

Wildlife and Vehicles: Analysis of Growing Conflict—a Case of the Sverdlovsk Oblast

N. S. Korytin^{a,*}, N. I. Markov^a, A. K. Kuznetsov^b, and I. Ye. Bergman^a

^a Institute of Plant and Animal Ecology Ural Branch of Russian Academy of Sciences, Yekaterinburg, 629144 Russia

^b Department for the Protection, Control and Regulation of Wildlife Use of the Sverdlovsk Region, Yekaterinburg, 620004 Russia

*e-mail: nsk@ipae.uran.ru

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Abstract—The dynamics of the number of wildlife-vehicle collisions (WVC) in the Sverdlovsk region for the period from 2012 to 2022 is analyzed. The species composition of animals affected by WVC is sharply shifted towards ungulates. The number of collisions with roe deer and moose grows faster than the animals' population abundance by an average of 3.1 times. The seasonal peak of incidents occurs in May–July for moose and Siberian roe deer, and in September–October for wild boar. A strong correlation between the number of WVC, roe deer and moose numbers and traffic volume was revealed. The rate of increase in the number of animals is about 31 and 33% (for roe deer and moose, respectively) of the rate of increase in the number of accidents, while the rate of increase in the number of cars on the roads is 7–10% of that. We hypothesize that the effect of animals' population growth on the growth in the number of accidents is higher than the effect of the growth in traffic volume.

Keywords: wildlife-vehicle collision, Siberian roe deer, moose, wild boar, Middle Urals, Sverdlovsk region

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Anthropogenic transformation of habitats and exploitation of game species have significant consequences for ecosystems. In particular, there are changes in the species composition of organisms, their population density, behavior, and movement patterns. Some anthropogenic factors can lead to an increase in the population density of some species, but most of them lead to negative consequences [1–4]. Such impacts include the construction of transportation highways, which can result in the disruption of historical ways of animal movements, but first of all their deaths on roads. Collisions between vehicles and wildlife take a shape of direct conflict, since humans are often injured. Therefore, there is a clear need to study this process in detail, assess the role of various factors and develop measures to reduce conflict tensions.

This problem received much attention in the regions with a high human population density and, accordingly, with a developed road network, thus primarily in the countries of Europe and the USA [5–17 and others]. The growth of research interest in the trends and causes of wildlife vehicle collision (hereinafter referred to as WVCs) is reflected in the change in the number of publications on this subject: while in the period from 1979 to 1999 only about 30 articles were published, in the last two decades from 10 to 80 papers are published annually [12]. In Russia, there are still very few publications on this topic [18–22]. One such

study was conducted in the Sverdlovsk region [23]. Thus, we can state a significant lack of information about the dynamics and causes of WVCs in Russia. The need to study the problem is also dictated by the growing number of road accidents [24].

Most studies have identified biological factors, road network and traffic intensity as equally important predictors of the probability of wildlife accidents [12]. The high significance of animal species, terrain features and vegetation surrounding the road has been shown [9]. The correlation between the number of WVCs and vehicle speed close to human settlements, and the peculiarities of large mammals' activity has been revealed [25]. In particular, it has been shown [25] that moose crossing the road depends on the season, time of day, and individual characteristics of animals. At the same time, we are not aware of any studies that would answer the question: what has a greater influence on the dynamics of WVCs – the growth of their populations or the characteristics of traffic volume and intensity? Obviously, the answer to this question cannot be given on a global scale – the contribution of factors may vary depending on the natural and economic characteristics of distinct regions. To our knowledge, this study is the first in Russia to quantitatively analyze the relationship between the dynamics of accidents and factors potentially affecting the probability of collisions. The latter include the abundance

of animals, the number of vehicles and the length of the road network.

The aim of our study is to provide an integrated assessment of the state of the problem “wild animals – motor vehicles” on the example of the Sverdlovsk region. In particular, we address the temporal (seasonal and inter-annual) dynamics of the number of accidents and species composition of animals involved in collisions. We especially focus on the relative influence of natural (animals’ abundance) and anthropogenic (number of vehicles and length of road network) factors on the variation in the number of WVCs over the 11-year period.

