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Impact assessment of Eurasian beaver reintroduction on riparian phytocenosis of the Raifa forest in Volga-Kama Nature Reserve

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Abstract. Statistically significant changes in microclimatic environmental factors under the influence of the activity of the European beaver in the territory of the Raifa section of the Volga-Kama Nature Reserve were revealed. The influence of the beaver reintroduction factor on the change in the moisture and illumination regimes of habitats, the richness of soils with nitrogen, the acidity and salt regime of soils has been established. In the conditions of fodder and construction activities of the beaver, an increase in the proportion of groups of aquatic, wetland and boreal plant species was noted, as well as the expansive nature of the change in their activity. There was a decrease in the activity of the distribution of ruderal species in the conditions of beaver activity. Based on phytoindication analysis, it has been shown that the reintroduction of the beaver into the water bodies of the Raifa section of the Volga-Kama Reserve is responsible for maintaining the necessary microclimatic conditions to preserve the natural boreal communities.

1 Introduction

The activity of the Eurasian beaver (*Castor fiber* L.) attracts the attention of researchers because of the peculiarities of its construction and food activity, leading to the transformation of the environment [1, 2]. All herbivores influence the structure and dynamics of the ecosystem [3-6], but the impact of the beaver is especially strong, he can make fell trees with a large trunk diameter. In addition, the biomass of woody and shrubbery vegetation withdrawn by the beaver from the ecosystem far exceeds the biomass that he consumes [7-9].

Thus, beavers are key species of animals that significantly affect the processes of the landscape level not only in the aquatic, but also in the terrestrial environment. Effects of beavers include changes in energy flow across the water-land boundary, changes in the heterogeneity of the environment. This is due to the direct impact of the beaver on the habitat: the ability to fall trees, the consumption of herbaceous vegetation and woody growth for food, the construction of beaver structures (dams, huts, half-huts, burrows, cobles, and canals), the formation of beaver trails. Due to this, beavers initiate long-term succession processes associated with the emergence, aging and collapse of beaver ponds,

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with a change in the hydrological regime of water bodies, significantly changing coastal and aquatic ecosystems [10].

In turn, the history of changes in distribution of the beaver reflects the destructive ability of human economic activity and, at the same time, demonstrates its ability to correct the damage caused to the natural environment [11]. A typical example of such activity is a sharp reduction in forest areas in the Volga-Kama region in the XIX century. This circumstance led to a change in the hydrological regime of small rivers and together with the large-scale commercial capture for the destruction of the beaver, which was previously common for this region [12].

In the middle of the twentieth century, work began on the reacclimatization of the Eurasian beaver in the Volga-Kama Territory. By that time, due to the poor food base and partially drying watercourses, the banks of which were used as arable land and pastures, the habitat conditions for the species were unfavorable here [13]. However, the imported beavers found suitable habitats for themselves, making them suitable for their existence. It should be noted that beaver reintroductions are functionally new invasions, and the old species is already non-native in the previously native ecosystem [14].

The modern tree stands of the Raifa forest, relating to its riparian part, was formed already in the absence of beaver activity after its disappearance from the local fauna [15, 16]. The fact that in places of reacclimatization these rodents in the coastal strip destroy plantations of some plant species, should be regarded as a stage in the process of restoring the natural coastal phytocomplex. In the case of beavers, they act as a natural factor, under the influence of which species fall out of the coastal stand that are not adapted to the conditions of prolonged flooding and do not have the ability to rapid vegetative reproduction by mature growth [17].

The purpose of this study is to assess the impact of the environment-forming activity of the Eurasian beaver on the phytocenosis of the Raifa section of the Volga-Kama Reserve after reintroduction.

