On the modeling of wild reindeer *Rangifer tarandus sibiricus* Murrey, 1886 migration processes using the example of the Taimyr-Evenki population

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On the modeling of wild reindeer *Rangifer tarandus sibiricus* Murrey, 1886 migration processes using the example of the Taimyr-Evenki population

V G Soukhovolsky, A P Savchenko and A N Muravyov

Institute of Ecology and Geography, Siberian Federal University, 79, Svobodny prospekt, Krasnoyarsk, 660041, Russia

E-mail: soukhovolsky@yandex.ru; zom2006@list.ru; sasha-mu@yandex.ru

Abstract. The work focuses on the developing further methods for assessing the state of species during migration using satellite observation methods for monitoring the displacement of selected individuals in populations. The characteristics of the movement mode are used as an indicator of the state of a single species. The situation with deer can be considered by analogy with the assessment of the quality of the car and its movement mode. The speed of movement depends, on the one hand, on the design of the car, on the other hand, on the quality of the road surface, the availability and quality of fuel, the driver's condition, etc. Similarly, the migration mode of a deer is determined by the physiological condition and physical capabilities of the individuals, landscape characteristics, feeding availability and quality. All these indicators are expressed through the deer displacement strategy: in the absence of resources on a certain area of the migration path in a satisfactory physiological condition, it is advisable for the individuals to increase the speed of movement in order to quickly get to the area with ample food. The characteristics of a possible stop-go strategy, determined by the alternating periods of fast running, resting and eating, can also depend on the state of a single species. It is also possible that there is a connection between the state of a single species, speed of movement and current weather conditions. The question arises whether it is possible to identify the type of migration strategy and the condition of individuals during their "marathon" run by time series of average daily speeds.

1. Introduction

The Taimyr-Evenki population of wild reindeer (*Rangifer tarandus sibiricus* Murrey, 1886) is the largest in Russia. However, its uniqueness lies not only in the number and vast areas of habitat (more than 1.5 million km^2), but also in the fact that most of the year animals are in motion, passing up to 6.5 thousand km per year [1, 2]. Obviously, the rational use of resources is impossible without studying and understanding the changes in the number and condition of individuals in the population, occurring both against the background of increasing operational load and global climate change [3-5]. In recent years, not only abroad, but also on the territory of the Russian Federation, tags with radio beacons of the Argos satellite system have increasingly been used in environmental studies. Obtaining such an array of data requires a wider use of the mathematical tools.

The aim of the work is to develop methods of mathematical analysis when using remote monitoring of wild reindeer migration.

2. Materials and methods

For remote monitoring of animals, specialized collars were used with radio beacons of the Argos satellite system manufactured by ES-PAS LLC (Moscow). In 2015-2016, 8 Argos beacons were used, to determine the Doppler positions and 2 beacons with built-in receivers of GLONASS and GPS navigation systems. In 2017-2019, 7 Argos beacons without navigation receivers were used. In the spring of 2015, 7 deer were caught in the area of Lake Yessey (Lake Tise-Suoh, 68°15'42 "N; 103° 51'32.33" E) and 3 deer - at Lake Talah (68°46'27 "N; 103°47'49" E). In the spring of 2017, 4 deer were caught near Lake Yessey (Lake Heptarah, 68°40'29 "N; 103°9'38" E), 2 deer - at the lake Dyupkun (68°7'50 "N; 99°9'30" E) and one deer at the Kheta river crossing site next the settlement Novaya (71° 44'51 "N; 101°11'13" E). In addition, the work used data from deer radio beacons for 2019, tagged by employees of the Taimyr Nature Reserves.

For each deer with a radio beacon, once a day (at 0.00 am), the location of an individual was recorded. Based on the coordinates of the individual, for two adjacent days, the distance between the current locations of the deer and the azimuth of the movement direction were calculated. To calculate the distance between two points and the direction of the motion vector on the Earth's surface, the formulas of spherical geometry were used [6, 7].

The distance between two points according to beacons was interpreted as the average speed of a deer per day. The average speed may depend on the condition of the individual, the availability of feed resources, and the landscape on the route. It should also be remembered that deer are herd animals and the average speed of an individual may depend on the state of other individuals in the herd (just like the speed of a squadron as a whole depends on the availability of vessels with a minimum speed).

3. Results and discussion

The simplest model of the dynamics of the reindeer population for one season can be written as a difference equation:

$$N(i+1) = \left[f(i) - d(i) \right] N(i) \tag{1}$$

where f(i) – fertility, d(i) – mortality, N(i) – i-year population.

Modern methods for census of reindeer population using airborne methods enable to estimate the current population density [3], but not the birth and death values, which will vary from year to year. It should be understood that the fertility and mortality functions f (x1 (i), ... xn (i)) and d (y1 (i), ... ym (i)) depend on a large number of factors - the current physiological state of individuals, the food availability, weather conditions, safety from predators, etc. The form of these functions and the values of these variables in some years are unknown.

