Some Characteristics of the Waybread (*Plantago major* L.) During its Settlement in a High-Altitude Area

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Abstract. The aim of this work is to study some characteristics of the waybread (*Plantago major* L.) during its settlement on the anthropogenically disturbed territories of the highlands. The studied traits were: plant height, number of inflorescences per individual, number of seeds per inflorescence, seed mass, percentage germination and germination rate. The studies were conducted in 2013, 2014 and 2018 at altitudes of 200, 600, 2050 and 2700 m above sea level on the territory of the Kabardino-Balkarian Republic (Central Caucasus). It was revealed that on the territory of the National Park "Priel`brus`e" there is an invasion of P. major on the territories disturbed by the construction of cable cars, located at altitudes (2700 m). During this invasion a number of characteristics of this species have changed under the influence of extreme conditions of the highlands. The plants height decreases, the mass of seeds increases and their germination percentage increases according to altitude gradient.

1 Introduction

The National Park "Priel`brus`e" (NP) was formed in 1986. It is one of the highest mountain parks in Russia and Europe. The territory of the park is located on the northern slopes of the Greater Caucasus in its central part (Central Caucasus) at altitudes of 2000 – 5000 m above sea level. The most developed part of the NP is the Southern Elbrus region, where intensive construction of a large tourist cluster with hotels, cafes and cable cars is underway. As a result, the size and altitude of anthropogenically disturbed territories, which are favorite places of alien species invasion, increases. The number of tourists is increasing annually, and by 2022 it amounted to 1.2 million.

The history of studying the effect of highland conditions on plants has been going on for more than a hundred years. Considerable attention was paid to the study of species diversity in mountainous areas and the reasons for this diversity [1-4]. To date, a number of morphological, anatomical and physiological traits inherent in the plants of the highlands have been established. It was revealed that according of elevation there is a decrease in the

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height and biomass of the aboveground part of plants [5,6]. In these plants, in addition to reducing the height of plants, the leaf surface area significantly decreases, but the number of leaves per individual does not change [7,8]. With increasing altitude above sea level, the size of the flowers does not change, but the duration of flowering of individual flowers increases [9-11].

The aim of this work is to study some characteristics of the waybread (P.major) during its settlement on the anthropogenically disturbed territories of the highlands.

2 Research Methodology

The investigation of the morphological traits of waybread (P. major) was carried out in 2013, 2014 and 2018 at altitudes of 200, 600, 2050 and 2700 m above sea level on the territory of the Kabardino-Balkarian Republic (Central Caucasus). This species is widely distributed on the plain, lowlands and highlands up to a height of 2000 m, which are its natural habitats. Two stages of cable cars were built on Cheget to a height of 2700 m in 1963 and 1969. In 1966, another stage of the cable car was built up to a height of 3050 m. Following the man, representatives of this species rose to a height of 2700 m. Currently, they have settled in the disturbed areas around the cable car stations. The population area is approximately 20000 m^2. The sampling points are shown in Figure 1.

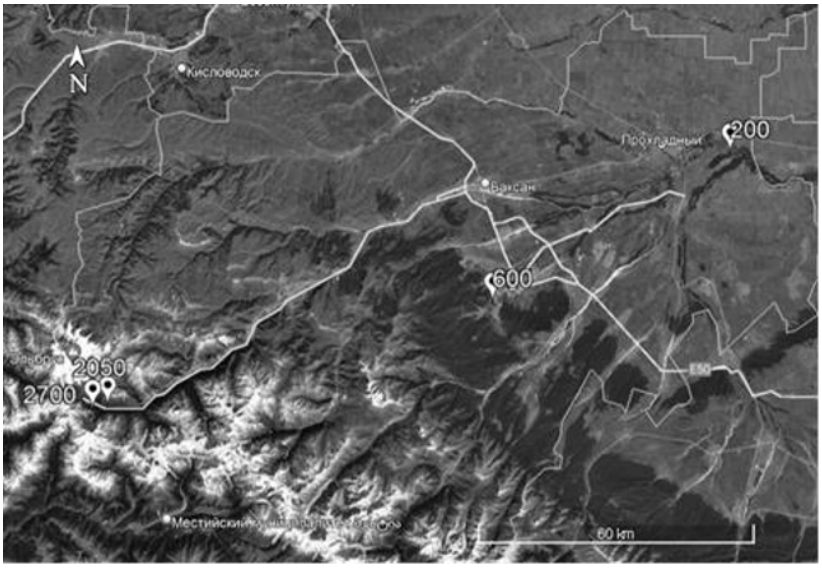

Fig. 1. Location of the sampling points

At least 30 plants were examined for each altitude. The plant height and the number of inflorescences per individual were calculated on the sampling points. One inflorescence was taken from each individual to count the number of seeds per inflorescence and placed them in labeled paper bags. To determine the seed mass, germination percentage and germination rate (GR), seeds were collected from at least 50 plants for each altitude and air dried at room temperature.

