Some Features of the Biology and Ecology of the Invasive Species *Hordeum jubatum* L. (Poaceae, Liliopsida) in the Southern Urals

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Abstract—The results of our study of the invasive species *Hordeum jubatum* L. in various ecological—geographical conditions of the Southern Urals are presented. The 32 coenopopulations (CPs) of the species in the Bashkir Cis-Ural and Trans-Ural regions in Orenburg and Chelyabinsk oblasts were investigated. The populations studied were revealed to belong to several types of vegetation communities, namely, the *Polygono avicularis–Hordeetum jubati* association (Abramova and Golovanov, 2016), the derivate community *Hordeum jubatum* [Scorzonero–Juncetea gerardii], the derivate community *Hordeum jubatum* [Cynosurion], and the derivate community *Hordeum jubatum* [Artemisietea vulgaris/Stellarietea mediae]. Our study of key morphometric parameters has shown that the undisturbed CP Zamorskoye-1 (Orenburg oblast) was in the lead, where the growth conditions were favorable for the species. The most variable morphometric parameters among the populations are as follows: the number of generative shoots, the leaf length, and the quantity of seeds. In the 17 prospering CPs, the prevalence of individuals of the highest class was noted; they were located in the undisturbed or weakly disturbed habitats. One CP was attributed to equilibrium ones, and the others were depressive. By the results of our cluster analysis, three CPs located in different geographic zones and having the maximum or minimum values in the majority of their morphometric parameters are most different from the total data set. Further monitoring of the centers of invasion and distribution of *Hordeum jubatum* species across the territory of the Southern Urals is necessary.

Keywords: *Hordeum jubatum*, invasive species, South Urals, morphometric parameters, vitality structure

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INTRODUCTION

Invasive plant species occupy a special position among the large number of weeds due to their high pest toxicity. In the absence of constraints, they cause a population outbreak, which can lead to the displacement of native plant species and, consequently, a decline in biodiversity.

Biological invasions are now occurring regionally and globally. They are recognized as one of the leading factors in the transformation of modern natural ecosystems and are reflected in many global studies (Pyšek and Richardson, 2010; Schrader et al., 2010; Stohlgren et al., 2011; Chytrý et al., 2012; Richardson and Pyšek, 2012; Fridley, 2013; Alexander et al., 2016; Braun et al., 2016; Pergl et al., 2016; Pyšek et al., 2017; Wagner et al., 2017). The significant damage from invasions in agriculture, forestry, and water management and the negative impact on ecosystem biodiversity are of general concern and require urgent measures to contain this process (Abramova and Golovanov, 2016a, 2016b).

An indicator of the stability of any population, including invasive ones, is the living conditions of the individuals that make up it. The life state of individuals is “a concentrated indicator of environmental conditions, ecological ones as well as cenotic” (Proskuryakova, 1968). The more the environmental conditions correspond to the ecological optimum of the species, the higher the life status of individuals and the more generative plants in the population, as under optimal conditions the juveniles develop faster and reach a sexually mature state earlier (Rabotnov, 1950). Differentiation of individuals by their vitality is one form of determining the internal heterogeneity of populations (Zlobin, 1989).

Assessment of the population vitality structure is of great importance for invasive plants, as it shows the degree of adaptation to the new habitat of alien species coming to a particular area from other regions. The more plastic a species and the greater its ecological amplitude are, i.e., the wider the range of conditions under which it can grow, the easier it is to naturalize
and propagate in anthropogenically disturbed or even natural communities.

One of the invasive species actively progressing across the territory of the Southern Urals is the North American foxtail barley (*Hordeum jubatum* L.), quickly settling not only in disturbed habitats, but also introducing itself into natural communities. This species is included in the Black-List of Flora of the Republic of Bashkortostan (RB) (Abramova and Golovanov, 2016a) and the Black Book of Flora of Middle Russia (Vinogradova et al., 2010). Until 2000, only a few localities of the species were known in Bashkortostan, but since that time foxtail barley has started to occupy an actively expanding area. Its short vegetation period and resistance to drought allowed it to naturalize in dry steppes, and its resistance to salinization in saline meadows, where it increasingly acts as the main clog of knocked down pastures, forms stable monodominant coenoses consisting almost exclusively of foxtail barley. At the same time, vast space of abandoned, usable lands are formed (Figs. 1–3), as barley is a plant not eaten by the majority of agricultural animal species, and even its presence in feeds can cause irritation of the digestive tract and ulcers (Vinogradova et al., 2010).

