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ADAPTABILITY TO LOCOMOTION ON SNOW CONDITIONS OF FOX, GACKAL, WILD CAT, BADGER IN THE REGION OF SREDNA GORA, BULGARIA

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ABSTRACT
Terrestrial carnivores occupying the region of Sredna Gora (Bulgaria) may experience reduced fitness through the deleterious effect of snow on locomotion, energy expenditure and food acquisition. Selection may favour mammals possessing lower foot load (body mass / food surface area).
The most common predators for Sredna Gora were the objects of our study. It was conducted during the autumn-winter seasons from 2005 to 2009 and based on carcasses of 19 foxes (*Vulpes vulpes*), 9 jackals (*Canis aureus*), 8 badgers (*Meles meles*) and 7 wild cats (*Felis silvestris*). Two methods have been used to measure foot surface: taking footprints and direct measuring of front and hind feet. The medium body mass of each species obtained for the region was divided by the foot surface and expressed in g/sm2.
Red fox is the best adapted mammal to snow conditions. Wild cat possesses a little more footload but is also well adapted to catch prey in winter.
The strangest footload of jackal produces deleterions effect on preying rodents.
Difficulties in locomotion (fitness) in snow of badgers vary greatly with changes in individual weight but are non essential for survival during the winter.

Key words: *Vulpes vulpes; Canis aureus*; footload; snow; locomotion

INTRODUCTION

Snow cover is an important factor in the life of wild mammals. Living conditions change drastically with its appearance. If in spring, autumn and summer green, brown and yellow tinges prevail, with snow the background changes entirely and the protective coat color of most species is no longer significant. The importance of that powerful ecological factor is measured not only through the change of colours, but with the occurrence of the new substrate on top of which the game moves securing his vital functions: search for food, rest, protection from enemies, migrations and reproduction. Regardless of the duration of snow cover, it causes difficulties in life and deterioration of condition resulting from the hampered locomotion, excessive energy expenditure and food acquisition. One can assume that in the deep and soft snow natural selection will give advantage to animals that move through greater foot surface area and have lower body mass (1).

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The object of our study are carnivorous mammals dwelling mostly in Sredna Gora and competing for shelter and food: red fox (*Vulpes vulpes*), golden jackal (*Canis aureus*), European wild cat (*Felis silvestris*) and badger (*Meles meles*). Our aim was to determine their abolition for locomotion and survival in snow in relation to footload. To that end we determined how many grams of the animal body mass correlate to 1 sm^2 of the foot surface area. For our country the problem has not been studied. Some authors provide information about the footprint size of wild carnivores but it is approximate and rather scarce due to the specifics of their papers (2;3). A similar study concerning the footprint size of wild carnivores in our country has not been conducted. Some Russian and Scandinavian authors conducted more detailed studies of footprints and foot surface of wild mammals in the northern latitudes of Europe and Asia (4,5,6,7,8). Of them only (6) published data about the foodload of carnivorous mammals dwelling in the northern latitudes of Russia. According to him: ”Footload differences can confirm the degree of adaptation of animals to life on snow”.

Having in mind Bergmann’s rule on the differences in the size of specimens of the same species, according to latitude we can expect the relevant differences in body mass/surface foot area ratio. That geographic specifics is related to adaptability of carnivorous mammals to snow conditions is proved convincingly by (1) about the territory of North America.

The studied issue on the territory of Sredna Gora mountain is probably related to the problem of Golden jackal expansion in the past 30 years (9), as well as the decrease in the population density of the European wild cat and the overall impact of climatic changes on wild carnivores.

The problem of locomotion of these mammals in snow conditions is related to trace finding as a method of studying behavioural reactions of game and finding out its number in the hunting farms.

HARACTERISTICS OF THE STUDIED AREA

The borders of the area in which the study has been conducted are specified on **fig. 1.** That territory includes forest areas alternating by tillable land. The terrain is predominantly hilly, with an altitude of 350 – 400 to 800 m. Slopes are oblique, cut by numerous ravines and rivers. Snowfall and retention depend on three main factors: air temperature in winter, amount of rain-/snowfall and soil temperature.