To determine the seed mass, germination percentage and germination rate (GR), the shelf life of seeds for all altitudes was the same and was one to two months. To determine the mass of seeds for each altitude, 1000 mature seeds of approximately the same size were counted and weighed on analytical scales. To determine germination percentage and germination rate, 100 seeds were germinated in Petri dishes on wet filter paper for 10 days.

The germination rate was defined as the average germination period of one seed. Measurements were carried out in five repetitions for each altitude.

All procedures related to the processing the collected data, as well as subsequent statistical analysis, were performed using the software package MicrosoftExcel XP (MicrosoftCorp., USA) and the integrated statistical software package STATISTICA 10.0 (StatSoftInc., USA). According to the results of the data distribution it was concluded that only the indicators of seed mass and germination percentage correspond to the criteria for the normal distribution of data. The remaining parameters do not correspond to the normal distribution and therefore were analyzed by nonparametric methods.

3 Results and Discussions

An assessment of the change in a number of traits of P. major in accordance with the altitude gradient was carried out. The initial task of the analysis is to evaluate descriptive statistics, in other words, the main parameters used in data research. This type of analysis is intended for the collection and processing of empirical materials with their further systematization, refinement of the results obtained. As a rule, descriptive statistics are evaluated for each of the studied parameters for the entire set of collected data, and then the indicators of interest are divided into certain groups and analyzed separately.

The following parameters were considered as the studied parameters: plant height (cm), number of inflorescences per individual, number of seeds per inflorescence, mass of 1000 seeds (g), total seed germination (%) and germination rate (day). All the obtained results of descriptive statistics are shown in Table 1.

Table 1. The results of calculation of descriptive statistics of selected indicators for plantain

Variables	N	M	Med	Min	Max	R	SD	V
Plant height (cm)	257	34.59	34.00	6.00	82.0	76.0	16.58	47.917
Number of inflorescences per individual	256	5.48	5.00	1.00	26.0	25.0	3.63	66.213
Number of seeds per inflorescence	257	439.23	383.00	127.00	1956.0	1829.0	250.40	57.010
Mass of 1000 seeds (g)	42	0.26	0.26	0.207	0.31	0.11	0.03	10.08
Germination (%)	40	33.68	33.50	1.000	76.00	75.00	20.12	59.74
Germination rate (day)	40	5.95	5.55	4.860	8.33	3.47	0.91	15.24

Note: N is the number of observations in the sample; M is the average; Med is the median; Min is the minimum; Max is the maximum; R is the range of variation; SD is the standard deviation; V is the coefficient of variation

The average value of a part of the studied parameters (plant height, mass of 1000 seeds, germination percentage, germination rate) is close to the median, which indicates a close to normal distribution of the sampler. The coefficient of the indicators variation is within the range of moderate variation values [30%; 70%], with the exception of the indicators mass of 1000 seeds and GR, which are characterized by values less than 30%, it generally corresponds to a homogeneous set.

The next stage of the analysis is to check the normality of the data distribution in order to determine statistical methods that can be applied to the collected data. According to the

results of the distribution study of these morphometric traits of P. major, it was concluded that only the indicators of seed mass and germination percentage correspond to the criteria of the normal distribution. The remaining parameters do not correspond to the normal distribution and were analyzed by nonparametric methods. Tables 2 and 3 show the results of a correlation analysis of the relationship of the studied features with altitude above sea level.

Table 2. Correlation analysis of the relationship of morphometric traits with the altitude gradient (Spearman correlation coefficient).

Pair of Variables	Valid N	Spearman R	t(N-2)	p-value
Plant height (cm) & altitude gradient	257	-0.681	-15.18	0
Number of inflorescences per individual & altitude gradient	256	-0.123	-1.98	0.048
Number of seeds per inflorescence & altitude gradient	257	-0.125	-2.01	0.044
Germination rate (day) & altitude gradient	40	0.452	3.13	0.003

According to the Table 2, the relationship between the plant height and the altitude gradient is strong negative; between the germination rate and altitude is strong positive; the indicators of the number of inflorescences per plant and the number of seeds per inflorescence are characterized by a weak negative correlation with the altitude. All the obtained correlation values are significant, or close to significant.