We have studied the species *Hordeum jubatum* from 2015 to the present day (Baimurzina et al., 2016, 2017). Invasive populations of the species in the Bashkir Cis-Urals and Trans-Urals, the mountainous and forest zones of the Southern Urals, and adjacent areas of Chelyabinsk and Orenburg oblasts were studied. It is revealed that this invasive species is widely represented in many settlements, and also naturalized on wet and saline meadows along riverbanks and around lakes and reservoirs of the Southern Urals. A total of 32 coenopopulations (CP) of the species were examined.

The goal of this work was to study the variability of the main morphometric parameters of the *Hordeum jubatum* plant and to reveal its life state in different ecological and geographical conditions of the Southern Urals. The tasks were to study the morphometric parameters of the species, to identify the determinant complex of features, and to evaluate the vitality structure of CP.

**MATERIALS AND METHODS**

According to the natural conditions, the territory of the Southern Urals can be divided into the western part with the Cis-Urals and the Mountain Urals and the eastern part with the Trans-Urals. In the northern part of the region, the average annual rainfall is 450–550 mm, the average annual air temperature is 1.0–2.5°C, the hydrothermal coefficient is 1.0–1.45, and the frost-free period reaches 95–100 days. In the mountain–forest zone, the precipitation is 500–600 mm, the air temperature is 1.0–2.0°C, the hydrothermal coefficient is 1.3–1.6, and the frost-free period is 80–100 days. In the southern part of the region, the precipitation is less at about 300–500 mm, and the air temperature is higher at about 2.5–3.5°C. The hydrothermal coefficient is 0.65–1.0, and the frost-free period is 110–140 days (Atlas ..., 2005).

The study of the morphometric parameters of the species *Hordeum jubatum* was carried out by the V.N. Golubev method (Golubev, 1962) on 25 middle-aged generative plants from each CP. The following basic parameters were taken into account: *Ngs* is the number of generative shoots per plant; *h* is the height of the generative shoot, cm; *Nl* is the number of leaves on one generative shoot; *Ll* is the leaf length, cm; *Sl* is the leaf width, cm; *La* is the spike length, cm; *Li* is the inflorescence length, cm; *Ns* is the number of seeds per shoot.

The methodology for evaluating the vitality composition was based on the differentiation of plants of the same ontogenetic state (middle-aged generative) into vitality classes. Factor and correlation analyses were performed to identify the determinant features complex. Vitality spectra are composed, reflecting the ratio of plants of the (a) highest, (b) intermediate, and (c) lower vitality classes (Zlobin, 1989), and also the quality index and types of CPs: prosperous, equilibrium, and depressed.

The static analysis was performed in MS Excel 2010. In the cluster analysis, the Euclidian distance was used as a measure of sample differences and a dendrogram was constructed using the single communication method (Khalafyan, 2008).
RESULTS AND DISCUSSION