STUDY AREA

The Sverdlovsk Oblast, the largest region of the Urals, located on the border between Europe and Asia, occupies most of the middle and about half of the northern part of the Ural Mountains, as well as the western edge of the West Siberian Lowland. Its area is 194,226 km², which is comparable to the area of some European countries. It is stretched 660 km from north to south and 560 km from west to east. The climate is continental, with average temperatures of –17°C in January and +17°C in July; precipitation is about 500 mm per year. Coniferous and mixed coniferous-deciduous forests are the dominating types of vegetation, in the extreme south-east there are areas of forest-steppe. Forests occupy 82.3% of the Oblast territory. The mammal fauna includes 66 species [26] and represents a typical boreal fauna. The Sverdlovsk Oblast is one of the most important industrial regions of Russia (presumably ferrous and non-ferrous metallurgy), as well as an important transport hub – railway, road and air routes of all-Russian importance pass through it. The density of railway and motorway networks exceeds the national average [27].

The diversity of natural communities and animal species of the region, combined with the high rate of economic development, particularly, the transport industry [27], makes it a convenient area for studying the problem of ‘wild animals–motor vehicles’. The choice of the Sverdlovsk region is also determined by the fact that the region has a standardized system for collecting data on wildlife-vehicle collisions.

MATERIAL AND METHODS

Primary data. The information from the database on registered cases of wildlife-vehicle collisions created by the Department for the Conservation, Control and Regulation of Wildlife Management of the Sverdlovsk Oblast was used in this study. The number of collisions was compared to the abundance of the main species of game animals in the region according to the annual winter route surveys (hereinafter referred to as WRS). Information on the road network was taken from Rosstat transport statistics ([\[tat.gov.ru/statistics/transport\]\(https://rosstat.gov.ru/statistics/transport\)\). In particular, information on the length of roads in the Sverdlovsk Oblast in 2012–2022 was obtained from the table ‘Length and characteristics of public motor roads \(since 2006\)’ \[28\]. The dynamics of traffic volume on the roads of the Sverdlovsk Oblast was estimated via the change in the number of cars and trucks in the region in 2012–2022. Information on trucks was obtained from the table ‘Number of trucks and passenger buses by fuel type in organizations of all types of economic activity \(since 2010\)’ \[29\]. Information on passenger cars was taken from the transport statistics of Rosstat \(<https://rosstat.gov.ru/statistics/transport>\) ‘Number of private passenger cars per 1000 population \(since 2000\)’ \[29\]. Passenger buses were not included in the total number of vehicles, as their main share is concentrated in urban areas, where accidents with wild animals are very rare.](https://ross-</p>
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For each year of observations, the number of passenger cars per 1000 people was multiplied by $N/1000$, where N is the population of the Sverdlovsk Oblast in the corresponding year [30]. As a result, the absolute number of passenger cars in the Sverdlovsk Oblast for the period 2012–2022 was obtained. Since only information on the condition of roads and motor transport was taken as predictors, information on accidents on railways was excluded from the accident statistics.

Methods. The following variables were included in the analysis: N_i – total number of accidents involving wild ungulates (moose, wild boar, roe deer) in the year i ; N_{ij} – number of accidents involving wild ungulates (moose, wild boar, roe deer) in the year i and in month j ; P_i , P_k – population abundance (number of individuals) of moose and roe deer, respectively, up to the WRS data; A_i – number of trucks and cars in the Sverdlovsk Oblast in the year i ; D_i – length of roads in the Sverdlovsk Oblast in year i .

In addition to absolute values of the above mentioned variables, we analyzed the dynamics of relative indices: \tilde{N}_i , \tilde{N}_k – the proportions of individuals of respectively moose and roe deer involved in road accidents (the number of individuals involved in road accidents related to the population abundance, N_i/P_i); A_i/D_i – the number of vehicles per 1 km of road (conditional traffic density) in a particular year.

We treat annual dynamics of the indices A_i and A_i/D_i as the variation in traffic volume on the roads of the Sverdlovsk region over the 11-year period under consideration.

Calculation of population abundance and WVCs growth rates. To bring temporal dynamics of the abovementioned indices to comparable and dimensionless values we used a formula for assessment of the animals’ population growth rate [31]:

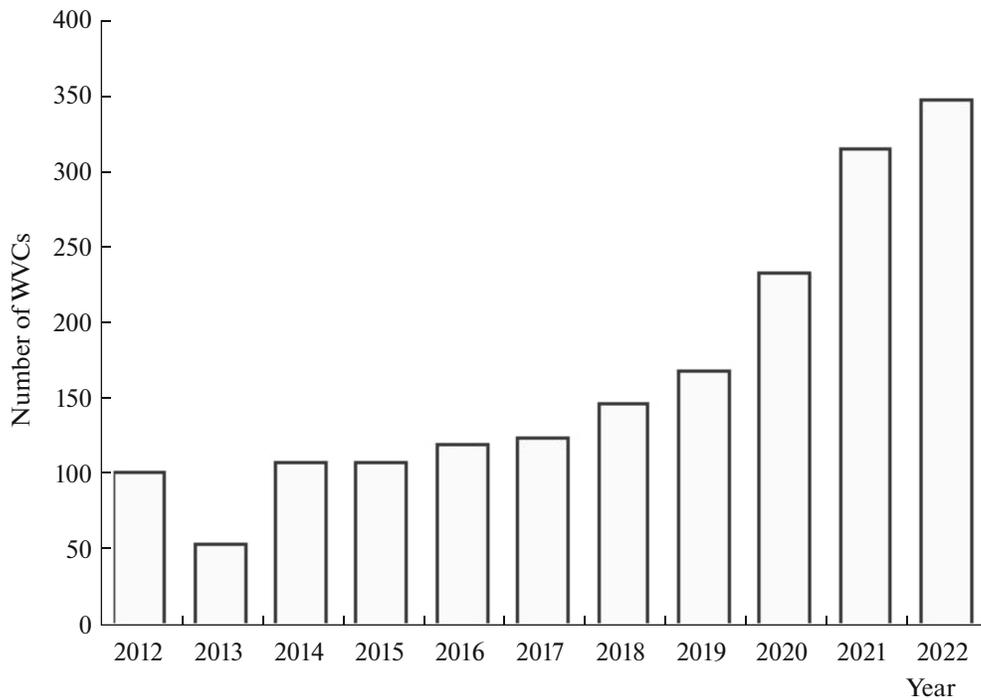


Fig. 1. Dynamics of the total number of wildlife-vehicle collisions in the Sverdlovsk oblast in 2012–2022.

$$r = \frac{\sum N_t - \frac{(\sum N)(\sum t)}{n}}{\sqrt{\sum t^2 - \frac{(\sum t)^2}{n}}}, \quad (1)$$

where N – natural logarithm of population abundance of moose and roe (P_1, P_k) or of the number of WVCs with respectively moose and roe deer (N_1, N_k); t – year number; n – total duration of observation period.

Statistical analysis was performed in the R environment (version 4.0.4) [32]. Effects of animal species and month of kill was assessed using ANOVA in package *stats*. Correlation between the number of WVCs and the animals' abundance, number of vehicles, and length of roads was assessed based on Pearson correlation coefficient. We build simple linear regression models in package *stats* to analyze the effect of traffic volume (A_i and A_i/D_i) on the proportions of animals affected by WVCs (\tilde{N}_1, \tilde{N}_k). Kendall rank correlation coefficients were calculated in the *DescTools* package [33] and the boxplots of those were plotted in package *stats*. During the observation period all independent variables (animals' abundance, number of vehicles, density of roads) varied unidirectionally (increased), the correlation between them was highly significant ($r > 0.61$, $p < 0.05$), which did not allow including them in multiple regression model. Thus, we build simple regression models. The dependent variable in these models was the proportion of animals of given species involved in WVCs from its estimated abun-

dance \tilde{N}_i . This allowed us to account for variation in population abundance. We modeled the effect of two predictors on the dependent variable:

$$\text{Model 1: } \tilde{N}_i = a + a_1 A_i, \quad (1)$$

where \tilde{N}_i – the proportion of individuals of given species involved in road accidents to the abundance in the given year, ind./ind.; A_i – the number of registered vehicles in the given year.

$$\text{Model 2: } \tilde{N}_i = a + a_1 (A_i/D_i), \quad (2)$$

where \tilde{N}_i – the proportion of individuals of given species involved in road accidents to the abundance in the given year, ind./ind.; A_i/D_i – the number of registered vehicles per 1 km of roads, or conditional traffic density of vehicles for the given year, car/km.

RESULTS

Species composition and annual dynamics of WVCs.

In 2012–2022 1831 WVCs were reported in Sverdlovsk oblast. During this period the number of accidents increased from 102 cases in 2012 to 349 cases in 2022, thus more than 3.4 times. In relative terms, the share of such incidents increased from 1.9 to 13.1% of the total number of road accidents with casualties [24].