Table 3. Correlation analysis of the relationship of morphometric traits with the altitude gradient (Pearson correlation coefficient)

Pair of Variables	r(X,Y)	t	p	N
Mass of 1000 seeds (g) & altitude gradient	0.57	4.277	0	40
Germination (%) & altitude gradient	0.61	4.76	0	40

According to the Table 3, the relationship between the studied indicators and the altitude gradient is significant and strong positive.

For an evident representation of the data, their visual display is necessary. Such display is provided by a statistical method called "Box-plot", which makes it possible to display the median of values together with the interquartile range, without taking into account outliers of values that are mapping separately. In Figure 2, we present a box-and-whisker plot for the plant height indicator.

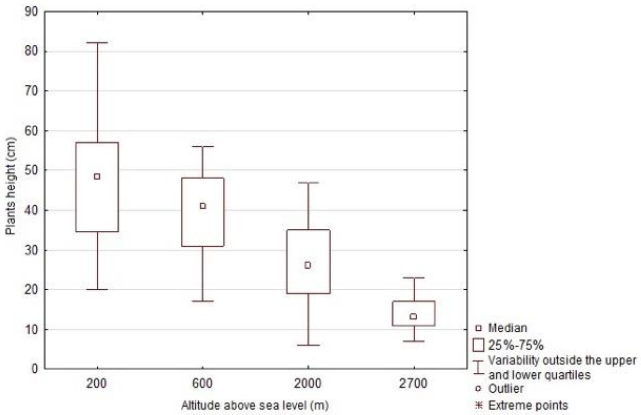

Fig. 2. The box-and-whisker plot for the plant height indicator (cm)

The correlation with altitude gradient for this trait is strongly negative. There are several reasons for reducing the size of plants with increasing altitude above sea level. Firstly, it is the effect of low temperatures [7,8]. Secondly, it is the effect of UV radiation [12-14]. Thirdly, under the influence of extreme conditions of the highlands, there is a selection of smaller phenotypes that are more advantageous in conditions that limit growth [6]. Small plants have a reduced requirement for resources [15], they are more resistant to the effects of strong winds inherent to upland [16].

In high-altitude conditions, in addition to reducing the plant height, there is a tendency to decrease their fertility, manifested in a decrease in the number of inflorescences per individual and the number of seeds per inflorescence. Our study revealed only a weak significant negative correlation of these traits with altitude above sea level (Table 2). The decrease in plant fertility under the influence of environmental conditions was studied mainly on agricultural plants and came to the conclusion that it is associated with exposure to low temperatures [17] and UV radiation [18,19].

Another studied trait was the mass of 1000 seeds, which increased with increasing altitude above sea level (a strong positive correlation) (Table 3). At an altitude of 2700 m, the seed weight decreases slightly compared to the height of 2000 m, but these differences are statistically insignificant. In Figure 3, we present a box-and-whisker plot for this trait.

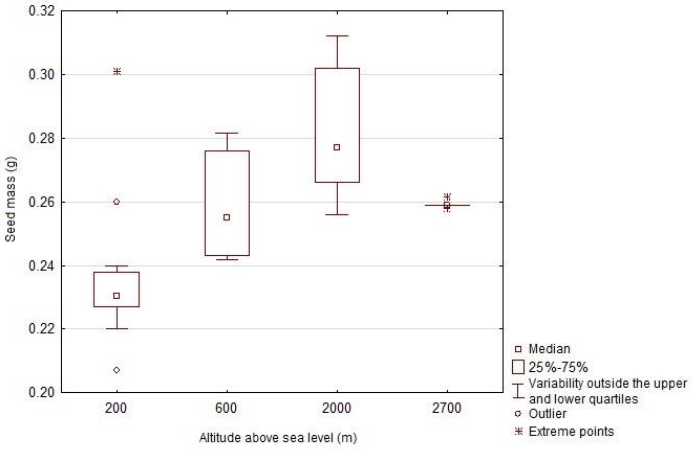

Fig. 3. The box-and-whisker plot for the mass of 1000 seeds indicator (g)

Our studies revealed a strong positive correlation between the altitude gradient and seed germination. A swing chart for this indicator is shown in Figure 4.