The studied CPs of the species *Hordeum jubatum* grow in several types of communities (Table 1). The derivative community *Hordeum jubatum–Juncus gerardii* [Scorzonero-Juncetalia gerardii] is the result of *Hordeum jubatum* plant invasion into natural saline habitats of the Southern Urals. Communities are widespread in the southern part of the Bashkir Trans-Urals and in Orenburg oblast, rarely in the Bashkir Cis-Urals. The grass canopy is quite dense (70–95%) and, along with the dominant species *Hordeum jubatum*, is composed of typical halophytes: *Festuca regeliana*, *Glaux maritima*, *Juncus gerardii*, *Puccinellia distans*, *Taraxacum bessarabicum*, and *Triglochin maritimum*. The association *Polygono avicularis–Hordeetum jubati*, which was first described by us in the Southern Urals territory (Abramova and Golovanov, 2016b), is mainly confined to the roadsides and outskirts of settlements. Communities of this association are encountered in the southern and central parts of the Bashkir Cis-Urals and Trans-Urals. The total projective cover varies from 75 to 90%. The grass canopy is composed mainly of synanthropic species adapted to the trampling factor (*Atriplex tatarica*, *Lepidium ruderale*, *Plantago major*, *Polygonum aviculare*, and *Taraxacum officinale*). The derivative community *Hordeum jubatum–Poa pratensis* [Cynosurion] is characteristic of the northern part of the Bashkir Cis-Urals, Chelyabinsk oblast, and the mountain–forest zone. It is formed by the invasion of the foxtail barley into knocked down meadow coenosis in settlements. In addition to the dominant species, the grass canopy includes meadow species such as *Achillea millefolium*, *Agrostis tenuis*, *Bromopsis inermis*, *Festuca pratensis*, *Poa pratensis*, *Trifolium pretense*, etc. The total projective cover varies from 70 to 95%. Occasionally, *Hordeum jubatum* plants grow in strongly disturbed garbage habitats with a high proportion of synanthropic plant species. They are identified as a derivative community of *Hordeum jubatum* [Artemisietea vulgaris/Stellarietea mediae]. The total projective cover in them varied from 80 to 85%.

When studying the state of CPs of invasive species, the analysis of variability of the qualitative and quantitative features is of great importance (Sinskaya, 1963). Based on the average values of the main morphometric parameters in 32 CPs of *Hordeum jubatum*, radial diagrams—morphograms—were made (Fig. 4). The morphograms allow visual comparison of similarities and differences in the morphological structure of individuals from different populations. Depending on the growth conditions, not only the size of individual structures may change, but also their number (number of generative shoots, number of leaves, etc.).

As can be seen from the Fig. 4, parameters such as the number of generative shoots, leaf length, and number of seeds were the most variable morphometric features between populations. No significant differences were found between the other signs. The greatest number of the generative shoots is observed in CPs no. 6 and no. 22, and the smallest number is observed in CPs no. 32 and no. 10. The latter population, which is affected by anthropogenic influences, also exhibits the minimal indices in terms of the spine length, inflorescence, and number of seeds. The height of the generative shoot revealed that this sign is slightly higher in the undisturbed CP no. 24, which also has the maximum length of the leaf and inflorescence. As for the number of leaves, CPs no. 23 and no. 30 differ, where this is higher, and it is minimal in CP no. 25. The lar-
Table 1. Phytocoenotic confinement of the *Hordeum jubatum* coenopopulations under study