2 Materials and Methods

2.1 Study Area

The study area is located within the Raifa section of the Volga-Kama State Nature Reserve (Figure 1), on the left slope of the valley of the Volga River. The territory from the surface is composed of Quaternary sandy-argillaceous alluvial-lacustrine deposits. The northeastern part of this section of the reserve lies on the upper terrace of the Volga River with absolute elevations of 125–130 m. The other part is located on the middle terrace (100–120 m). The surface of the middle terrace was heavily processed by erosion, karst, suffosion and eolian processes in the Neopleistocene and Holocene. The surface of the terraces is dissected by the valleys of the Sumka River and its tributary, the Ser-Bulak River. The length of the Sumka River is 37 km (within the Raifa forest–10 km). The bottom of the valley, hundreds of meters wide, is complicated by karst depressions and sinkholes, mainly occupied by lakes, among which the largest are Lake Beloye (9.7 ha), Lake Raifa (33 ha), and Lake Ilyinskoye (6.2 ha). The length of the Ser-Bulak River is 11.5 km. A constant flow is maintained only in the upper reaches. In the valley of the lower reaches of the river, 3 km from the mouth, there is Lake Linevo with an area of 7 hectares. Almost ubiquitous plowing of land in the basin of the upper reaches of the Sumka River resulted in an increase in surface runoff, a sharp intensification of erosion processes, siltation of lakes, and a decrease in their areas and depths [17,18].

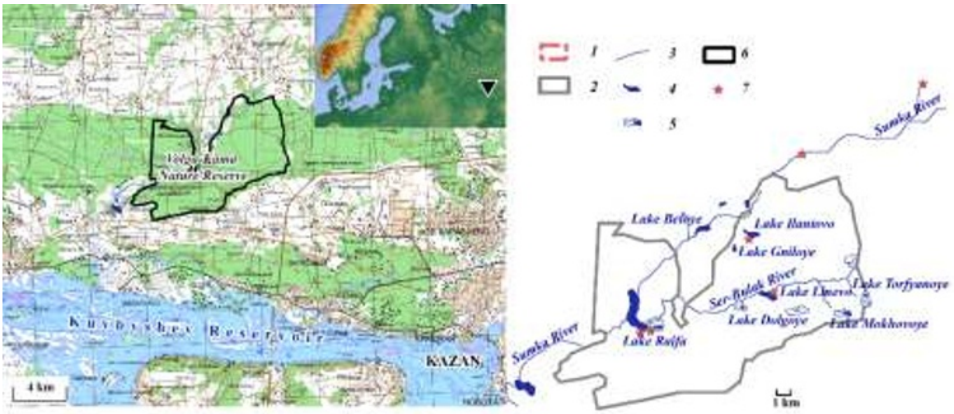

Fig. 1. Scheme of a trial plot to determine the influence of beaver on near-river floodplain vegetation. – round plot with radius R=17,84 m; –"inland transects" (3 m×7 m), –"bank transects" (3m×7m), – test plots (1m×1m); – starting point with notation sign.

2.2 Materials

In 1996, work on the reintroduction of the Eurasian beaver in the watercourses of the Raifa forest began. The main goal was to reduce the rate of siltation of the reserve's lakes and improve microclimatic humidity conditions to preserve boreal plant communities [19].

The study of the influence of beaver activity on the plant communities of the Volga-Kama State Nature Reserve began from the first moment of reintroduction of animals [19]. This made it possible to identify and fix changes in the composition and structure of phytocoenoses from the "zero mark". In [19], no statistically significant differences were found between the indicators of 1997 and 2002, collected on the control plots, while a number of significant changes were noted on the test plots subjected to the beaver's environment-forming activity. According to this study, the main changes in the composition and structure of phytocoenoses under the influence of the beaver occurred in the near-river zone, where the beaver actively feeds. In addition, construction activities have resulted in a rise in the level of surface and ground waters, which also directly affected the vegetation of the riparian zone.

In the work, fund materials of research of the scientific department of the Volga-Kama State Nature Reserve for 1997 were used. In 2010 and 2022, we continued to study vegetation in order to monitor the succession processes caused by the reintroduction of the beaver.