Accidents with (by descending order) Siberian roe deer (*Capreolus pygargus*), moose (*Alces alces*), wild boar (*Sus scrofa*), brown bear (*Ursus arctos*), red fox (*Vulpes vulpes*), mountain hare (*Lepus timidus*), black

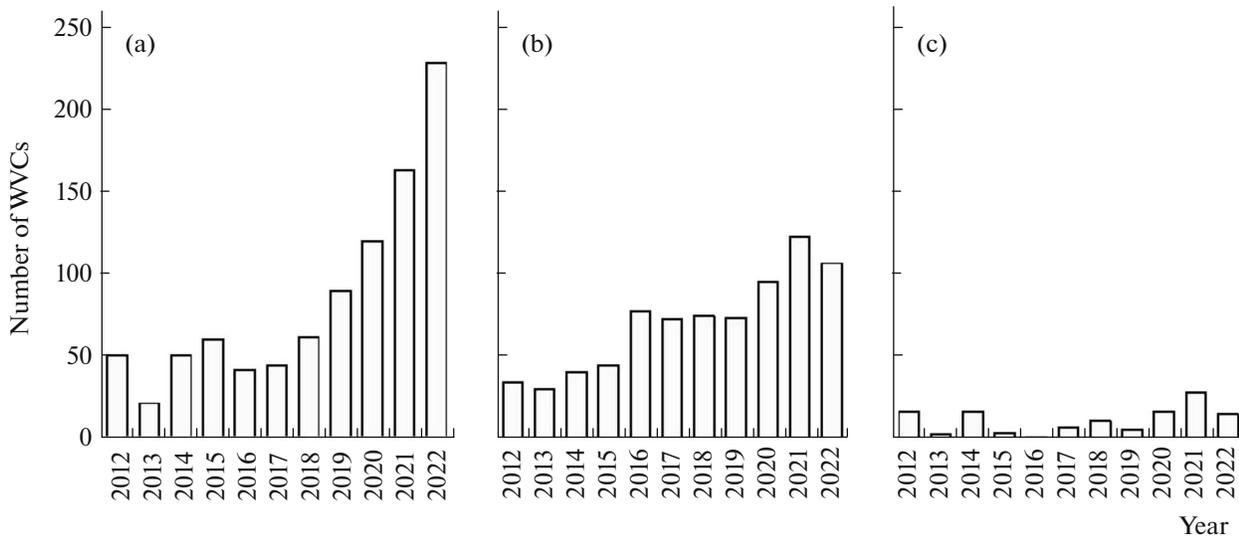


Fig. 2. Dynamics of the number of wildlife-vehicle collisions with wild ungulates in the Sverdlovsk oblast. a – Siberian roe deer, b – moose, c – wild boar.

grouse (*Lyrurus tetrix*) – 924, 767, 126, 7, 4, 2, 1 number of cases respectively. Most WVCs happen with ungulates. From all the WVCs reported in 2012–2022 ninety nine per cent (1817 of 1831) are accidents with moose, roe deer and wild boar, of those the vast majority (1691) are collisions with roe deer and moose (Fig. 2). For the last two species the number of WVCs in 2012–2022 significantly increased (4.5 and 3.1 times respectively) but for wild boar only weak changes were reported (Fig. 2).

Seasonal dynamic of collisions. The number of WVCs varies according to season and species of ungulates. The minimum number of accidents happens in February–May, the highest number – in June (Fig. 3). The results of 2-way ANOVA show statistically significant effect of month ($F_{11}; 360 = 9.96; p < 0.001$), and species ($F_2; 360 = 68.02; p < 0.001$), and their interaction ($F_{22}; 360 = 3.51; p < 0.001$).

Seasonal dynamics of the number of accidents through the study period appears to be the most stable for moose: the minimum number of collisions was observed in March, the maximum – mainly in June (Kendall's concordance coefficient (W_t) is equal to 0.78). For roe deer and wild boar the values of this index are lower: $W_t = 0.35$ and 0.28 , respectively, with minimum number of incidents recorded in the first quarter of the year and maximum in June (roe deer) and September–October (wild boar). For all species the W_t is statistically significant ($p < 0.001$). The highest number of collisions with roe deer and moose happens in June (16.1 and 21.6% from total number of WVCs with these species respectively), while the peak of accidents with wild boar is in October (more than 25%), and it is noticeably higher than that for moose and roe deer. On average, 0.20 percent of roe deer and 0.16 percent of moose were involved in road accidents

during the study period; differences between species were statistically insignificant ($F_1; 20 = 1.4; p = 0.24$). Roe deer and moose account for the majority of incidents (1691 incidents, or over 92%), and it is therefore these two species that we will consider in the following sections of this paper.

