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The Status of Mammal Populations in the Middle Urals and Factors Determining Their Distribution and Density

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Abstract—Changes in the distribution and abundance of some game mammals have been analyzed over the past 100–150 years. Correlations between changes in the population density of species in slightly and strongly transformed habitats have been revealed, which show that the influence of anthropogenic factors on the population density of species has a highly complex pattern. Transformation of habitats leads to disturbances in the species composition of communities, changes in the population density of species, and disruption of functional relationships between them.

Keywords: mammals, distribution, abundance, transformation, habitat, influence

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The intensive economic development of the Urals began approximately 300–400 years ago. Since that time, forest and forest-steppe communities of the Middle Urals have undergone significant transformations. During the past 150 years, the abundance and ranges of some mammal species have decreased significantly; some species have disappeared, while others have expanded their rages and increased in numbers.

The red deer (*Cervus elaphus*), Russian desman (*Desmana moschata*), and West Siberian subspecies of the European beaver (*Castor fiber pohlei*) have become completely extinct in the Middle Urals and neighboring areas. The local range of Russian desman reintroduced in Kurgan and Chelyabinsk oblasts is also shrinking. This species lived along the Tobol River and in floodplain lakes upstream from the city of Kurgan and along its tributaries, the Ui and Toguzak rivers, but has decreased in abundance during the past 15 years and disappeared from many areas. The European mink (*Mustela lutreola*) has also become much less abundant: no reliable information on its occurrence have been obtained over the past 20 years. The ranges of reindeer (*Rangifer tarandus*) and wolverine (*Gulo gulo*) have also become smaller.

Various aspects of the impact of anthropogenic landscape transformation on animals have been considered by many Russian researchers (Formozov, 1937, 1959, 1962; Kirikov, 1966; Yurgenson, 1968, 1973; Danilov et al., 1966; Vladyshevskii, 1980; Kurkhinen et al., 2006; etc.). Studies on the fauna of the Urals were initiated by scientists and explorers of the 18th and 19th centuries such as P.I. Rychkov, I.I. Lepekhin, P.S. Pallas, and S.P. Sabaneev. In the 20th century, these faunistic studies were continued by S.A. Kuklin (1938), S.S. Shvarts, V.N. Pavlinin, N.N. Danilov (1951), M.Ya. Marvin (1968, 1969), K.I. Berdyugin (1979, 1997), V.N. Bol'shakov (1977; Bol'shakov et al., 2000), and others.

Faunistic and population ecological studies in the Urals were mainly focused on small mammals, rodents and insectivores. Large- and medium-sized mammals received less attention. Meanwhile, many of them are exposed to a double anthropogenic impact: on the one hand, transformation of ecosystems leads to significant changes in the structure of communities, as well as in trophic and other relationships between species; on the other hand, game mammals suffer additional pressure as they are directly exterminated, i.e., they are at higher risk for extinction of drop in abundance than other mammals.

In this context, it appears important to perform a general analysis of changes that have taken place in the structure of communities of game mammals. In addition, the effects of particular anthropogenic factors on populations and communities of carnivores and ungulates mammals are as a rule known only qualitatively, while their quantitative aspects have not been studied sufficiently.

The purpose of this study was to analyze changes in the distribution and abundance of some mammal species in the Middle Urals over the past 100–150 years, reveal the causes of changes in the composition of the fauna, and quantitatively characterize the dependence of species density on particular factors. Our main task was to quantitatively evaluate the influence produced by the most powerful habitat-transforming factors on

a series of mammal species within large territories. The interest in large territories stems from the following reasons: first, many local effects of anthropogenic transformations have already been studied in detail; second, within a large territory (subzone, zone, or province), it is always possible to find habitats that markedly differ in the density of inhabiting species. The question is whether it is adequate to characterize a large territory using some average parameters and whether correlations observed at the local level hold true in meso- and macrolandscapes. The degree of landscape generalization in our study corresponds on the whole to the maximum degree used by Kurkhinen (2001) to analyze the impact of forest exploitation on the fauna and structure of communities in Fennoscandia.

Sverdlovsk oblast is not uniform with respect to topography, climate, and vegetation. The Urals, being extended in a meridional direction, determine specific features of its climate and the pattern of vegetation zones. These mountains serve as a barrier for northwesterly air masses, which in significant amount are detained at the western macroslope, where the precipitation in some areas reaches 800 mm. The southeastern part of the oblast turns out to be in the shadow, receiving about 400 mm of precipitation. Another feature is that July and January isothermal lines in the central part of the oblast pass in a meridional direction. Some areas in the north are in the northern taiga subzone, while most of the territory is in the middle and southern taiga subzones. The southeastern part of the oblast lies is located in the subzone of pre-forest-steppe pine–birch forests. There also is a fragment of northern forest–steppe.

