

The effect of the height gradient on morphological traits of *Dracocephalum nutans* L.

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Abstract. Individuals of *Dracocephalum nutans* L. have been studied at different altitude levels from 460 to 2437 m above the level seas. The influence of the height gradient on morphological characters has been shown: the number of generative and vegetative shoots, the height of the generative shoot, the length and width of the leaf blade, length of its petiole, and inflorescence length. It was found that the height gradient has the greatest influence on the height of the generative shoot and the length of the inflorescence. When individuals grow higher along the altitude gradient, the height of the generative shoot and the length of the inflorescence decrease. The fluctuation of the average values of the traits of *D. nutans* in a wide range was established. The intrapopulation analysis of *D. nutans* individuals does not depend on the height factor.

The study of the structure and development of plants in a variety of ecological conditions makes it possible to identify variants of the morphological structure and features of their development. The analysis of morphological traits of plants with a wide range allows us to assess the patterns of their changes depending on the phytocenotic situation, which is the basis for solving various issues in the ecology and systematics of plants. *D. nutans* L. is a very common species of the family *Lamiaceae*. Due to its polymorphism and a large range of ecological conditions (from low–mountain plains to the alpine belt), this species can act as a model object for studying functional traits in ecology. Many researchers consider *D. nutans* differently depending on the height gradient. Some researchers believe that as it moves towards the subalpine belt, individuals of *D. nutans* only become lower and multi–shoots [1]. However, as noted by B.K. Shishkin [2], sometimes low–growth and multi–shoots plants are found on the plains. Our research is devoted to a comparative analysis of morphological traits that will fill a gap in the controversial issue of the taxonomy of this species and will be useful in the theoretical developments of the functional ecology of plants.

In this regard, the purpose of the work is to show the dependence of morphological traits on the height gradient and to establish correlations between the studied features.

D. nutans is a sympodial growing oligocarpic, hemicryptophyte, developing according to a sympodial semirosellat model of shoot formation. The root system is mixed. The main

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root is most often preserved throughout the life of the plant. The inflorescence is a frondis, open spike-shaped tears formed from dichasias consisting of monochasias. The fruit is four-camera. The plant is summer-wintergreen with wintering leaves on rosette shoots. The range of *D. nutans* extends from the European part of the continent to the Far East, capturing the northern regions of Central Asia, China and Mongolia [2].

The ecological and cenotic habitat of *D. nutans* is diverse. *D. nutans* growing on dry and floodplain meadows, in the steppes, in light-coniferous and birch forests, on rocky-crushed and open slopes, on sandy deposits, pebbles, both on the plains and in the mountains. In the upper belt of the mountains, it is found on alpine lawns and in mountain tundras [1].

Coenopopulations (CP) of *D. nutans* were studied on the territory of Khakassia (CP 1), Altai Mountains (CP 2,3,4,5), and Tuva (CP 6,7,8,9). Ecological and coenotical characteristic of habitats is given below.

CP 1,2,3 were studied at a height of up to 1000 m above the level seas (m a.s.l.). CP 1 was recorded in the petrophytic steppe, bushed *Caragana pygmaea* (L.) DC. and *Spiraea hypericifolia* L. The total cover reached –70–80%. Dominated by *Bupleurum scorzoniferolium* Willd., *Artemisia frigida* Willd., *Veronica incana* L., *Artemisia glauca* Pall. ex Willd. CP 2 – in meadow steppe, bushed *Spiraea trilobata* L. The cover –85%. Dominated by *Poa transbaicalica* Roshev, *Allium nutans* L., *Achnatherum confusum* Tzvelev, *Artemisia gmelinii* Web. ex Stechm., *Fragaria viridis* Duch. CP 3 – in the degraded meadow steppe with *Potentilla anserina* L., *Elytrigia repens* (L.) Nevski, *Elymus mutabilis* (Drob.) Tzvel., *Plantago major* L., *Achillea asiatica* Serg., *Artemisia vulgaris* L. The total cover reached –80%.