Effect of factors (correlations and regression analysis). The increase in the number of road accidents occurred in parallel with both an increase in the number of roe deer and moose and growth in the number of vehicles and the length of motorways (Figs. 4 and 5).

Pearson correlation coefficients of the ungulates populations, number of vehicles and length of roads with the number of WVCs are very high: for the number of incidents and population abundance correlation is statistically significant ($p < 0.05$) and equals $r = 0.85$ for roe deer and 0.95 for moose. Correlation of the number of WVCs and the number of vehicles is also statistically significant ($p < 0.05$) with $r = 0.83$ for roe deer and 0.97 for moose, while correlation of the number of accidents with the length of roads is 0.41 ($p = 0.21$) for roe deer and $r = 0.64$ ($p = 0.035$) for moose. Finally the correlation of the number of accidents with the conditional traffic volume (A_i/D_i) is $r = 0.65$ ($p = 0.03$) for roe deer and $r = 0.56$ ($p = 0.07$) for moose.

The regression models indicate statistically significant positive effect of the number of vehicles on the proportion of animals involved in WVCs. Coefficients of determination in model 1 (proportion of animals involved in WVCs versus absolute number of vehicles) are very high (Fig. 6). Coefficients of determination in model 2 (effect of conditional traffic volume) are noticeably lower (for moose $R^2 = 0.27$, for roe deer $R^2 = 0.36$) and the significance level (p) of the effect of

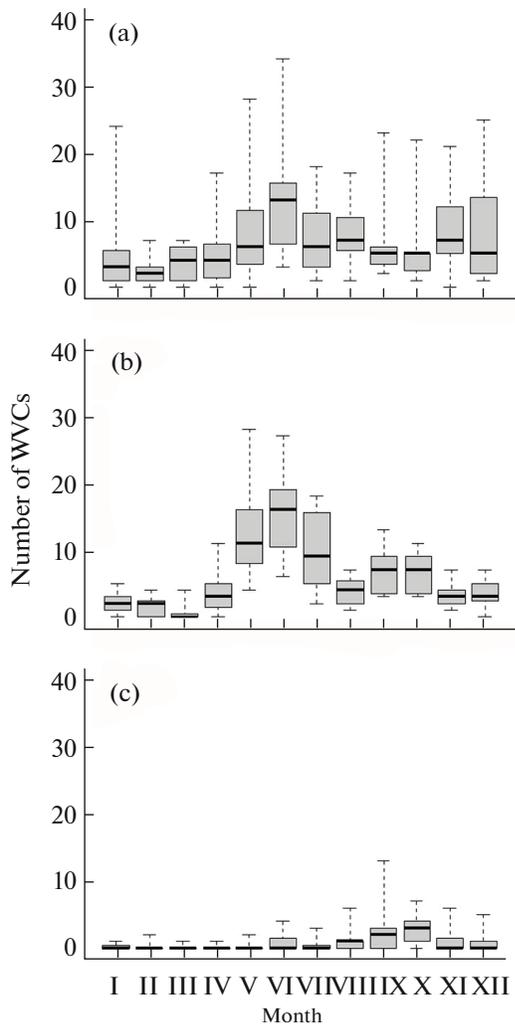


Fig. 3. Seasonal dynamics of the absolute number of wild-life – vehicle collisions with wild ungulates. a – Siberian roe deer, b – moose, c – wild boar. Line, rectangle and whiskers denote respectively the median, interquartile variance and maximum–minimum values.

conditional traffic volume on the number of incidents with moose is slightly higher than 0.05 (Fig. 7).

Analysis of the growth rates. Table 1 illustrates alternative way to assess the effect of animals’ populations and variation in traffic based on the estimates of the growth rates. The populations of both species grow at the similar rate, but for roe deer this index is slightly higher.

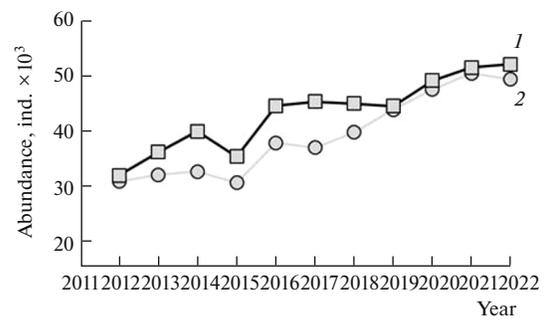


Fig. 4. Population dynamics of ungulates (1 – moose, 2 – Siberian roe deer) in the Sverdlovsk oblast in 2012–2022.