2.3 Methods

In 1997, to determine the influence of the beaver on the near-river vegetation of the Raifa forest of the reserve and its buffer zone, 59 test plots were established according to the method proposed by [20]. At an arbitrary point located in the near-river zone (determined from a table of random numbers), the first test (trial) plot was laid. All subsequent sections were laid 200 m apart. The location of the first area (right or left bank) was determined by a table of random numbers, and then alternated, so that all the even numbers of the area were on the right shore, and the odd numbers were on the left, or vice versa [20]. We determined the coordinates of the starting point using GPS with an accuracy of up to tenths of a second; in addition, the starting point was marked with pegs and notes on the trees.

The test plot consisted of two mutually perpendicular transects (Figure 2). One of the transects, "along-bank transects", ran parallel to the river, the second one, "inner transects", is from the river perpendicular to the first. Each of the transects included three rectangular sites ("box") (3m×7m), the distance between them was 3 m. In each of the "boxes", the number of trees less than 10 cm in diameter at the cut point (50 cm from the ground) was counted by species.

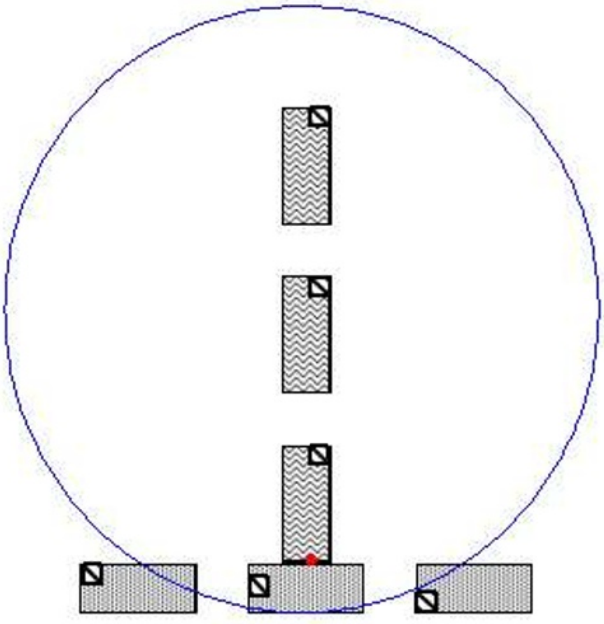

Fig. 2. Scheme of a trial plot to determine the influence of beaver on near-river floodplain vegetation. – round plot with radius R=17,84 m; –"inland transects" (3 m×7 m), –"bank transects" (3m×7m), – test plots (1m×1m); – starting point with notation sign.

All geobotanical descriptions in 1997, 2010, and 2022 were performed according to the above methodology. In 2010 and 2022, we investigated only 27 test plots out of 59 plots described in 1997. Data from these 27 sites formed the basis of this work.

Depending on the activity of the Eurasian beaver along the rivers and lakes, we divided the plots into two groups: (1) 19 plots exposed to beavers (experimental group); (2) 8 plots where beaver activity was not observed (control group). We carried out this division based on our own observations during the collection of field material at the test plots studied. At the same time, we took into account the presence of traces of beaver activity on each plot (gnawed and fallen trees, beaver structures). We also used data on the distribution of the beaver in the water bodies of the Raifa forest of the reserve. Moreover, in this study, for a more detailed assessment of the influence of the environment-forming activity of the beaver, we decided to divide the experimental group into two more independent groups. These are plots where only feeding activity of rodents was observed (8 plots), and plots where construction activity was observed (11 plots).