The southwestern part of the oblast is specific: there are areas of southern taiga, deciduous–coniferous forest subzone, and forest–steppes. Moreover, the main forest-forming species in the southwest is spruce, instead of pine that dominates in most regions in other parts of the oblast. Unevenness of topography and vegetation adds to the complexity of our task: it is clear that anthropogenic transformations superimposed on specific natural features of landscapes and vegetation may cause the development of processes by different scenarios. For these reasons, the southwestern region was excluded from analysis when correlations in the northern and southern parts of the oblast were evaluated.

MATERIAL AND METHODS

The study was performed with 13 mammal species whose population density was assessed by means of winter route censuses taken in the administrative units of Sverdlovsk oblast. Predators were represented by the red fox (*Vulpes vulpes*), wolf (*Canis lupus*), lynx (*Lynx lynx*), sable (*Martes zibellina*), pine marten (*Martes martes*), stoat (*Mustela erminea*), Siberian weasel (*Mustela sibirica*), and wolverine *Gulo gulo*; ungulates, by the Siberian roe deer (*Capreolus pygargus*), moose (*Alces alces*), wild boar (*Sus scrofa*), and, partly, reindeer *Rangifer tarandus*. In addition, changes in the density of two dominant species, red squirrel (*Sciurus vulgaris*) and mountain hare (*Lepus timidus*), were analyzed. Average values of population density over periods of 20 to 40 years were used, beginning from 1970.

Influencing factors included in analysis were as follows: the proportions of farmlands and forest areas, human population density, patchiness of forest habitats, and proportion of young trees in the forest structure. The patchiness (beta diversity) of forest lands was determined as the number of compartments within a randomly chosen area in forest inventory maps. On the whole, about 1000 plots, 100 ha each were processed (Korytin and Pogodin, 2002; Korytin et al., 2003).

The territory of Sverdlovsk oblast was divided into five regions by the criterion of similarity in the population dynamics and average density of the moose (Pogodin, 1996). The regions were designated according to their geographic location: northwest, northeast, southwest, center, and southeast. The boundaries of these regions proved to be 80% coincident with those of forest subzones and provinces as well as with the theriogeographic division of the Middle Urals (Bol'shakov et al., 2000). The analysis was performed at different levels of generalization: at the level of municipal formations and at the level of regions distinguished by Pogodin (1996), which included several municipal districts each,.

RESULTS AND DISCUSSION

Communities in the southeast has been transformed to the greatest extent. Simpson's diversity index reflecting stress level in the community is the highest in this part of the oblast, maximal, while the total long-term average population density of the squirrel, mountain hare, predators, and ungulates is the lowest. This part of the oblast is characterized by a high proportion of farmlands, one of the highest densities of rural population, and low proportion of forests (Table 1).

Habitats in the mountain part of the Northern Urals turned out to be the least transformed. The curve of species diversity–dominance in this area is similar to that one typical for slightly disturbed territories, Simpson's index is minimal, and the total population density of the above-listed species is maximal.

Below, we consider changes in the distribution and abundance of individual carnivore and ungulate species.

The moose is widespread throughout Sverdlovsk oblast. it was absent in the forest-steppe zone of this region and in districts adjacent to present-day Kurgan oblast in the second half of the 19th century (Sabaneev, 1988) but populated this region by the mid-20th century. After World War II, the abundance of moose increased along with intensification of logging. As a result of such intensive forest exploitation, the proportion of mature and old-growth forests

Table 1. Description of regions with different degrees of anthropogenic transformation of habitats in Sverdlovsk oblast

Parameter	Northeast	Northwest	Southwest	Center	Southeast
Total animal density, ind./1000 ha	15.6	29.9	19.4	15.5	13.3
Total animal biomass, kg/1000 ha	270.0	470.0	512.3	617.8	566.1
Number of species	13	13	12	10	13
Simpson's diversity index: $D = 1/\Sigma(n_i/N)^2$	2.98	2.55	2.80	3.19	4.02
Patchiness of forest habitats (compartments per plot)	8.0	13.0	14.5	17.9	21.5
Proportion of farmlands, %	5.1	6.2	27.5	17.0	33.6
Rural human population density, ind./km^2	0.9	3.4	4.9	11.3	7.0

Table 2. Correlation between population density of anthropotolerant species with factors of anthropogenic transformation in the north and south of Sverdlovsk oblast ($p < 0.05$ or lower)