The growth rate of the number of WVCs with moose is 3.0 times higher and with roe deer – 3.2 times higher than their population growth rates. Comparing population growth rates (P_i) and the number of vehicles (N_i), we can suggest that the increase of the number of WVCs resulting from increase of the animals’ abundance is about 31–33% of the total number of accidents. The growth rate of the traffic volume (A_i/D_i) equaled 0.013. The effect of this factor on the increase of the WVCs growth rate could be estimated as 7% for roe deer and 10% for moose (see Table1).

DISCUSSION

The number of WVCs in Sverdlovsk oblast increased 3.4 times in the last 11 years. This estimate is generally similar to those previously reported for other regions. In Norway the number of accidents with ungulates increased 2.3 times in 1987–1993 (8 years), and in the last 30–40 years the number of moose killed in accidents with trains and cars increased 10 times [34]. In Sweden the number of WVCs with moose increased 6.6 times in 1970–1980 (from 902 to 5951 incidents) [35]. Another study reported that in 1989–1993 the number of WVCs with roe deer in Sweden increased from 15000 to 50000 incidents (thus 3.3 times), while the number of incidents with moose remained at the level of 4000–5000 [35].

Similar rates of growth of the number of WVCs with wild boar and roe deer (3-fold and 2.4-fold in 10 years respectively) are presented by T. Cserkecz and J. Farkas [36] for Hungary. Many authors [7, 34, 36] mention that the increase in the number of WVCs was

Table 1. Growth rates of moose and roe deer populations, numbers of WVCs with these species and the conditional traffic volume

Growth rates, (r)	Moose	Roe deer
Population abundance, P_i	0.045	0.055
Number of WVCs, N_i	0.135	0.178
Conditional traffic volume, A_i/D_i	0.013	0.013

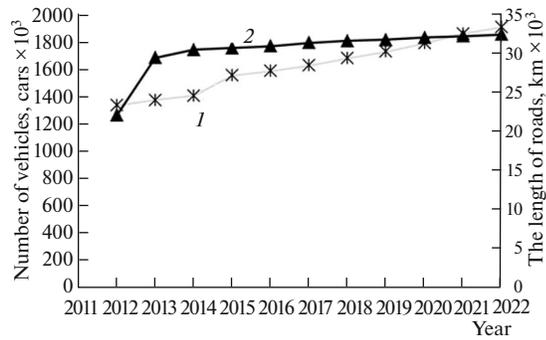


Fig. 5. Dynamics of the number of vehicles (1) and the length of motorways (2) in the Sverdlovsk oblast in 2012–2022.

higher than their population growth rates. For example, the annual number of accidents in Finland increased with growth of moose abundance and a 2-fold increase in abundance resulted in an almost 3-fold number of WVCs [7]. In our case the moose population increased 1.6 times in the last 11 years, while the number of incidents increased 3.1 times, thus almost 2-fold against the population growth. On the other hand in Sweden (in 1970–1999) the growth rate of the number of WVCs coincided with the growth rates of moose and roe deer populations [35]. In Sverdlovsk oblast roe deer population in 2012–2022 grew 1.6 times, while the number of WVCs – 4.5 times, thus almost 3-fold against the population growth.

It was also interesting to compare the rates of growth of population abundance and the number of accidents. In our case, the increase in the number of accidents exceeded the rate of population growth 3 times for moose and 3.2 times for roe deer. Based on the ratio of growth rates, the contribution of an increase in population abundance to the increase in the number of accidents can be tentatively estimated at 33% for moose and 31% for roe deer. The effect of increase in the traffic volume on the dynamics of the number of accidents, estimated in the same way, is noticeably smaller. This allows us to assume that the observed increase in the number of WVCs was caused to a greater extent by biological rather than anthropogenic factors. Note that, against the of very high Pearson correlations between animal numbers and the number of road incidents, the contributions of biological and anthropogenic factors estimated on the basis of growth rates appear not very high. This suggests that possibly a number of random (or non-random) factors affect the probability of WVC on the local level. These could be the quality of road, weather, technical condition of the vehicle, driver's behavior. The effect of such factors is not essential for analyzing the situation at the spatial scale of a big region. It is impossible to draw a precise conclusion about the contribution of changes