CP 4–7 were investigated at a height of 1000–2000 m a.s.l.. CP 4 – in the petrophytic steppe in high mountain. The cover – 45–50%. Dominated by *Sedum hybridum* L, *Festuca valesiaca* Gand, *Phleum phleoides* (L) Karst., *D. nutans*, *Stipa capillata* L., *Carex pediformis* C. A. Mey. CP 5 – in a highmountane steppe. The total cover reached –35–40%. Dominated by *Artemisia santolinifolia*, *Potentilla acaulis* L., *Festuca valesiaca* Gand, *Kitagawia baicalensis* (Redow. ex Willd.) Pimenov, *Ziziphora clinopodioides* Lam. CP 6 – in the serial group with *Achillea millefolium* L. on the pebble. The cover – 15–20%. Dominated by *Chamerion latifolium* (L.) Holum, *Veronica longifolia* L., *D. nutans*, *Androsace maxima* L. CP 7 – on the steppe meadow with *Pentaphylloides fruticosa* (L.) O. Schwars, *Salix trianda* L., *Leontopodium ochroleucum* Beauverb, *D. nutans*, *Tanacetum vulgare* L. The total cover reached – 30–35%.

CP 8,9 were studied at a height of 2000 – 2500 m a.s.l. CP 8 – in a highmountane steppe, the total cover reached – 50%. Dominated by *Phleum phleoides*, *D. nutans*, *Polygonum alpinum*, *Galatella macrosciadia*, *Veronica pinnata*, *Bistorta officinalis* Delarbre. CP 9 – in the subalpine meadow with *D. nutans* var. *alpinum*, *Hedysarum consanguineum* DC., *Rhodiola rosea* L., *Saussurea subacaulis* (Ledeb.) Serg., *Leontopodium ochroleucum* Beauv. var. *campestre* (Ledeb.) Grab. Hand., *Aconitum decipiens* Worosch. et Anfalov. The total cover reached – 75–85 %.

The following traits the number of generative and vegetative shoots, the height of the generative shoot, the length and width of the leaf plate that developed in the second node below the inflorescence zone, the length of its petiole, and the length of the inflorescence were analyzed. The level of variability of morphological traits was determined on the scale of S.A. Mamaev [3]. Biometric characteristics are given for 20–25 adults. Statistical characteristics are obtained using Microsoft Excel. Evaluation of validity of mean values is given by Student's t-distribution (t). The effect of the height factor on morphological variation was determined by Fisher's test (F). With reliable exposure ($F > F_{cr}$, $P = 0.05$) was calculated the degree of influence (R^2 , %). To assess the intraspecific variability of *D.*

nutans were calculated at different altitudes the arithmetic mean and its error, the coefficient of variation (V, %) for 7 traits in coenopopulation.

In individuals of *D. nutans* the parameters of individuals differ in their mean value in different types of communities (Table 1). For most indicators individuals are significantly different from each other CP 3/CP6, CP 3/CP 7,8,9 and CP 6/CH 7,8,9 (mainly 4 significantly different indicators (for $t = 2.26$ (at a 95% significance level) out of 7). The differences in other indicators are in most cases insignificant.

Table 1. Individual variability of the metric characters of *Dracocephalum nutans* L.