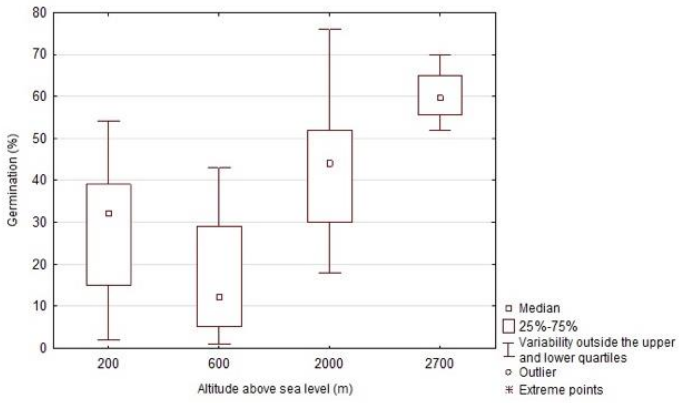

Fig. 4. The box-and-whisker plot for the germination percentage indicator

The effect of germination conditions on germination percentage and germination rate of Alpine plants seeds has been studied in sufficient detail [23, 25, 26]. Seeds of plants growing at high altitudes showed greater germination percentage and germination rate at lower temperatures compared to low-altitude populations, but these differences disappeared at a temperature of 25°C [23, 25]. We germinated the seeds at room temperature not exceeding 20°C, and according to our data, the germination percentage of *P. major* seeds increased with increasing altitude above sea level.

4 Conclusions

In the National Park "Priel`brus`e" there is an invasion of *P. major* on the territories disturbed by the construction of cable cars, located at high altitudes (2700 m). During this invasion a number of characteristics of this species have changed under the influence of the highlands conditions. According to altitude gradient, the plants height decreased, the seeds mass increased and their germination percentage increased.

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References

1. C. Körner, Alpine plant diversity: a global survey and functional interpretations, In: Arctic and Alpine Biodiversity: Patterns, Causes and Ecosystem Consequences, Ecol. Studies, **113**, 45-62 (1995).
2. C. Körner, E. M. Spehn, Mountain Biodiversity, a Global Assessment, 336 (2002).
3. W. D. Bowman, M. Damm, Causes and consequences of alpine vascular plant diversity in the Rocky Mountains, Mountain Biodiversity, a Global Assessment, 35-47 (2002).
4. J. A. Grytnes, Ecography, **26**, 291 (2003).
5. A. H. Halbritter, S. Fior, I. Keller, J. Evol. Biol., **31(6)**, 784 (2018).

6. P. Kiełtyk, Alpine Botany, 131, 117 (2021).
7. C. Körner, M. Neumayer, S. Pelaez, A. Menendez-Riedl, Smeets-Scheel, Flora, **182(5-6)**, 353 (1989).
8. S. Cordell, G. Goldstein, D. Muller-Dombois, D. Webb, P. M. Vitousek, Oecologia, 113, 188 (2012).
9. G. J. Blionis, J. M. Halley, D. Vokou, Ecography, 24, 696 (2001).
10. G. J. Blionis, D. Vokou, Plant System and Evolution, 232, 89 (2002).
11. Th. Fabbro, C. Körner, Flora, 199, 70 (2004).
12. M. A. K. Jansen, V. Gaba, B. M. Greenberg, Trends Plant Sci., **3**, 131 (1998).
13. Sh.-B. Shi, W.-Ya. Zhu, H.-M. Li, D.-W. Zhou, F. Han, X.-Q. Zhao, Ya.-H. Tang, Environ. and Exp. Bot., 51, 75 (2004).
14. P. Zhu, L. Yang, Field Crops Research., 171, 79 (2015).
15. J. Herrera, Ann. Bot., 95, 431 (2005).
16. K. Takahashi, Ecol. Res., 29, 121 (2014).
17. H. Ji, L. Xiao, Y. Xia, H. Song, B. Liu, W. Cao, Y. Zhu, L. Liu, Agric. For. Meteorol. 243, 33 (2017).
18. B. Liua, X. Liua, Ya.-Sh. Li, S. J. Herbert, Field Crops Research, 154, 158 (2013).
19. E. Bacelara, J. Moutinho-Pereira, H. Ferreira, C. Correia, Proc. Environ. Sci., 29, 219 (2015).
20. H. Guo, S. J. Mazer, G. Du, Journal of Ecology, 98, 1232 (2010).
21. H. Bu, X. Chen, X. Xu, K. Liu, P. Jia, G. Du, Plant Ecol., 191, 127 (2007).
22. A. Ayana, E. Bekele, Euphytica, 115, 91 (2000).
23. J. Lord, New Zealand Journal of Botany, 32, 227 (1994).
24. K. Oyama, J. of Plant Res., 106, 15 (1993).
25. S. Mariko, H. Koizumi, J. Suzuki, A. Furukawa, Ecol. Res., 8, 27 (1993).
26. E. Fernandez-Pascual, A. Carta, A. Mondoni, New Phytologist, 229, 3573 (2021).