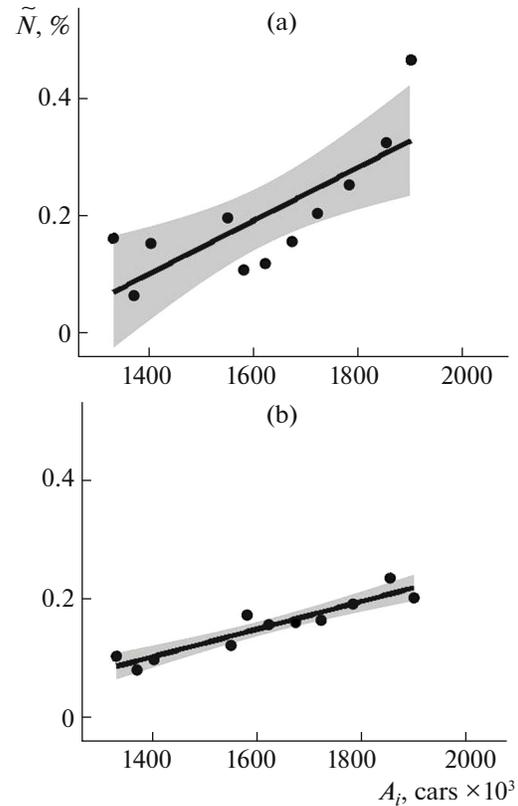


Fig. 6. The regression of the number of animals involved in wildlife-vehicle collision (% of population) on the number of vehicles (A_i): a – Siberian roe deer ($y = -5.22e^{-1} + 4.47e^{-7}x$, $R^2 = 0.55$, $p < 0.001$), b – moose ($y = -2.19e^{-1} + 2.32e^{-7}x$, $R^2 = 0.86$, $p < 0.001$): dots – original values, line – regression line, shadowed area – 95% confidence interval.

in the number of animals and traffic to the increase in the number of WVCs, since their growth rates can vary significantly over different time intervals, but it is noteworthy that, in general, our estimates coincide with the trends described in the literature [7].

Note that the COVID-19 pandemic did not lead to a decrease in the number of accidents with wild animals in the Sverdlovsk region; on the contrary, the number of accidents increased dramatically in 2020–2022. This is significantly different from the picture observed in the USA, Europe, South Korea, and Australia, where the number of accidents with wild animals decreased by 19–79% during the pandemic [37].

The ratio of species among road animals involved in WVCs is sharply shifted towards large mammals – moose, roe deer, wild boar, brown bear. We believe that in our case the predominance of large animals is a biased estimate, since the data of other researchers [38, 39], as well as the authors' own observations, suggest that the number of foxes hit by cars can be comparable, for example, with that of roe deer. According to [40], indexes of the number of road traffic accidents for many representatives of carnivores, rodents and

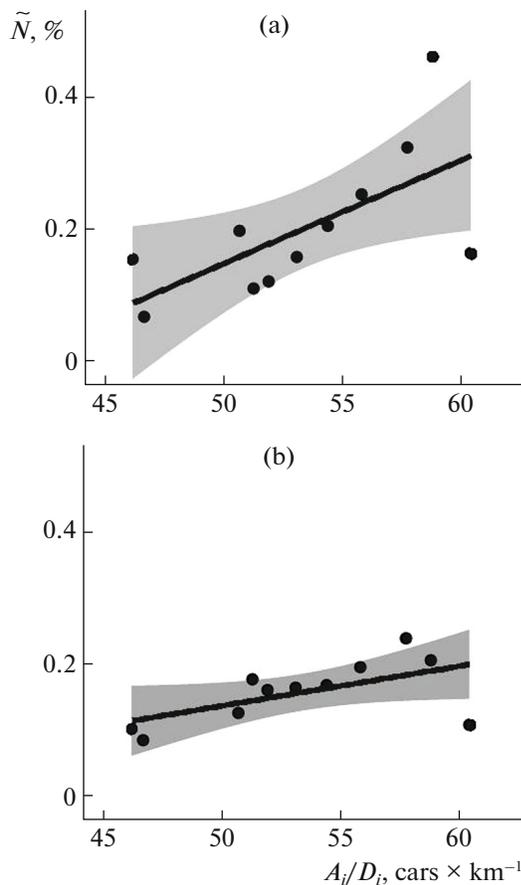


Fig. 7. The regression of the number of animals involved in wildlife-vehicle collision (% of population) on the number of vehicles per 1 km of road (A_i/D_i): a – Siberian roe deer ($y = -6.37e^{-1} + 1.57e^{-2}x$, $R^2 = 0.36$, $p = 0.03$), b – moose ($y = -1.66e^{-1} + 6.03e^{-3}x$, $R^2 = 0.27$, $p = 0.058$): dots – original values, line – regression line, shadowed area – 95% confidence interval.

hares in southwestern Virginia (USA) were higher than for white-tailed deer.