Traits	Coenopopulations								
	1	2	3	4	5	6	7	8	9
Number of generative shoots, pc	$\frac{4}{44,42}$	$\frac{2,3}{40,20}$	$\frac{3,6}{45,13}$	$\frac{4,8}{43,62}$	$\frac{4,9}{62,91}$	$\frac{13,4}{58,22}$	$\frac{5,6}{45,96}$	$\frac{8}{40,69}$	$\frac{5}{44,72}$
Height of the generative shoot, cm	$\frac{42,1}{6,50}$	$\frac{24,3}{22,74}$	$\frac{48,2}{12,59}$	$\frac{21,2}{20,67}$	$\frac{16,7}{33,07}$	$\frac{24,7}{20,60}$	$\frac{15,1}{21,60}$	$\frac{17,11}{11,21}$	$\frac{12,84}{25,07}$
Number of vegetative shoots, pc	$\frac{0,13}{41,84}$	$\frac{1,1}{43,21}$	$\frac{1,13}{39,15}$	$\frac{1,54}{59,79}$	$\frac{1,5}{62,14}$	$\frac{0,26}{46,66}$	$\frac{1,31}{43,1}$	$\frac{2,3}{47,82}$	$\frac{3,3}{45,04}$
Length of the leaf plate, cm	$\frac{2,68}{26,10}$	$\frac{1,92}{10,62}$	$\frac{1,8}{23,48}$	$\frac{0,86}{53,86}$	$\frac{0,82}{41,91}$	$\frac{1,09}{13,50}$	$\frac{2,01}{24,5}$	$\frac{1,06}{21,59}$	$\frac{1,61}{34,07}$
Width of the leaf plate, cm	$\frac{1,08}{19,77}$	$\frac{0,74}{33,75}$	$\frac{0,84}{29,51}$	$\frac{0,62}{35,48}$	$\frac{0,54}{42,74}$	$\frac{1,01}{14,75}$	$\frac{0,86}{34,18}$	$\frac{0,48}{27,63}$	$\frac{1,02}{25,11}$
Length of the inflorescence, cm	$\frac{21,8}{21,58}$	$\frac{12,43}{25,08}$	$\frac{23,15}{33,32}$	$\frac{10,09}{34,35}$	$\frac{10,37}{56,91}$	$\frac{12,82}{7,80}$	$\frac{6,3}{31,19}$	$\frac{8,13}{25,50}$	$\frac{4,83}{36,94}$
Length of the petiole of the leaf, cm	$\frac{0,8}{44,72}$	$\frac{0,4}{41,83}$	$\frac{0,44}{39,84}$	$\frac{0,4}{42,28}$	$\frac{0,6}{41,58}$	$\frac{0,54}{29,85}$	$\frac{0,64}{39,54}$	$\frac{0,87}{26,73}$	$\frac{1,35}{37,66}$

Note: in the numerators – the average value of the traits, cm; the denominator is the coefficient of variation V, %; pc – pieces; cm – centimeter.

Using single-factor analysis at different altitude levels, 7 quantitative features were analyzed against the effect of the altitude gradient (Table 2). It was found that the factor of the altitude gradient, with varying degrees of influence, affects all the studied morphological characters, except for the length of the leaf blade.

One of the most representative morphological traits in herbaceous plants is the height of the generative shoots of the plant. The height of generative shoots in herbaceous plants plays a particularly important role in the process of adaptation of species to certain conditions [4]. Shoot height negatively correlates with extremely low temperatures [5] and, as a consequence, usually decreases with height [6]. Our studies confirm the dependence of the shoot height of *D. nutans* on the height distribution of individuals above sea level, since $F > F_{cr}$ (Table 2). The height gradient has the maximum influence (71.5%) on the height of the generative shoot. Analysis of the values of the height of the generative shoot (Table 1) showed that individuals growing in the steppes at an altitude below 1000 m a.s.l. (CP 1, 3) can reach 54 cm, and in a subalpine meadow at an altitude of 2437 m a.s.l. (CP 9) do not exceed 15 cm.

The size of the generative shoot of *D. nutans* specimens determines the length of the inflorescence. The degree of influence of the height gradient on the length of the inflorescence (70.9%). The variation in the size of the inflorescence at different heights is associated with a change in the length of the lower metameres between whorls and with a

reduction in the number of whorls in the inflorescence. The study of the parameters of the lower metameres of inflorescences showed that in plants growing up to 1000 m a.s.l., their length varies from 3–7 cm. With the growth of individuals higher along the height gradient, the length of the metameres decreases to 1.5 cm, and in the subalpine belt, to 0.7 cm. The number of whorls in the inflorescence of low–mountain and mid–mountain individuals often depends on the height of the shoot and the length of the inflorescence and varies from 8 to 18 to shoot. However, the inflorescence of individuals growing above 2000 m a.s.l. consists of only 3–6 proximate together whorls.

Table 2. Values of indicators of single–factor analysis of cenopopulations of *Dracocephalum nutans* L.