| Region                  | No. CP | CP name       | General projective coverage, % | Community                              | Nature of disturbances |
|-------------------------|--------|---------------|-------------------------------|----------------------------------------|------------------------|
| Bashkir Cis-Urals       | 1      | Karmanovo     | 95                            | Community *Hordeum jubatum–Poa pratensis* [Cynosurion] | Trampling              |
|                         | 2      | Neftekamsk-1  | 80                            | Community *Hordeum jubatum–Poa pratensis* [Cynosurion] | The same               |
|                         | 3      | Neftekamsk-2  | 70                            | Community *Hordeum jubatum–Poa pratensis* [Cynosurion] | »                       |
|                         | 4      | Buzdyak       | 90                            | Community *Hordeum jubatum–Poa pratensis* [Cynosurion] | »                       |
|                         | 5      | Leninskii     | 95                            | Community *Hordeum jubatum–Poa pratensis* [Cynosurion] | »                       |
|                         | 6      | Aslykul       | 80–95                         | Community *Hordeum jubatum–Juncus gerardii* [Scorzonero–Juncetalia gerardii] | Recreation, grazing    |
|                         | 7      | Alga          | 90–95                         | Association *Polygono avicularis–Hordeetum jubati* | Trampling              |
|                         | 8      | Davlekanovo   | 85–95                         | Association *Polygono avicularis–Hordeetum jubati* | The same               |
|                         | 9      | Rayevskii     | 90                            | Community *Hordeum jubatum* [Cynosurion] | »                       |
| Bashkir Trans-Urals     | 10     | Sibai-1       | 75                            | Association *Polygono avicularis–Hordeetum jubati* | »                       |
|                         | 11     | Sibai-2       | 75                            | Association *Polygono avicularis–Hordeetum jubati* | »                       |
|                         | 12     | Baimak        | 75–85                         | Community *Hordeum jubatum* [Cynosurion] | »                       |
|                         | 13     | Semenovsk-1   | 85                            | Association *Polygono avicularis–Hordeetum jubati* | »                       |
|                         | 14     | Semenovsk-2   | 80                            | Community *Hordeum jubatum–Juncus gerardii* [Scorzonero–Juncetalia gerardii] | Grazing                |
|                         | 15     | Semenovsk-3   | 75–85                         | Association *Polygono avicularis–Hordeetum jubati* | The same               |
|                         | 16     | Baishevo-1    | 80                            | Community *Hordeum jubatum–Juncus gerardii* [Scorzonero–Juncetalia gerardii] | Without damage         |
|                         | 17     | Baishevo-2    | 80                            | Community *Hordeum jubatum* [Artemisietea vulgaris/Stellarietea mediae] | Anthropogenic pollution|
|                         | 18     | Urgaza        | 80                            | Community *Hordeum jubatum–Poa pratensis* [Cynosurion] | Grazing                |
|                         | 19     | Bakalovka     | 70–75                         | Community *Hordeum jubatum–Juncus gerardii* [Scorzonero–Juncetalia gerardii] | The same               |
| Bashkir forest–steppe zone | 20     | Uchaly        | 80                            | Com. *Hordeum jubatum–Poa pratensis* [Cynosurion] | Trampling              |
|                         | 21     | Inzer         | 75                            | Community *Hordeum jubatum–Poa pratensis* [Cynosurion] | The same               |
|                         | 22     | Beloretsk-1   | 80–85                         | Community *Hordeum jubatum–Poa pratensis* [Cynosurion] | »                       |
|                         | 23     | Beloretsk-2   | 80                            | Community *Hordeum jubatum–Poa pratensis* [Cynosurion] | »                       |
The largest number of seeds is observed in CP no. 22, and the smallest number is observed in CPs no. 10 and no. 21.

An effective method of classification, which allowed us to split the collection of objects into groups, within which the similarity of classification features is the greatest, is cluster analysis. The results of the cluster analysis (treelike clustering) on the basis of average sample values of morphometric parameters of plants are presented in Fig. 5. The studied *H. jubatum* coenopopulations at a distance of 13.8 were divided into the most isolated CP no. 21 and other population groups. CP no. 21 is located in the mountain–forest zone, and there are practically no upper class individuals in it, which indicates low rates of most morphometric parameters. The second cluster at a distance of 10.7 separates CP no. 12, and the third cluster at a distance of 10.3 separates into the undisturbed CP no. 24 and the remaining populations. The CPs no. 12 and no. 24 have powerful plants with maximal values in most morphometric parameters and are notable for their high vital status. The rest of the CP at the distance 9.0 can be combined into two groups. In the first group, there are five CPs characterized by low living status and minimal morphometric parameters. The second group combines CP no. 22 and the remaining populations, which form several smaller clusters. These clusters mainly integrate populations growing in similar ecological conditions in the same climatic zone.

The factor and correlation analysis allowed us to examine a deterministic complex of features, such as the height of generative shoots and the length of inflorescence, which were used for estimation of the vitality spectrum of CPs among the investigated parameters of the *Hordeum jubatum* plant. The results of distribution of individuals of the species by classes of vitality in the CPs are presented in Table 2.

The life state of the *Hordeum jubatum* CPs varies in different ecotopes. In most CPs, individuals of higher and intermediate classes prevail and are categorized as prosperous. The CP quality index here is maximal and ranges from 0.36 to 0.50. These CPs are mainly confined to more humid habitats, with optimal climatic characteristics, in various environmental conditions—from the saline habitats to streets of settlements. In CP no. 12, located on the saline habitat within the city of Baimak, and CP no. 24, noted along the bank of the Iriklinskii reservoir, there are no lower class individuals. These CPs have maximum parameters for most morphometric features. CP no. 5 is classified as balanced. The rest of the analyzed CPs are depressed, and the quality of the population ranges from 0 to 0.30.