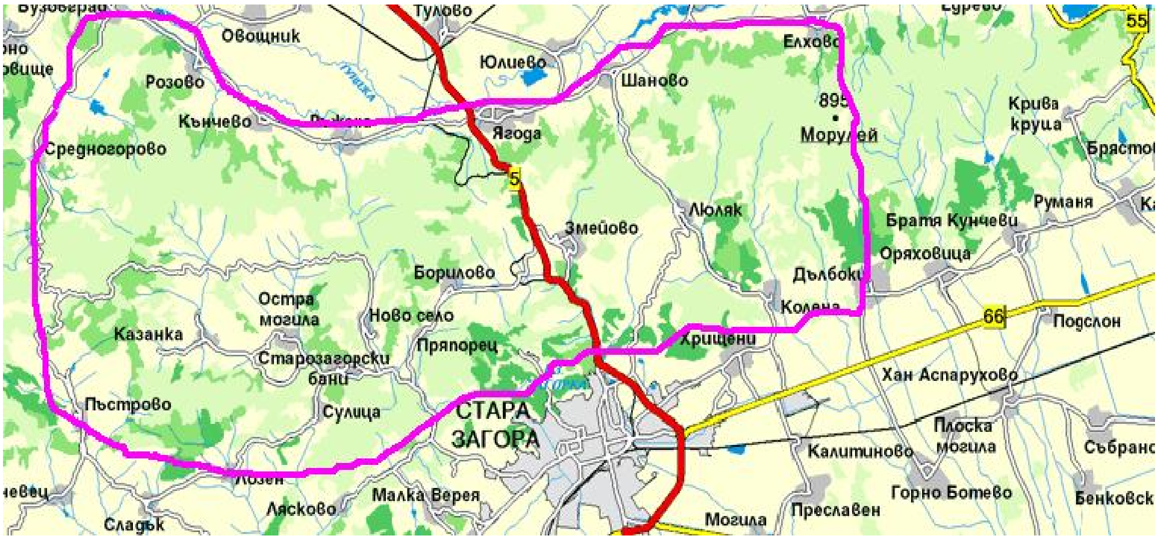

Figure1. Area research

Average January temperature is relatively high. For a period of 60 years it is from -1^{o} to $+ 1^{o}$ C. Between 4^{o} and 8^{o} C is the average diurnal air amplitude in winter the highest being in January – up to 12^{o} C (10).

Rain-/snowfall is from 130 to 200 mm, 50 % of it being rain (10).

The average January soil temperature at 2 cm depth in the studied area is between $1{,}5^{o}$ and 2^{o} C, which facilitates the relatively quick snow melting (10).

As a result of these three main factors in Sredna Gora mountain and along the Tundzha river the first snow cover appears in the second decade of December. The average annual number of days with snow cover varies greatly and is from 5 to 25 (11). For the area of Stara Zagora (the southern slopes of Sredna Gora mountain) only 3 or 4 winters have durable snow cover (12).

The height of snow is another characteristics accounting for difficulties in game locomotion. For the altitude of Sredna Gora it is from 15 to

25 sm, and in the lowlands such as the valley of the Tundzha river and around Stara Zagora it is up to 15 sm (13).

In spite of the short presence of snow cover we find it an important ecological factor influencing the life of carnivorous mammals in the area.

MATERIAL AND METHODS

Our material comprised the carcasses of 19 red foxes, 9 golden jackals, 8 European wild cats and 7 badgers, shot in the studied area. The study was conducted during the autumn-winter seasons of 2005 – 2006, 2006 – 2007, 2008 – 2009. That made it possible to study the European cat before it became a protected animal (in 2005). For greater precision 2 similar methods were used.

For the first one the biggest foot length and width of fore and hind left limbs have been measured. The measurement has been performed with no extra pressing by means of a caliper gauge with precision up to 0,1 mm. For length we determined the distance between the rear end of the heel to the tip of the claws on the III^{-rd} and IV^{-th} digit. The width was determined as the distance between the outer sides of the II^{-nd} and V^{-th} digit **(Fig. 2).**