We carried out a description of the herbage on areas of 1m× 1m in each "box" of the transects. When describing the test plots, we identified the plant species present on the site, and simultaneously visually determined their abundance for each species as a percentage of the area and on the Drude scale. The projective cover of plants was taken as abundance. We entered all data into herbage description sheets indicating the conditional name of the test plot, the name of the river or lake, and the date of description. Light indicators (%)

measured with a densitometer in the first and third "boxes" of the along-bank and inner transects are also recorded. All data of geobotanical descriptions obtained at the stage of collecting field material were entered into the FLORA database for further analysis: assessment of the values of environmental factors according to the ecological scales of Tsyganov [21], ecological and coenotic analysis of the vegetation cover on the established test plots and calculation of the index of species activity.

In each group of herbage descriptions, the values of environmental factors were calculated using Tsyganov ecological scales. To do this, first, for each species in each description, the values of the average abundance were calculated by dividing the sum of the abundance values in 1 m^2 areas by their number (6, three on each transect, Figure 2):

$$P_i = \sum P_n/6 \quad (1)$$

where P_i is the average abundance of the i species (%), P_n is the abundance in each "box" of transects, 6 is the number of plots with an area of 1 m^2.

We converted the data on the species into values of environmental factors prior subsequent analysis. The obtained values of the average abundance are recalculated and expressed in fractions of one. Using data on the abundance of species and limit indicative values of for each species according to the tables of the Tsyganov ecological scales, we calculated the values of each environmental factor (f_i) for all test plots in the analyzed groups:

$$f_i = \sum(C_{av} \times P) \quad (2)$$

where C_{av} is the arithmetic mean of the environmental factor (in points), P is the mean abundance of the species (in fractions of one).

Thus, we obtained information about the nature of environmental factors such as temperature, climate continentality, dryness-humidity, cryoclimatism, humidity, soil salt regime, nitrogen content in the soil, soil acidity, illumination and humidity variability. We carried out the entire calculation of the values of environmental factors in Microsoft Office Excel 2010. We used a general linear ANOVA test to determine differences in environmental factors between groups . Calculations were carried out using Statistica for Windows, version 12.

To assess the degree of success in the development of landscape species, we calculated the activity of each species (A) based on the indicators of abundance (D) and occurrence (F):

$$A = (F \times D)^{0.5} \quad (3)$$

The leading value is the occurrence of species in each group of descriptions, expressed in points (maximum 10). The occurrence of the species was automatically calculated in the FLORA database. The number of species was determined by the projective cover of the species according to the 5-point Drude scale.

3 Results

Based on the ecological-cenotic analysis, we determined the ecological-cenotic spectra of the studied vegetation groups. On the control test plots described in 1997, the proportion of forest species was 51.2%, including 11.1% of boreal species, 22.4% of nemoral species, and the remaining 17.7% are species that grew in forests of various type (mixed, pine, and alder). The group of meadow species accounted for 37.7% of the entire described flora. Plants growing in meadows of various types accounted for 11.1%, in wet meadows–4.4%, in forest meadows–22.2%. The group of wetlands was represented by 6.7%. A separate group was made up of weed (ruderal) plant species associated in their distribution with disturbed habitats. They accounted for 4.4%.

On the same test plots in 2010, there was a general decrease in the share of forest species to 47.7%, including boreal species–9.4%, nemoral–23.8%, the remaining 14.5% are species growing in forests of various types. The proportion of wetland species increased to 12.7%. The group of meadow species reduced their share in the community to 30.6%: those growing in meadows of various types accounted for 9.5%, wet-meadow species–7.9%, forest meadows (forest edges)–12.7%. The appearance of steppe species was noted–1.6%. The proportion of ruderal species increased to 7.4%.

In the control descriptions of 2022, an increase in the share of forest species to 63.2% was noted, including 7% of boreal species, 34.2% of nemoral species, and 22% of mixed forest species. Wetland and steppe species were not noted. The share of meadow species decreased to 21% against the background of an increase in the share of ruderal species–15.8% (10.5%– weedy species, 5.3%–cultural species).

