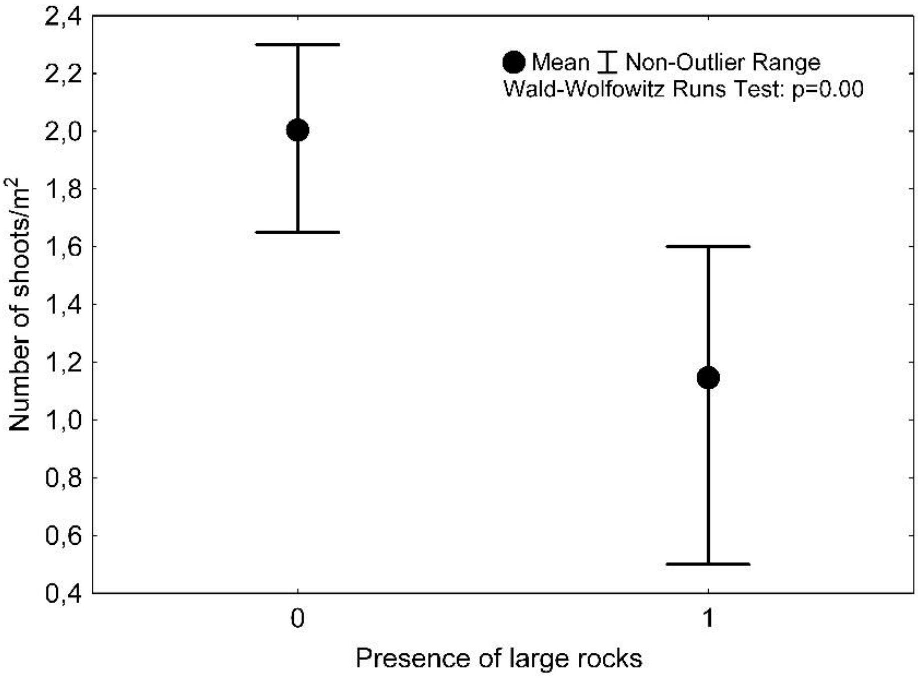

Fig. 5. Abundance of *R. carthamoides* in habitats with absence (0) and presence (1) of large-rocky substrate

The anthropogenic load almost has not an effect on the average density of *R. carthamoides* however significantly affects the scope and sample dispersion indicating the heterogeneity of the stress factor. Populations of *R. carthamoides* are restored after a weak human impact (periodic grazing, gentle harvesting) thanks to the ability of vegetative propagation and high seed production. This contributes to the weakening of competing species which *R. carthamoides* ahead successfully in such cases due the speed of reproduction. However, a strong anthropogenic load (regular grazing, industrial harvesting, road construction, and mining operations) leads to decrease in abundance (Fig. 6). As a rule this plant disappears completely in localities where grazing and industrial harvesting affect together.

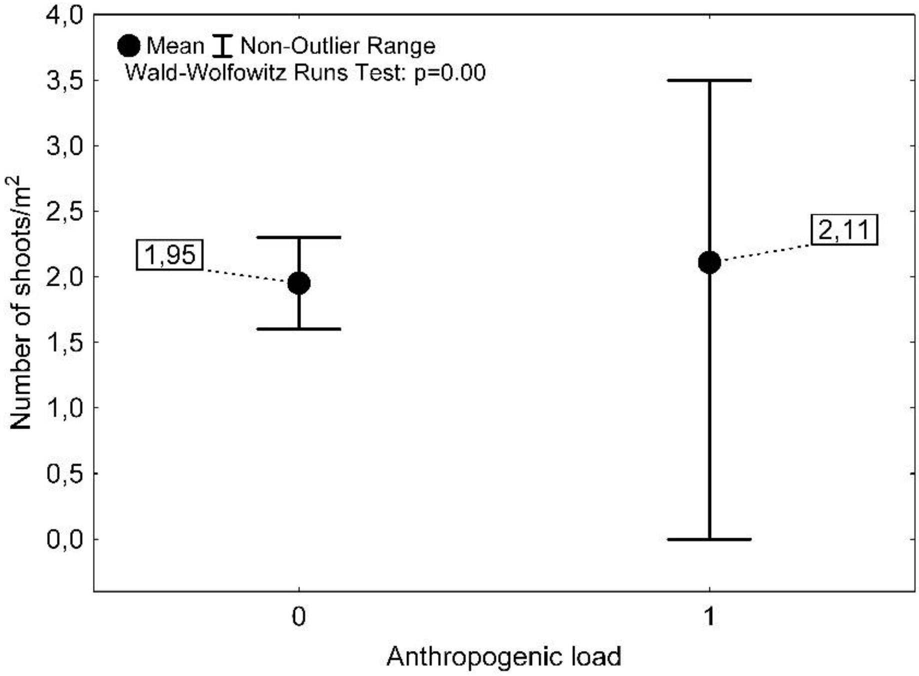

Fig. 6. Abundance of *R.* in habitats with absence (0) and presence (1) of anthropogenic load