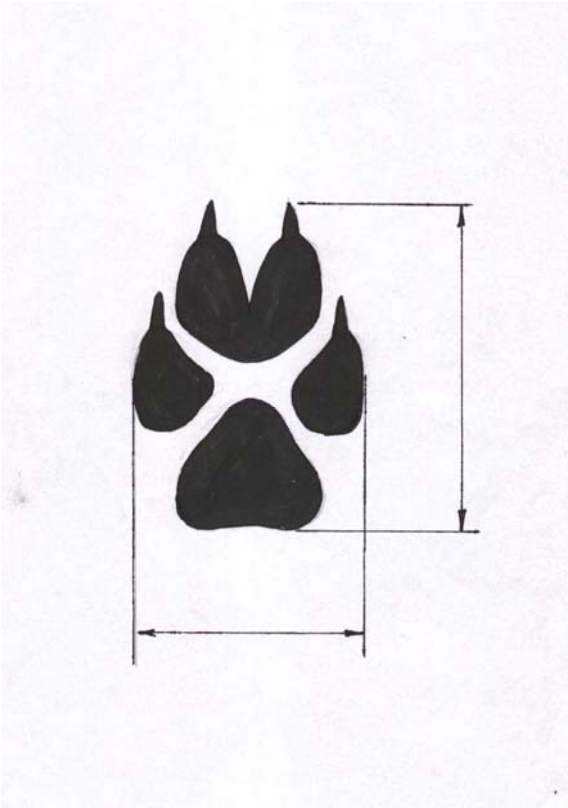

Figure 2. Footprint parameters

Taking into account the effect of paw deformation when stepping onto the substrate, we measured the size of steps as a second method. For that purpose we made footprints of the left fore and hind limb on a plate of plaster (plaster cast). For 3 to 4 minutes we pressed the paw to imprint all foot components, including the claws (except for the European cat), as is the case on wet snow. Then we took away the foot in the direction from heel to digits as when the animal moves. We decided that due to full symmetry of left and right limbs it is enough to make a footprint of left fore and hind ones only. The measurement of footprints already hard-set was done analogically to the measurement of the foot size.

It is well-known that footprints of carnivorous mammals have the shape of a more or less elongated ellipse. We took it as foot surface area and measured it according to the formula $S = \pi.a.b$, where a and b are the lengths of the small and big semi-axes in the ellipse **(Fig.3)**.

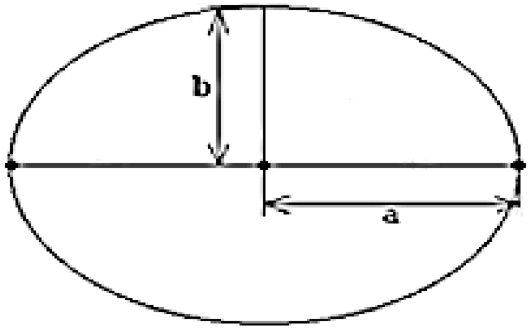

Figure 3. Determining of elipse surface (S = π.a.b)

We calculated the total foot surface area of the four limbs.

In order to calculate the footload we divided the known average weight according to our data for each animal species in the studied area (14) by the average surface area.

This was done in parallel with measured feet and footprints in g/sm^2.

RESULTS

The typical shape of footprints of a red fox, golden jackal, European wild cat and badger is presented in **Fig. 4.**

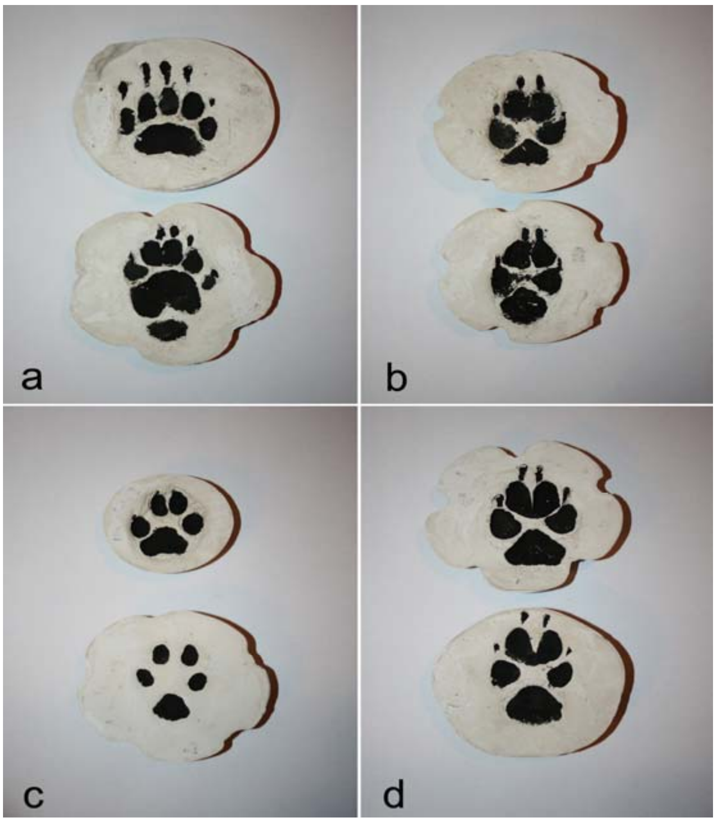

Figure 4. Footprints from fore and hind limbs of: **a** – badger**; b –** red fox**; c –** european wild ca**t; d-** jaskal