The analysis of ecological-coenotic groups (ECG) of the experimental areas in 1997 revealed the same regularities as in the control areas of 1997: species of the forest group also prevailed there, although in a different ratio. The share of forest species was 46%, including boreal–15%, nemoral–10.9%, growing in forests of various types–20.1%. The group of weed plant species accounted for 13.5%, among which the leading position belonged to ruderal species–10.1%, cultivated species–3.4%.

According to the results of the ECG analysis in the experimental plots for 2010, there was a tendency to change the dominant group. Along with the forest group, species of the wetland group accounted for the largest share. The share of forest species was 44.5%, among them the share of boreal species increased–24%, nemoral–7.9%, the remaining 12.6% were species growing in forests of various types. 25.7% of the species were associated with wetland communities. The group of meadow species accounted for 19.4% of the total flora. Steppe plant species accounted for 1.7%. The group of weed plant species accounted for 8.7%, among which the leading position belonged to ruderal species–6.2%, cultivated–2.5%.

The share of forest species in the experimental plots for 2022 was 46.3% (boreal species–27.6%, nemoral species–6%, 12.7%–species growing in forests of various types). The share of the group of species of wetlands decreased to 28.2%. The group of meadow species accounted for 23.1%. Steppe species were not noted. The weed group accounted for 2.4% of the species.

According to the results of the analysis of ecological-coenotic groups, it is noted that, in contrast to the control test plots, in areas where beaver activity is noted, there is an increase in the proportion of boreal phytocoenoses, conservation of meadows, and a decrease in the proportion of ruderal species. On the control plots, the proportion of boreal species decreased, and the group of wetland species completely disappeared. At the same time, there was a steady trend towards an increase in the role of ruderal species in communities. These results also correlate with the results on changes in moisture conditions obtained from the analysis of ecological scales and species activity.

To study the behavior of species under the influence of the Eurasian beaver, it was important to determine the activity and its changes, which makes it possible to judge the dynamics of vegetation. The activity scores of each species were calculated in all description groups. The calculation of species activity revealed the maximum activity in the species of the ruderal group in the control plots in 1997, which was 4 points (*Urtica dioica* L.), which belongs to the middle class of activity. At the areas 2010 and 2022, the highest activity also belongs to the ruderal species (*U. dioica* L., *Chelidonium majus* L.)–5 points (class – active). Thus, in this group of species, there is an expansive degree of change in activity. The rest of the species and groups of species had rather low activity scores (1 and 2 points) in the descriptions of all years. At the same time, a fading degree of activity was observed in the species of the wetland and aquatic groups, and they were not noted at all in the descriptions of 2022. This also reflects the trend of change in the flora of the Raifa forest of the reserve, where an increase in the activity of ruderal species is observed.

On the experimental test plots in 2010 and 2022, on the contrary, despite the general expansion of ruderals, there was a fading degree of change in the activity of the ruderal group and an expansive one in boreal and wetland species. The maximum value of species activity in these areas in 1997 was for *U. dioica* L. (ruderal group) and amounted to 3 points (fairly active class), the nature of the activity was expansive. In 2010 and 2022, the maximum value was associated with *Lemna minor* L., belonging to the aquatic group–4 points (medium active class), the nature of the activity was expansive. In 2010 and 2022, there was a fading degree of activity (from 3 to 2) for ruderals. The maximum activity value for this group (2–inactive class) was in *U. dioica* L. These results also provide evidence of changes in vegetation cover and environmental conditions in areas that are directly affected by the European beaver.

Based on phytoindication analysis using Tsyganov ecological scales, we obtained information on the nature of changes in such environmental factors as air temperature regime, continentality of climate, aridity-humidity, cryoclimatism, moisture content, salt regime of soils, soil nitrogen availability, soil acidity, illumination and variability of moisture for both groups of descriptions studied [21].