The abundance of *R. carthamoides* varies considerably depending on the type of plant communities. Four groups of phytocenoses can be identified according to the number of shoots per 1 m^2 (Fig. 7). The highest abundance is observed in the subalpine meadows on automorphic soils in which *R. carthamoides* dominates or is an edificator. The number of shoots is almost 3 times less in the subalpine meadows on hydromorphic soils. Here it gives leading positions in the community to moisture-loving species: *Deschampsia caespitosa* (L.) Beauv., *Veratrum lobelianum* Bernh., *Bistorta officinalis* Delarbre, *Euphorbia pilosa* L., *Carex aterrima* Hoppe, *Geranium albiflorum* Ledeb. and others. The alpine meadows are characterised by low abundance of *R. carthamoides*, and it is somewhat higher in forest meadows, woodlands and thickets of shrubs due to the similarity of these habitats to the subalpine meadows on the moisture factor. *R. carthamoides*' populations grow on the border of the ecological niche and feel oppressed in the wastelands and tundras.

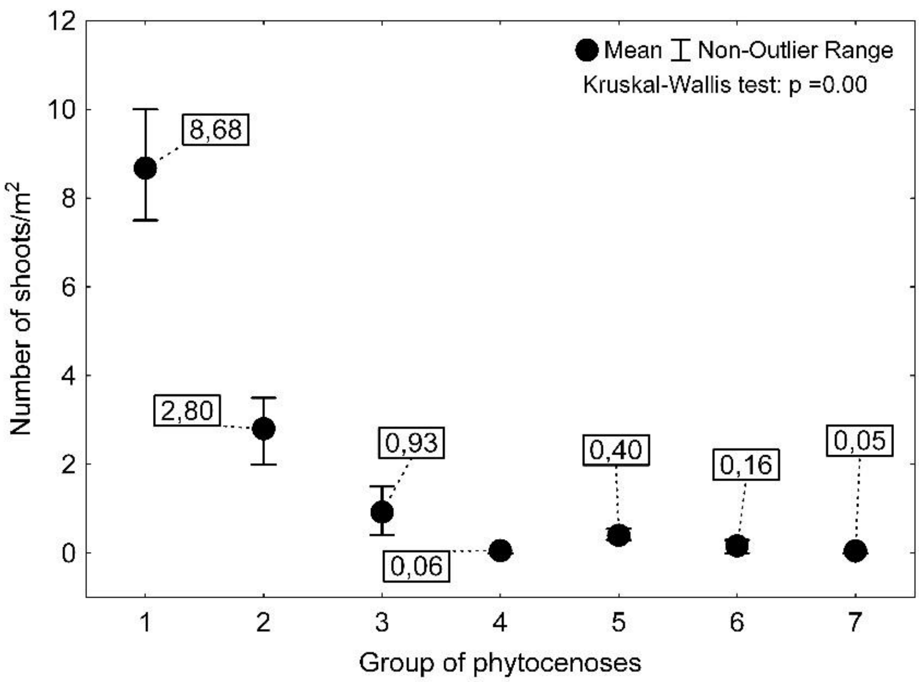

Fig. 7. Abundance of *R. carthamoides* in different plant communities. 1 – subalpine meadows on automorphic soils, 2 – subalpine meadows on hydromorphic soils, 3 – alpine meadows, 4 – forest meadows, 5 – rare forests, 6 – shrubs, 7 – tundras.

Rapid resource assessment is based on the values of the area occupied by plant population and the weight of raw materials (subsurface parts in the case of *R. carthamoides*). The inversely exponential dependence exists between the number of shoots per 1 m^2 and the weight of roots and rhizomes (Fig. 8).