With the digitigrades red fox, golden jackal and European wild cat 4 digits are imprinted from II^{-nd} to IV^{-th}. The heel is comparatively small, on the fore imprint it is concave at the and on the hind one - convex. The badger belongs to the plantigrades species, similar to the bear. All five digits and a wide heel are imprinted with it. The claws of the fore limbs are well developed, brought to the front in a line. In all four species the front footprint is wider than the hind one. (7) explained that fact by distribution of the body weight. The weight load of the fore limbs is bigger that that of the hind ones. They take the load of half of the body plus the head and neck and the hind ones take only the weight of half of the body. In other words, the centre of gravity is located nearer the fore limbs. Moreover, when moving in snow or in soft soil, the Canidae and Felidae representatives often put their hind limbs in the fore footprints or in a prepared place. Hence, they need smaller foot surface area and do not sink.

The results from the study of feet and footprints of red fox, golden jackal, European wild cat and badger are given in **Table 1, Table 2, Table 3, Table 4**, respectively.

***Table1**. Red fox*

Studied object	Length, sm	Width, sm	a sm	b sm	π.a.b sm^2	2.π.a.b sm^2	Total area, sm^2	Footload, g/sm^2
Fore foot	4.60	3.31	2.30	1.65	11.92	23.84	45.26	116.3
Hind foot	4.47	3.07	2.23	1.53	10.71	21.42		
Fore footprint	5.38	3.84	2.69	1.92	16.22	32.44	63.9	82.38
Hind footprint	5.66	3.53	2.83	1.77	15.73	31.46		

n = 19, $G_{average}$ = 5264 g

***Table2.** Golden jackal*

Studied object	Length, sm	Width, sm	a sm	b sm	π.a.b sm^2	2.π.a.b sm^2	Total area, sm^2	Footload, g/sm^2
Fore foot	5.87	3.72	2.94	1.86	17.17	34.34	64.4	159.52
Hind foot	5.60	3.43	2.80	1.71	15.03	30.06		
Fore footprint	6.63	4.38	3.32	2.19	22.83	45.66	87.22	117.78
Hind footprint	6.52	4.06	3.26	2.03	20.78	41.56		

n = 9, $G_{average}$ = 10273 g

***Table 3.** European wild cat*

Studied object	Length, sm	Width, sm	a sm	b sm	π.a.b sm^2	2.π.a.b sm^2	Total area, sm^2	Footload, g/sm^2
Fore foot	3.70	3.06	1.85	1.53	8.89	17.78	35.58	122.4
Hind foot	3.36	3.07	1.84	4.54	8.90	17.80		
Fore footprint	4.23	3.59	2.15	1.79	12.08	24.16	47.96	90.80
Hind footprint	4.28	3.55	2.14	1.77	11.90	23.8		

n = 8, $G_{average}$ = 4355 g

***Table 4.** Bagder*

Studied object	Length, sm	Width, sm	a sm	b sm	π.a.b sm2	2.π.a.b sm^2	Total area, sm^2	Footload, g/sm^2
Fore foot	6.37	4.51	3.19	2.26	22.64	45.28	79.4	107.43
Hind foot	5.20	4.18	2.6	2.09	17.06	34.12		
Fore footprint	6.76	5.00	3.38	2.5	26.53	53.06	99.10	86.07
Hind footprint	6.46	4.54	3.23	2.27	23.02	46.04		

n = 7, $G_{average}$ = 8530 g

Comparing the data from the footload distribution it becomes clear that the load is the slightest with the badger – 107,43 g/sm^2, followed by the red fox – 116,3 g/sm^2, the European wild cat – 122,4 g/sm2. The greatest is the footload with the golden jackal – 159,52 g/sm^2. The same parameter referred to the footprint area shows similar distribution among the species, except that for the badger (86,07 g/sm^2) it is bigger than that of the red fox (82,38 g/sm^2).