Parameter	North			South		
	wild boar	roe deer	red fox	wild boar	roe deer	red fox
Proportion of farmlands	0.90	0.75	0.50	0.67	0.75	0.73
Proportion of forests	ns	ns	ns	–0.66	–0.73	–0.79
Rural human population density, ind./km^2	ns	ns	0.54	ns	ns	ns
Patchiness of habitats	0.54	0.55	0.56	ns	0.46	ns

ns, not significant.

decreased over 40 postwar years from 50 to 30%, while the proportion of young forests of the first age category increased from 9 to 19%. Moose became more abundant along with increase in the proportion of young tree growth in forest stands. However, its current spatial distribution does not depend on food reserves. In the northern, slightly disturbed part of Sverdlovsk oblast, the distribution of moose depends on the patchiness of forest lands: the higher the patchiness, the higher the moose population density ($r = 0.67$; $p = 0.006$; $y = 0.427 + 0.63x$). It should be noted that the patchiness of forest lands also develops under anthropogenic impact (logging). In the north of the oblast, the density of moose is also correlated with the density of rural human population ($r = 0.64$; $p = 0.0098$; $y = 0.86 + 0.01x$) and the amount of forests ($r = 0.54$; $p < 0.05$). In addition, it shows a strong negative correlation with the proportion of bogs ($r = -0.74$; $p = 0.0017$; $y = 1.31 - 2.11x$). Positive correlations with the amount of forests, forested area, and the proportion of farmlands and a strong negative correlation with the proportion of bogs were also revealed in Eastern Fennoscandia, which lies mainly in the middle and northern taiga subzones (Kurkhinen et al., 2006). In the southern part of the oblast, which has been transformed significantly, relationships with the patchiness and human population density (both much higher than in the north) disappear, and only the correlation with the amount of forests is observed ($r = 0.75$; $p = 0.00002$; $y = -0.009 + 2.57x$).

The spatial distribution of roe deer has also changed significantly over the past 150 years. In the second half of the 19th century, this species inhabited the southern low-mountain and piedmont parts of the Middle Urals but was sparse or absent in the southeastern pre-forest-steppe region of Sverdlovsk oblast and in the areas adjacent to Kurgan oblast (Sabaneev, 1988). Today the density of roe deer in the southeastern region is maximal for Sverdlovsk oblast. The species is abundant in regions with a large proportion of farmlands and high human population density (Table 2), expands northwards only in areas where the proportion of farmlands is relatively high ($y = -0.027 + 0.71x$), and positively reacts to anthropogenic transformation of its habitats. Therefore, it can be placed among anthropotolerant species.

The wild boar began its natural invasion to the Middle Urals in the late 1960s and the early 1970s, which coincided with unprecedented spread of this species in European Russia. In the same years, wild boar was introduced to the Middle Urals (Kiselev, 1986; Markov, 1997a, 1997b). The population density of the species is positively correlated with the proportion of farmlands in both heavily and slightly disturbed habitats: $y = 0.147 + 0.885x$ and $y = -0.005 + 1.24x$, respectively (see Table 2).

The range of reindeer in the second half of the 19th century was much greater than that of moose. Similarly to wolverine, reindeer spread along the mountains to the southern extremity of the Urals. Today, small, isolated populations of this species occur in the Northern Urals and, locally, in the plain, waterlogged part of northeastern Sverdlovsk oblast. The range of reindeer was also found to decrease in European Russia (Geptner et al., 1961; Perovskii, 1975; Sokol'skii, 1975; Syroechkovskii, 1986; Neifel'd, 2003). Many researchers attribute this to direct pursuit of the species and logging of sphagnum pine forests. Distribution of wolverine is also limited by the northern, slightly disturbed part of the oblast, where its density is negatively correlated with the proportion of farmlands ($r = -0.52$; $p = 0.05$; $y = 0.019 - 0.14x$).

The spatial distribution of the wolf is similar to that of wolverine. Its population density of wolf is close to maximal (0.036 ind./1000 ha) in the northeastern part of the oblast, where the human population is sparse, and low in the densely populated southern regions, except for the southwest. We attribute this to more intensive persecution of wolf in the southern regions. In general, the wolf population density in Sverdlovsk oblast negatively correlates with rural human population density ($r = -0.62$; $p = 0.00002$; $y = -0.0324 - 0.00016x$) and proportion of farmlands ($r = -0.62$; $p = 0.00003$; $y = 0.033 - 0.0615x$). It also directly depends on the proportion of forests in this administrative unit ($r = 0.67$; $p = 0.000003$; $y = -0.0234 + 0.0683x$).