We determined the following environmental conditions for control test plots in 1997: (a) the temperature regime (Tm) refered to the type of boreal-nemoral zones with an annual value of total solar radiation of 40 kcal/cm^2; (b) climate (Kn) of continental type, semi-arid, according to the ombroclimatic factor; (c) the cryoclimatic factor (Cr) was characterized by moderate winters (average air temperatures of the coldest month were from –8 to –16 °C); (d) conditions of humid forest-meadow zones according to the moisture factor (Hd); (e) poor soils in terms of the salt regime (Tr); (f) nitrogen-poor soils under conditions of nitrogen richness (Nt); (g) slightly acidic soils (pH = 5.5–6.5) according to the soil acidity regime (Rc); (h) light forest conditions to the illumination factor (Lc) [21]).

We obtained the same indicators when analyzing data from these test plots for 2010 and 2022. Statistically significant differences in indicators for all years were assessed. On the control plots, the constancy of the main environmental factors was noted, with the exception of the content of soil nitrogen, the value of which showed a steady increase.

For the experimental plots of 1997, the same indicators of environmental factors were obtained as in the control plots of 1997. But already when compared with the values of environmental conditions obtained in 2010, a change in the indicators of the following factors was noticeable: an increase in the humidity index by 3 steps, illumination, salt regime of the soil, variability of humidity (all by 1 step), decrease in nitrogen richness and acidity of soils (by 1 step). The results of phytoindication analysis according to Tsyganov ecological scales, obtained for geobotanical sample plots in 2022, are consistent with the results of 2010. These results are confirmed by statistical calculations ($p = 0.000$). In contrast to the results of studies of near-river vegetation conducted in the Kostomuksha Nature Reserve (Karelia, European Russia) [22], there were no changes in all Tsyganov scales in the Raifa forest as a result of the reintroduction of the beaver. An increase in characteristics only in terms of humidity, illumination, soil salt regime and moisture variability was noted. However, in contrast to [22], under the influence of the beaver vital activity factor, there is a decrease in nitrogen richness and soil acidity. It is possible that this difference is due to different characteristics of the soils of these territories.

For a more detailed assessment of the impact of the beaver's activity, the environmental conditions of the selected sites (according to the Tsyganov scales), where only feeding activity was observed, and the sites where construction work was carried out, were compared. The results obtained were completely identical to the results for the entire experimental group and differed slightly. Although the results of construction activities were most noticeable at the initial stages of the beaver colonization [23].

At this moment, the main transformations of the landscape, habitat conditions and changes in phytocoenoses take place. However, under conditions of a sufficient amount of food resources, both the stabilization of the beaver population and its habitat and the decrease and further extinction of the construction activity of beavers occur. In the future, only the food activity factor remains the most significant and constant [23-26]. In our work, repeated studies of vegetation and phytoindication evaluation of control and experimental plots were carried out 13 and 25 years after the reintroduction of beavers. Probably, during this time, the beaver population in the Raifa forest stabilized, which resulted in the stabilization of new conditions [24,27-29].

Our study has shown that in the test plots where the life activity of beavers is noted, there is a greater taxonomic richness and diversity of near-river flora. The results reflecting an increase in the species diversity of herbaceous plants in the zone of activity of the beaver are consistent with the results of other researchers [25,28-34]. Against the background of an increase in the number of species, the proportion of ecological-coenotic groups characteristic of boreal phytocoenoses also increases. In the test plots of the fodder and construction activities of beavers, the structure of near-river floodplain phytocoenoses becomes more complex. This is an indicator of increasing environmental sustainability [35] of floodplain plant communities.

While in a number of numerous works [9,22,23,27,36-39] the influence of beavers on phytocoenoses was studied, no studies have been carried out previously in the Volga-Kama Nature Reserve. Our data document for the first time the role of beaver reintroduction in the riparian vegetation of the Raifa forest. Also, in previous studies, the activity of plant species under the influence of a beaver was not assessed. Our results indicate a decrease in the activity and participation of ruderal plant species in near-rive floodplain phytocoenoses. Ruderal species are mainly adventitious elements and indicators of increased anthropogenic impact. There is a change of ruderals by forest and moisture-loving species, there is a restoration of more characteristic groups of herbaceous vegetation for the boreal forest.