Unlike the other species the badger has additional morphophysiological characteristics that help it in the survival under the severe winter conditions. It accumulates body fat prior to the first snow cover. By the end of the winter, being a source of energy for him, this is reduced to a minimum. That results to great changes in the body mass of the animal, pointed out by various authors. According to (15), in summer its body mass varies from 7 to 13 kg, and in winter – from 16 to 24 kg. According to (3), the badger usually weighs 12 – 16 kg, and in winter it reaches 23 – 25 kg. In our opinion, these data are exaggerated.

Our measurements showed significant differences in body mass. At the beginning of December a badger weighing 16000 g was measured and at the end of February – 5800 g. Changes in the body mass of this animal species are reflect on footload (from 73,0 to 201,5 g/sm^2) (Table 4), and according to the footprint – from 58,5 to 161,4 g/sm^2. This means that according to its condition it can exert smaller footload than that the red fox and greater than the golden jackal.

An important peculiarity of the badger limbs is that about $^1/_4$ of the fore foot surface and $^1/_5$ of the hind one are long claws that do not retrieve. That makes it very distinct from the Canidae and Felidae representatives in our country.

The characteristics of the badger footprint shows that both the foot surface area and the footload are not a function of its free locomotion on soil or snow only and are not direct reflection of its adaptability for life in conditions of snow. The badger locomotion is not important for its survival in winter. On the contrary, the sufficient fat reserve and its restricted activity during winter lethargy facilitate that.

Nevertheless, our observations show that the badger goes out of its den in snowy weather especially when temperature exceeds 1 or 2° C. Keeping close to its den, it has some difficulties in locomotion.

Comparing the footload of digitigrade mammals: red fox, golden jackal and European wild cat, we found out that the most adapted for running in snow is the red fox. It exerts the least footload per 1 sm^2 of the foot surface area – 82,38 g/sm^2. In our opinion this helps the finding and catching of the main prey in winter – mouse-like rodents (16,17,14). Similar in value, but a bit stronger footload is exerted by the European wild cat (90,8 g/sm^2). Like the fox, it performs the typical high jump in catching the basic prey – rodents (18,19). However, unlike the red fox it does not cover such great distances in search of food.

The area of distribution of the golden jackal in Europe and Asia is further to the south than that of the red fox. According to (15), it lives in Southeast Europe, Central and some parts of South Asia, North and East Africa. Its distribution in the highlands of our country is rather limited. Its secondary expansion started from Strandzha and Sakar about 30 years ago (20,9). Its basic diet is offal meat from wild and domestic animals, as well as waste resulting from human activity (21,22,14,23). It rummages a lot, but eats dead prey and is a typical collecting carnivore. In our opinion its eating habits and the latitude it dwells in have been reflected in the footload, which is considerable (159,52 g/sm^2), and calculated by the footprint – 117,78 g/sm^2. That makes it rather non-adaptable to conditions of snow, is probably a constraint on its eating and results in accumulation around settlements.

In similar interspecies comparisons, (1) found differences in the footload of the grey fox (*Urocyon cinereoargenteus*), the red fox (*Vulpes vulpes*), the arctic fox (*Alopex lagopus*), the coyote (*Canis latrans*) and the wolf (*Canis lupus*) in North America.

They found interspecies differences depending on latitude, but with red and arctic fox only.

Comparing our data with those of (6) for the mammals in the middle parts of Russia we obtained considerable differences in the footload of red fox and European wild cat. For the red fox, for example, it is only 25 – 43 g/sm[2], i.e. two times less than that of the red foxes in Sredna Gora.

It is quite possible such although small differences to exist within one species dwelling in the highlands and lowlands on the territory of Bulgaria.

CONCLUSIONS

Judging by the footload of the surface area of limbs the red fox is the most suited for moving on snow. The European wild cat has a bit greater footload but it is also well adapted for locomotion and catching the prey in snow. The golden jackal is the worst adapted to the snow condition due to the greatest footload. In the indirect food competition for rodents under the winter conditions in Sredna Gora mountain, the red fox and the European wild cat have advantage to the golden jackal. Difficulties in locomotion in snow for the badger vary greatly with the changes in its individual body mass, but they are not significant for its survival in winter.

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