### Table 1. (Contd.)

| Region          | No. CP | CP name          | General projective coverage, % | Community                                | Nature of disturbances |
|-----------------|--------|------------------|-------------------------------|------------------------------------------|------------------------|
| Orenburg oblast | 24     | Zamorskoe-1      | 80–85                         | Community *Hordeum jubatum–Juncus gerardii* [Scorzonero–Juncetalia gerardii] | Without damage         |
|                 | 25     | Zamorskoe-2      | 90                            | Association *Polygono avicularis–Hordeum jubati* | Trampling              |
|                 | 26     | Iriklinskii      | 80                            | Community *Hordeum jubatum–Juncus gerardii* [Scorzonero–Juncetalia gerardii] | Grazing                |
|                 | 27     | Starokhalilovo   | 75–80                         | Community *Hordeum jubatum–Juncus gerardii* [Scorzonero–Juncetalia gerardii] | The same               |
| Chelyabinsk oblast | 28 | Oktyabrskii       | 80–90                         | Community *Hordeum jubatum–Poa pratensis* [Cynosurion] | »                       |
|                 | 29     | Uyskoe           | 75–80                         | Community *Hordeum jubatum–Poa pratensis* [Cynosurion] | Trampling              |
|                 | 30     | Verkhneuralsk    | 70                            | Community *Hordeum jubatum–Poa pratensis* [Cynosurion] | Grazing                |
|                 | 31     | Spasskoye        | 85                            | Community *Hordeum jubatum–Poa pratensis* [Cynosurion] | The same               |
|                 | 32     | Narovchatka      | 85                            | Community *Hordeum jubatum [Artemisietea vulgaris/Stellarietea mediae]* | »                       |
in disturbed but also in natural habitats. This species is included in the Black List of Flora of the Republic of Bashkortostan and the Black Book of Flora of Central Russia. The *Hordeum jubatum* CPs studied grow in several types of plant communities, including the association *Polygono avicularis–Hordeetum jubati* Abramova and Golovanov, 2016, the derivative community *Hordeum jubatum–Juncus gerardii* [Scorzonero–Juncetalia gerardii], the derivative community *Hordeum jubatum–Poa pratensis* [Cynosurion], and the derivative community *Hordeum jubatum* [Artemisietea vulgaris/Stellarietea mediae].

Out of 32 CPs of the species investigated according to the majority of morphometric parameters of both vegetative and generative phases, the leader is the undisturbed CP of Orenburg oblast (CP no. 24), where the most favorable growth conditions for the species have formed. The CPs no. 6 and no. 22, which grow on weakly disturbed habitats, also have high parameter values. The minimum values for all parameters are marked in the strongly disturbed CP no. 10. The distribution of *Hordeum jubatum* plants in vitality classes showed that 17 CPs had a predominance of higher and intermediate classes and were classified as prosperous. The CP quality index here is maximal and ranges from 0.36 to 0.50. One CP is equilibrated. The rest of the investigated CPs are depressed, the quality of the population ranges from 0 to 0.30. According to the results of cluster analysis, three CPs (nos. 12, 21, and 24) located in different geographical zones and having maximum or minimum values for most morphometric parameters are most different from the whole data set.