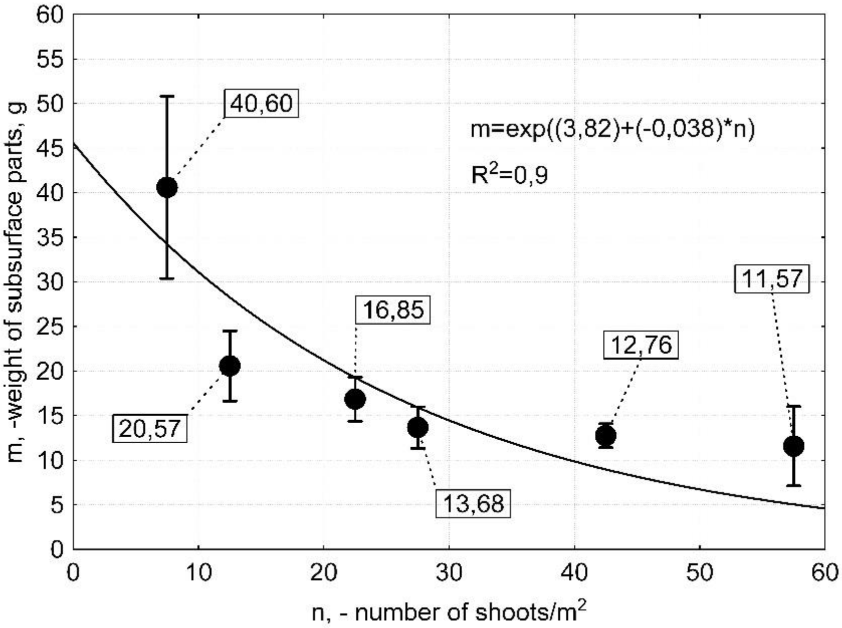

Fig. 8. Dependence of *R. carthamoides* subsurface parts weight on density

We created the model describing the dependence of the average density of *R. carthamoides*' populations on the altitude above sea for zone with its frequent occurrence (Fig. 9). The most abundant populations are concentrated in the range of 1300-1400 m above sea level.

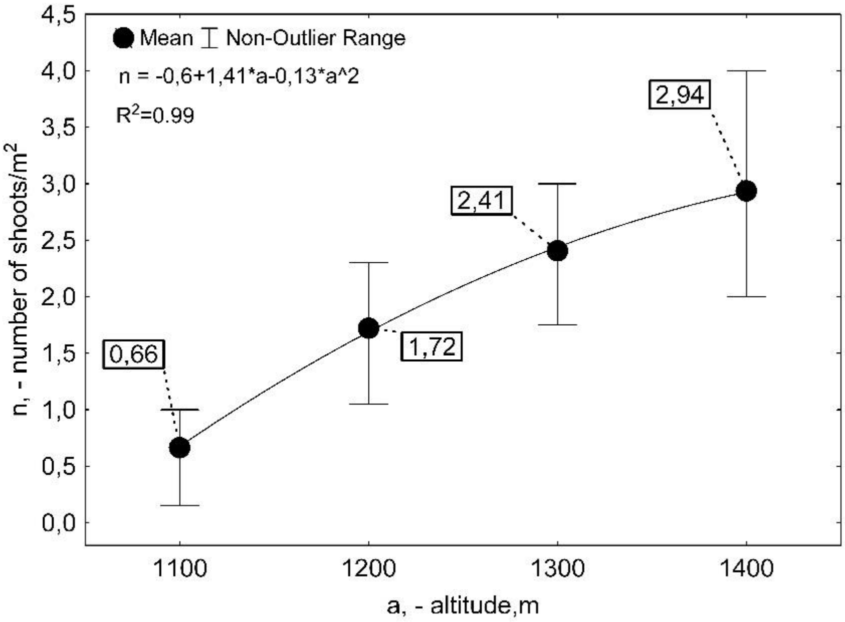

Fig. 9. Dependence of *R. carthamoides* abundance on altitude

Conclusion

The spatial distribution of *R. carthamoides* populations and their abundance are associated with some environmental factors among which the most important are the altitude and the exposure of the slope. These factors can be surveyed with remote GIS techniques, which further enable to simulate patterns of strategic resources of valuable medicinal species. Abundance-weight dependence model of resources is an important tool to assess reserves. Such studies, in the first place, should be carried out for the most valuable and rare medicinal plants. They are the basis for monitoring and quantitative assessment of resources, effective organization of the protection and creation of conditions for the recovery of populations in wild.

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