Overall, the results obtained correlate with the results of the studies of other researchers who investigated the environment-forming activity of the European beaver in Novgorod Oblast (Valdai National Park, Priilmenskaya Lowland) [27], Bryansk Oblast (Bryansk Forest Reserve) [36], Vologda Oblast (Darwin Reserve) [37] and Moscow Oblast (Prioksko-Terrasnyi Nature Biosphere Reserve) [38], Udmurt Republic (Nizhne-Svirsky Reserve) [39] and in Orenburg Oblast (Burtinskaya Step) [40] of European Russia. The vital activity of the European beaver in its natural habitat is one of the main components in maintaining a higher species diversity of flora and in preserving the microclimatic factors characteristic of these territories.

4 Conclusion

Thus, we can conclude that the activity of the Eurasian beaver does not affect the functioning of phytocenoses associated with such more global factors as climate continentality, temperature regime, ombroclimatism, and cryoclimatism. Statistically significant changes in microclimatic factors of the environment under the influence of the activity of the European beaver in the territory of the Raifa forest of the Volga-Kama Reserve were revealed. The influence of the beaver reintroduction factor on changes in the moisture and illumination regime of habitats, the richness of soils with nitrogen, the acidity and salt regime of the soils. Under the conditions of foraging and building activities of the beaver, an increase in the proportion of groups of aquatic, wetland, and boreal plant species was noted, as well as an expansive nature of the change in their activity. A decrease in the activity of distribution of ruderal species under the conditions of beaver activity was noted. Changes in factors such as humidity and illumination of the habitat are most likely directly related to the activity and lifestyle of the beaver. This is due to the direct removal of trees from the forest stand, which leads to an increase in the illumination of near-river areas. Flooding and, as a result, an increase in the water level in rivers leads to an increase in floodplain moisture in quantities sufficient to cause the replacement of some ecological-coenotic groups by others that are more adapted to changing conditions. From the obtained results, it follows that in the areas affected by the European beaver, the effect of adverse climatic factors, such as drought, is smoothed out, and the most optimal conditions are provided for the conservation and development of boreal plant species.

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References

1. V.V. Dezhkin, Y.V. Dyakov, V.G. Safonov, *Beaver* (Agroprom Publisher, Moscow, 1986)
2. M.M. Balodis. The thesis for the degree of candidate of biological Sciences, *Biological bases of beaver farming (on the example of Latvia)* (1989)
3. B.D. Abaturov, *Mammals as a component of ecosystems* (Nauka Publisher, Moscow, 1984)
4. S.P. Bratton, Ecology, *The effect of the European wild boar (Sus scrofa) on gray beech forest in the Great Smokey Mountains* (1975).
5. S.J. McNaughton, Ecol. Monogr. **55**, 259-294 (1985)
6. N.J. Huntley, Ecology, **68**, 274-283 (1987)
7. C.A Johnston., R.J. Naiman, Landscape Ecology, **1**, 47-57 (1987)
8. D.Y. Gorshkov, Y.A. Gorshkov, N.V. Kochetkov, In: Proceedings of the I Euro-Amer. Beaver Congr., 14-16 (1999)
9. N.A. Zavyalov, A.V. Krylov, A.A. Bobrov, V.K. Ivanov, Y.Y. Dgebuadze. *Influence of the river beaver on the ecosystems of small rivers*, (Nauka Publisher, Moscow, 2005)
10. V.V. Dezhkin, In: Proceedings the I Euro-Amer. Beaver Congr., 20-26 (1999)
11. V.A. Popov, *Mammals of the Volga-Kama region*, (1960)
12. N.D. Grigoriev, In: Proceedings of the Voronezh state reserve, **16**, 86-99 (1969)
13. Y.Y. Dgebuadze. In: Proceedings of the Kola Scientific Center of the Russian, 35-50 (2000)
14. V.S. Porfiriev, Transaction of the Volzhsko-Kamsky National Nature Zapovednik, **1**, 17-23 (1968)
15. A.S. Taisin, *Raifa forest in the boreal forests of Eurasia* (2008)
16. I.S. Legeyda, The thesis for the degree of candidate of biological Sciences, *Environment-forming activity of beavers and protection of coastal biogeocenoses of Ukraine* (1992)
17. F.N. Lisetskii, A.O. Poletaev, Z.A. Buryak, Journal of Physics: Conference Series, **2388 (1)**, (2022)