**CONCLUSIONS**

The North American invasive *Hordeum jubatum* L. species is one of the most actively progressing invasive species in the Southern Urals, rapidly settling not only
Further monitoring of the centers of invasion and distribution of *Hordeum jubatum* plants on the territory of Southern Urals is necessary as it occupies increasing areas in the steppe zone leading to replacement of natural steppe and saline communities by derivatives (replacing), which changes the natural ecosystems and leads to their floristic pollution. The wide ecological range of the species allows it to grow all over the Southern Urals, in different geographical conditions, including the mountain–forest zone, where in contrast to the steppe zone it does not form extensive CPs and, as a rule, has lower values of the morphological parameters. The wide ecological range of the species allows it to grow all over the Southern Urals, in different geographical conditions, including the mountain–forest zone, where in contrast to the steppe zone, it does not form extensive CPs and, as a rule, has lower values of the morphological parameters. The

| No. CP | Relative frequency of dimensional classes | Population quality, $Q$ | Vitality of CP type |
|--------|----------------------------------------|------------------------|---------------------|
|        | $c$ | $b$ | $a$ |                      |                       |
| 12     | 0   | 0.16 | 0.84 | 0.50 | Prosperous          |
| 24     | 0   | 0.20 | 0.80 | 0.50 | The same            |
| 1      | 0.04 | 0.16 | 0.80 | 0.48 | "                   |
| 6      | 0.04 | 0.16 | 0.80 | 0.48 | "                   |
| 4      | 0.04 | 0.16 | 0.80 | 0.48 | "                   |
| 31     | 0.04 | 0.48 | 0.48 | 0.48 | "                   |
| 23     | 0.08 | 0.20 | 0.72 | 0.46 | "                   |
| 20     | 0.08 | 0.48 | 0.44 | 0.46 | "                   |
| 25     | 0.12 | 0.40 | 0.48 | 0.44 | "                   |
| 28     | 0.12 | 0.44 | 0.44 | 0.44 | "                   |
| 22     | 0.12 | 0.52 | 0.36 | 0.44 | "                   |
| 3      | 0.16 | 0.24 | 0.60 | 0.42 | "                   |
| 32     | 0.16 | 0.32 | 0.52 | 0.42 | "                   |
| 2      | 0.20 | 0.24 | 0.56 | 0.40 | "                   |
| 26     | 0.24 | 0.40 | 0.36 | 0.38 | "                   |
| 8      | 0.24 | 0.52 | 0.24 | 0.38 | "                   |
| 19     | 0.28 | 0.24 | 0.48 | 0.36 | "                   |
| 5      | 0.36 | 0.20 | 0.44 | 0.32 | Equilibrium         |
| 7      | 0.40 | 0.36 | 0.24 | 0.30 | Depressive          |
| 29     | 0.40 | 0.20 | 0.40 | 0.30 | The same            |
| 27     | 0.44 | 0.56 | 0  | 0.28 | "                   |
| 13     | 0.48 | 0.48 | 0.04 | 0.26 | "                   |
| 9      | 0.52 | 0.40 | 0.08 | 0.24 | "                   |
| 30     | 0.60 | 0.24 | 0.16 | 0.20 | "                   |
| 15     | 0.72 | 0.24 | 0.04 | 0.14 | "                   |
| 17     | 0.80 | 0.20 | 0  | 0.10 | "                   |
| 11     | 0.80 | 0.20 | 0  | 0.10 | "                   |
| 18     | 0.80 | 0.16 | 0.04 | 0.10 | "                   |
| 21     | 0.80 | 0.12 | 0.08 | 0.06 | "                   |
| 14     | 0.84 | 0.16 | 0  | 0.08 | "                   |
| 10     | 0.96 | 0.04 | 0  | 0.02 | "                   |
| 16     | 1.00 | 0  | 0  | 0  | "                   |
ecological optimum of the species is located in favorable conditions along the shores of various reservoirs in the steppe zone, where the CPs have the maximal parameters for the greatest morphometric features.

Retardation of the Hordeum jubatum invasion process is nowadays very difficult, as there are no methods developed to control this alien species. As other authors have shown (Tsvetkov, 1991; Seledets and Probota, 2016), the foxtail barley, having penetrated into natural communities, becomes a common component of ecosystems, and it is impossible to displace it from communities, especially from communities along the banks of water bodies, as the water protection zone does not allow the use of chemical protective equipment. Therefore, it is important to prevent its distribution to new territories and to control the railway and road routes along which the species is drifting from invasion.

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COMPLIANCE WITH ETHICAL STANDARDS

The authors declare that they have no conflict of interest. This article does not contain any studies involving animals or human participants performed by any of the authors.

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