Indicators	Traits						
	1	2	3	4	5	6	7
F	55,06	21,46	16,49	45,7	1,2	3,21	2,45
Fcr	2,29	2,44	2,45	2,49	2,29	2,26	2,3
R2 (%)	71,5	37,9	41,2	70,9	–	21,3	7,9

Note: F and Fcr at P= 0,05; 1– height of the generative shoot; 2 – number of generative shoots; 3 – number of vegetative shoots; 4 – length of the inflorescence; 5 – length of the leaf plate; 6 – width of the leaf plate; 7– length of the petiole of the leaf.

The height gradient has a much smaller effect on the number of generative and vegetative shoots (37.9 and 41.2%, respectively).

A comparative analysis of the number of generative shoots of individuals from different phytocenotic conditions suggested the dependence of the studied trait on the sodding of the community. Thus, in communities of CP 2–5, where cereals are found, the minimum number of generative shoots is noted (up to 6 per individual). In CP growing with minimal or no sodding, the number of generative shoots can reach 15. *D. nutans* has a reactive strategy type [7]; therefore, sodding of the soil and, consequently, an increase in the degree of competition adversely affects individuals.

The effect of the height gradient on the number of vegetative shoots is stronger than on the number of generative shoots. The minimum number of vegetative shoots develops in individuals of CP 1 at an altitude of 460 m a.s.l., maximum is in CP 9 at an altitude of 2437 m a.s.l. In high–mountain climates, plants undergo seasonal development, using a warm and short growing season, which activates a larger number of renewal buds and an intensity of branching of shoots for growth.

The dependence of the sheet parameters on the height factor is small. The greatest correlation was observed for the width of the leaf blade (R2 = 21.3%), and there is no effect on the length of the leaf blade at all. At the same time, the minimum values of the length of the leaf blade are noted in most CP at an altitude of 1000–2000 m a.s.l., and the maximum in plants is up to 1000 m a.s.l. At an altitude of 2000 m a.s.l., the plants had average values. As noted by Atkin et al [8], usually highland plants have a more powerful photosynthetic apparatus than middle–mountain plants, which are formed by a large number of vegetative shoots and leaves.

For the analysis of the study of the variation of traits, the coefficient of variation of different traits within the cenopopulations was calculated (Table). According to the classification of S.A. Mamaev [9], such traits as the number of generative and vegetative shoots, the length of the petiole in all nine CPs have an increased, high, and very high (in some cases) level of variability (V> 26). Comparison of the coefficients of variation in the height of generative shoots, length, and width of the leaf blade in the CP did not show its dependence on the height factor. CP 1 (V> 21.58) has the lowest variability in inflorescence

length. This CP grew at an altitude of 460 m above sea level. Other CP have a higher level of variability for this parameter.

Changes in the direction of improving or worsening growing conditions are reflected in the morphometric parameters of the traits. Analysis of the average values of the height of the generative shoot (Table 1) showed that the largest are individuals growing in the steppes at an altitude below 1000 m a.s.l. (CP 1, 3), the lowest – in a subalpine meadow at an altitude of 2437 m a.s.l. (CPU 9). Changes were also noted in the inflorescence area. In individuals on up to 2000 m a.s.l., the whorls are spaced, while in plants growing higher, the whorls are proximate together and a reduction in their number is observed. As noted by Körner [10] and Rasmann, Pellissier et al. [11], the intensity of biotic interactions decreases with increasing altitude, but the influence of abiotic factors increases. Low values of indicators of *D. nutans* specimens in high mountains are most likely associated with the intensity of solar radiation, strong winds, and a short growing season, which negatively affects the development of the shoot sphere.

Thus, using single-factor analysis showed the effect of the height gradient on all traits except the length of the leaf blade. The greatest impact was noted on the height of the generative shoot and the length of the inflorescence. In communities below 2000 m a.s.l. individuals are characterized by high and average parameters of the average values of most morphological characters. Individuals with the smallest morphometric parameters dominate above 2000 m a.s.l. Intra-population analysis showed that all the studied characters, except for the height of the generative shoot, have a relatively high level of variability. The average values of *D. nutans* traits vary widely, which indicates good adaptability of the species to changing environmental conditions.

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