The seasonal dynamics of the number of incidents with cervids in the Sverdlovsk Oblast mainly coincides with the results of other researchers. The maximum number of cases is recorded in May–June and the minimum in January–February [9, 12, 39, 41–43]. A similar trend is also characteristic of carnivores [44] and some birds [40]. At the same time, many authors (see review [12]) note that there is also an autumn peak in the number of WVCs, which is less pronounced compared to the spring-summer peak.

In the countries of Fennoscandia (Finland, Sweden, Norway), the maximum number of collisions with moose occurs during the fall and winter period with small differences between countries [7]. W. Neumann et al. [45] studied moose crossing times and the number of accidents in northern Sweden and suggested that the fall-winter peak probably results from poor lighting and road conditions than from increased

moose movements on the road. Limited visibility affects a driver's ability to detect ungulates crossing the road [46], and the detection distance of moose during darkness can average only about 100 m [47].

We did not detect an autumn peak for either moose or roe deer. At the same time for wild boar the maximum number of WVCs is observed in the fall. The same fall peak in the number of collisions with wild pigs has been shown for Italy [43], Czech Republic [9], Croatia [48], Georgia in the USA [49].

The presence of the second (fall) peak in the number of WVCs with cervids has also been reported from a number of Russian regions [18, 21, 50], including the Sverdlovsk region [23]. Our data show that the number of accidents decrease in the fall and winter compared to summer months, despite the ungulate rut and seasonal migrations of moose. This suggests that the peak in the number of WVCs in spring and summer results not only from increased activity of ungulates, but also from increased traffic due to the prolongation of daylight and other factors. Another reason for high activity of animals in May–June may be spring forest fires while the low number of collisions in January–March is due to the seasonal decrease in both the mobility of wild ungulates and the intensity of traffic flow.

CONCLUSIONS

The increase in the number of accidents with wild ungulates, which is faster than the rate of growth in the number of these species and the number of cars, indicates a growing conflict between the interests of the hunting industry and the developing transport industry. The conflict, insignificant even 10 years ago, is now gaining significant proportions in the Sverdlovsk region – the number of collisions with wild animals in 2022 amounted to at least 10% of the total number of registered road accidents with injured people. The effect of WVCs on animal populations is relatively small – less than one percent of the estimated number of animals involved in incidents on roads. Damage to humans may be higher – threat to health and life of drivers and passengers, insurance payments, cost of repair of vehicles, etc.

The problem of wildlife-vehicle collisions is a part of the problem of coexistence of man and the biosphere, which can only be solved by finding a compromise between technogenesis and preservation of the basic properties of the biosphere. The specific solution to finding a balance between the number of wildlife collisions and the development of the road network falls to reduction of the number of such incidents. Due to the relatively low severity of the WVCs problem in the Sverdlovsk Oblast (compared to Europe), possible initial solutions would be to study migration and seasonal movements and to build wildlife crossings in the places where animals usually cross the roads. Studies have shown that wildlife crossings in combination with

fencing reduce wildlife accidents [51] and allow large ungulate species [52–55] and smaller animals [55, 56] to cross the road safely. The use of measures such as road signage are still relatively experimental and their effectiveness is questionable [6, 57–59].

We believe that we have been able to show not only the correlation of natural (population growth) and anthropogenic (traffic volume) factors, but also the scale of influence of these predictors on the number of WVCs. The increase in the number of incidents involving moose and roe deer is mainly the result of an increase in the abundance of these species and, to a much lesser extent, an increase of the traffic flow. At the same time, despite high correlations between the analyzed predictors and number of collisions, the contributions of both biological and anthropogenic factors based on growth rate estimates appeared to be relatively small.

Understanding the causes of accidents involving animals is a prerequisite for developing measures to prevent them. In the future, it seems justified to continue accumulating comprehensive data on road traffic accidents and in-depth analysis of the ‘traffic – wildlife’ interactions, particularly taking into account the dynamics of socio-economic factors and various forms of animal behavior.

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This work does not contain any studies involving human and animal subjects.

CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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