The current spatial distribution of the fox has also changed significantly, compared to that in the second half of the 19th century and the first three decades of the 20th century. The fox was rare in the southeastern pre-forest-steppe and forest-steppe parts of Sverdlovsk oblast and in the areas adjacent to Kurgan oblast, which follows both from published data (Sabaneev, 1988; Chirkova, 1967) and from trade in pelts at the Irbit Fair (Silant'ev, 1898), as well as from the fur procurement during the Soviet period. Today, fox population density in these regions is maximal (Korytin, 1989).

In the southern part of the oblast, fox density is directly correlated with the proportion of farmlands: the higher this proportion, the higher the density ($y = 0.233 + 0.546x$; see Table 2); i.e., the fox, as well as roe deer and wild boar, may be placed among anthropotolerant species, which are relatively resilient to anthropogenic transformation of their habitats. In addition, the population density of these three species is much higher in transformed landscapes than in their natural habitats.

Some species (for example, the stoat, lynx, and mountain hare) positively react to certain changes in landscapes, while others respond negatively. Thus, in the north of Sverdlovsk oblast, the population density of stoat ($r = 0.68$, $p = 0.005$; $y = -0.021 + 11.18x$), lynx ($r = 0.58$, $p = 0.02$; $y = -0.017 + 1.095x$), and mountain hare ($r = 0.51$, $p = 0.05$; $y = 0.39 + 73.98x$)

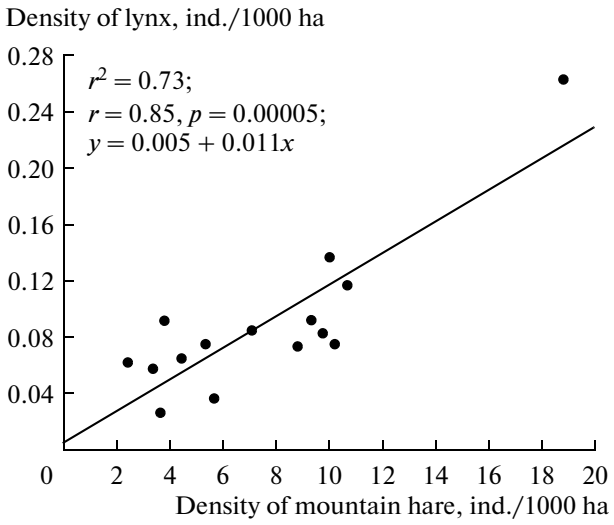

Fig. 1. Dependence of changes in the density of lynx on that of mountain hare in administrative districts of the northern part of Sverdlovsk oblast.

increases in areas with the high proportion of young trees grown up after logging, but no such correlations are observed in the southern part. On the other hand, the density of lynx in the south is negatively correlated with the proportion of farmlands. Some species in the north of Sverdlovsk oblast show a positive correlation with rural human population density, which is quite low and varies from 0.26 to 5.04 people per km^2. This concerns the densities of stoat ($r = 0.55$, $p < 0.05$), mountain hare ($r = 0.68$, $p < 0.01$), fox ($r = 0.54$, $p < 0.05$), moose ($r = 0.64$, $p < 0.01$), and lynx ($r = 0.58$, $p < 0.05$). Probably, this correlation may be explained by the well-known effect of "false profusion" (Reimers, 1972). Sparse villages in the north create surround themselves with a diverse mosaic environment consisting of fields, hay meadows, logging areas, etc. Such biotopes attract animals, and their density there is higher than in continuous taiga forests. This effect apparently has a limit imposed by human population density: when this density is relatively high, as in the southern part of the oblast, some of correlations turn from positive into negative.

The effect of significant anthropogenic transformation of habitats is not limited to considerable changes in the initial composition of communities, where the abundance of some species increases and that of other species decreases. In addition, it leads to disruption of functional relationships between species. Let us consider this phenomenon using the pair "lynx–mountain hare".