18. A.S. Taisin, A.P. Dedkov, Transaction of the Volzhsko-Kamsky National Nature Zapovednik, **6**, 115-127 (2005)
19. Y.A. Gorshkov, D.Y. Gorshkov., A.L. Easter-Pilcher, B.K. Folia Zool. **51**, 67-74 (2002)
20. A.L. Easter-Pilcher, Forage utilization, habitat selection and population indices of beaver in Northwest Montana. M.S. thesis, (1987)
21. D.N Tsyganov, Phytoindication of ecological regimes in the subzone of coniferous broad-leaved forests, (Nauka Publisher: Moscow, 1983)
22. F. Fyodorov, A. Yakimova, Baltic forestry, **18(2)**, 278-287 (2012)
23. P.I. Danilov, F.V. Fyodorov, Russian Journal of Theriology, **15(1)**, 43-48, (2016)
24. A. Law, K.C. Jones, N.J. Willby, Aquatic Botany, **116**, 27–34 (2014)
25. M. Elmeros, A.B. Madsen, J.P. Berthelsen, Lutra, **46**, 153–162 (2003)
26. N.T. Donkor, J.M. Fryxell, Plant Ecology, **148**, 1–12 (2000)
27. A.A. Porokhov, The thesis for the degree of candidate of biological sciences *Reacclimatization and biocenotic role of river beavers Castor fiber L. in the territory of the Priilmenskaya lowland* (1998)
28. M.M. Pollock, T. Beechie, J. Wheaton, C. Jordan, N. Bouwes, N. Weber, C. Volk, BioScience, **64 (4)**, 279–290 (2014)
29. G. Sjoberg, J. P. Ball., Restoring the European Beaver: 50 Years of Experience (Eds., Pensoft Pub., Sofia, 2011)
30. R.T. McMaster, N.D. McMaster, RHODORA, **103(915)**, 293–320 (2001)
31. D. Müller-Schwarze, L. Sun, Cornell University Press, *The beaver. Natural History of a wetlands engineer*, 192 (2003)
32. F. Rosell, O. Bozser, P. Collen, H. Parker, Mammal Review, **35**, 248–276 (2005)
33. L. Simonavičiūtė, A. Ulevičius, Ekologija, **53(3)**, 34–44 (2007)
34. J. Bonner, J. Anderson, J. Rentch, W. Grafton, Wetl. Ecol. Manag, **17(5)**, 543–554 (2009)
35. E.P. Odum, *Fundamentals of Ecology*. *Third Edition* (1971)
36. A.A. Aleinikov, Bulletin of Tver State University. Series: Biology and Ecology, **18**, 60-68 (2010)
37. N.A. Zavyalov, The thesis for the degree of candidate of biological Sciences, *Dynamics of the number and environment-forming activity of the beaver in the Darwin Reserve* (1999)
38. Y.Y. Dgebudze, N.A Zavyalov, V.G. Petrosyan, KMK Scientific Press Ltd., 150 (2012)
39. T.I. Oliger, in: Proceeding of the Preservation and study of geo- and biodiversity in the protected areas of the European North of Russia, 166–170 (2014)
40. E.V. Ustabaeva, The thesis for the degree of candidate of biological Sciences, *Regional ecological features of the river beaver population with an assessment of its impact on steppe biocenoses of the Orenburg Region* (2013)