In the slightly disturbed northern part of the oblast, there is a distinct correlation between the abundance of lynx and mountain hare in both space and time (Figs. 1, 2). The correlation in time is typical for not only the northern region as a whole, but also, individually, for the majority of administrative districts: 11 out

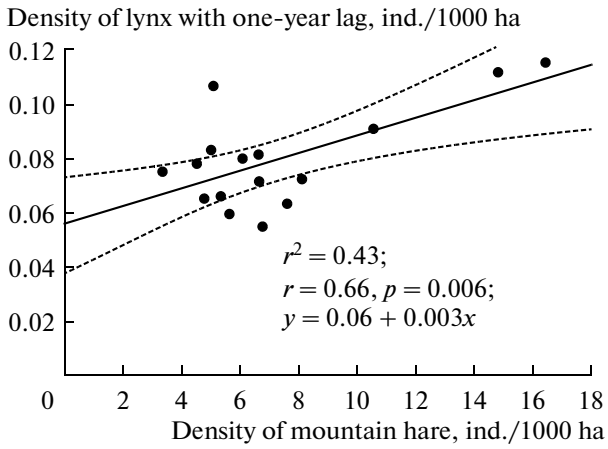

Fig. 2. Time dependence of changes in the density of lynx on that of mountain hare in the north of Sverdlovsk oblast.

of 15 districts were found to correlate with each other. If there is no direct correlation, a relationship can be found between the abundance of mountain hare and that of lynx in the previous year; i.e., the abundance of lynx in the majority of districts increases or decreases along with the abundance of mountain hare or with one-year lag (Table 3).

In 29 southern administrative districts, the direct correlation was found only in four districts and the correlation with one-year lag in three most densely forested districts. The question arises concerning factors responsible for the absence of functional relationship between the abundance of lynx and mountain hare in the southern, strongly transformed area of the oblast. The average population density of mountain hare in the south and north is similar, while that of lynx is very low in many southern districts. Hence, the ratio between the abundance of mountain hare and lynx in the north is about 100 : 1. In the south, it is almost 10 times higher (950 : 1). The influence of lynx on the abundance of mountain hare at such a rate will be very weak.

On the whole, it can be concluded that an increase in the proportion of farmlands has given advantage to 3 out of 13 species: roe deer, wild boar, and fox. The numbers of moose per unit total area also increase when the proportion of farmlands is low and begin to decrease when it exceeds 30% of the territory.

Therefore, the fauna of game mammals in the Middle Urals has undergone significant changes during the 20th century, which we attribute mainly to anthropogenic transformation of habitats and direct persecution by humans. Three species (the roe deer, wild boar, and fox) positively respond to anthropogenic transformations of ecosystems, and their abundance will increase in case of its further progression. We classify these species as anthropotolerant, The moose and mountain hare occupy an intermediate position: some anthropogenic factors cause an increase in their abundance, while other factors reduce it. The remaining species positively respond only to slight, local changes of their habitats. Significant transformations of large areas lead to reduction of their abundance, which is, especially true of large carnivores such as the lynx and wolverine. The population density of these two species

Table 3. Correlation between the abundance of lynx and hare in northern districts of Sverdlovsk oblast

District	Average density, ind./1000 ha		Lynx hare correlation	Lynx–hare correlation (lynx with one-year lag)
	mountain hare	lynx		
Karpinskii	8.82	0.08	0.62**	–0.07
Kushvinskii	18.84	0.24	0.37	0.58**
Gornozavodskii	9.78	0.08	0.56*	0.49*
Nizhneturinskii	10.70	0.08	0.19	–0.36
Novolyalinskii	9.30	0.11	0.52*	0.26
Severoural'skii	10.25	0.09	0.51*	0.65**
Alapaevskii	2.45	0.03	0.02	0.51*
Verkhoturskii	3.79	0.05	0.59**	0.77***
Saldinskii	7.05	0.07	0.15	–0.21
Garinskii	3.35	0.04	0.44	0.58**
Ivdel'skii	5.63	0.07	0.08	–0.48
Krasnoural'skii	10.02	0.14	0.11	–0.06
Serovskii	5.29	0.05	0.64**	0.88***
Taborinskii	3.65	0.03	0.35	0.76***
Tavdinskii	4.42	0.03	0.92***	0.54*

Asterisks indicate that $*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

is higher in slightly transformed habitats with the low human population density. They may be characterized as rare: their average density is low, and the density of lynx has been decreasing over several decades (Korytin, 2011).

To sum up, the results of analysis provide evidence for a complex and ambiguous reactions of game mammals to different anthropogenic factors were revealed. Most correlations between the density of species and particular factors are described by linear equations, although it would be logical to assume that they are nonlinear. A sort of bell-like curve has been obtained only for moose, but there are still some doubts as to whether or not this curve is valid. In general, anthropogenic transformation of habitats affects the species composition of communities, changes the population density of species, and interrupts functional relationships between them, which, in turn, should have a negative effect on functioning of the entire ecosystem.

It is obvious that further escalation of anthropogenic impact on ecosystems will cause even more profound transformations in the composition of primary (conditionally primary) communities and complete loss of original pattern in forest and forest–steppe communities.

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