One of the most important indicators associated with population dynamics is the state of individuals in the population. The characteristics of the state positively correlate with fertility and negatively correlate with the impact of predators, parasites, and the incidence of individuals. To assess the dynamics of the population size and the state of individuals, it is possible to use methods based on information about the patterns of migration processes in the population.

Table 1 shows an example of a seasonal database for an individual specifying its migration (deer with a collar No. 34340). Similar data were collected for other individuals. The differences between the databases for individuals with collars are the length of the measurement period and the presence of data gaps.

Further, on the example of several individuals (two deer that migrated during 2019 and one during 2015), the methods for analyzing the data presented in tables 1 and 2 are considered.

As the simplest indicator of the migration mode, the average "cruising" speed V and standard deviation σ of this value can be used:

$$V = \frac{1}{n}\sum_{i=1}^{n} v(i) \quad \sigma^2 = \frac{1}{n-1}\sum_{i=1}^{n} \left(V - v(i)\right)^2 \tag{2}$$

where v(i) – daily average speed i, n – number of observation days.

Table 1. Characteristics of the displacement of a deer with a collar No. 34340 in February-July 2019.

Date	Latitude	Longitude	The average daily speed, m/day	Daily azimuth	The interval between adjacent measurements, days	Daily rate
14.02.19	70.21564	94.62467	5401.20	87.80	0.91	
15.02.19	70.29578	94.67832	9138.78	12.72	0.67	
04.03.19	70.35484	94.61696	6959.30	340.75	17.51	
05.03.19	70.35057	94.60734	595.81	217.15	0.79	2.13
06.03.19	70.34871	94.59216	604.30	249.99	1.29	0.97
07.03.19	70.36707	94.60783	2124.49	16.00	1.00	1.70
08.03.19	70.35178	94.62903	1876.26	155.00	1.37	2.30
09.03.19	70.36113	94.54271	3390.97	287.90	1.24	3.24
11.03.19	70.32568	94.58819	4294.47	156.64	1.92	3.53
12.03.19	70.34037	94.61948	2010.37	35.62	0.54	2.24
14.03.19	70.3385	94.63646	668.60	108.12	2.50	1.09
15.03.19	70.33987	94.60793	1078.48	278.14	0.73	1.14
17.03.19	70.32544	94.58874	1758.42	204.12	2.03	1.49
18.03.19	70.335	94.60993	1326.66	36.72	1.18	1.18
19.03.19	70.33646	94.60366	285.38	304.69	0.81	0.71
20.03.19	70.3388	94.62983	1013.41	75.11	0.72	1.38
21.03.19	70.30947	94.61942	3285.48	186.82	1.00	2.79
22.03.19	70.33683	94.66463	3482.48	29.07	0.53	3.04
25.03.19	70.34598	94.62345	1846.64	303.46	3.17	2.11
26.03.19	70.34136	94.65575	1313.19	113.02	1.33	1.29
27.03.19	70.33975	94.67317	676.00	105.35	1.01	2.11

Table 2 shows the values of V and σ for a number of individuals.

Table 2. The average "cruising" speed (km/day) for the number of individuals in 2015 and 2019.

Collar No.	34400	163819	163820	163821	163826	163829	163832	112853	108969
Year	2019	2019	2019	2019	2019	2019	2019	2015	2015
Average speed	5.90	22.56	21.52	18.47	18.21	18.97	18.65	14.97	11.75
Standard deviation	7.56	14.48	15.01	14.41	14.79	10.91	14.62	33.48	13.96

As shown in table 2, the values of V for different individuals vary widely. The standard deviation values characterize the unevenness of the migration speed, and taking into account the reasons why the speed of movement varies, it is important to understand the features of the deer migration mode.

To do this, an analysis of the temporal dynamics of the movement azimuths should be carried out and migration periods should be classified. In this regard, the time series of the expected values for the movement azimuths φ were studied, which varied from 0 to 360°. The azimuths of 0 and 360 ° characterize the migration to the north, the azimuth of 180° describes the displacement to the south, the azimuth of 90° describes the movement to the east, and the azimuth of 270° describes the movement to the west. The azimuth from φ = 0° to φ = 45° characterizes the movement in the direction of the NNE point, the azimuth from 315 to 360° - the movement in the direction of the NNW point, etc. Migration to the north will be characterized by movement along the NNE and NNW directions within the azimuths of 9-45° or 315-360°. Random walk on a certain area will be characterized by alternating movements in azimuths in all directions from 0 to 360°. Thus, according to the distribution of azimuths, the migration direction of an individual can be identified.

For instance, figure 1 shows a graph of daily movement azimuth values for a deer with a collar No.34340.

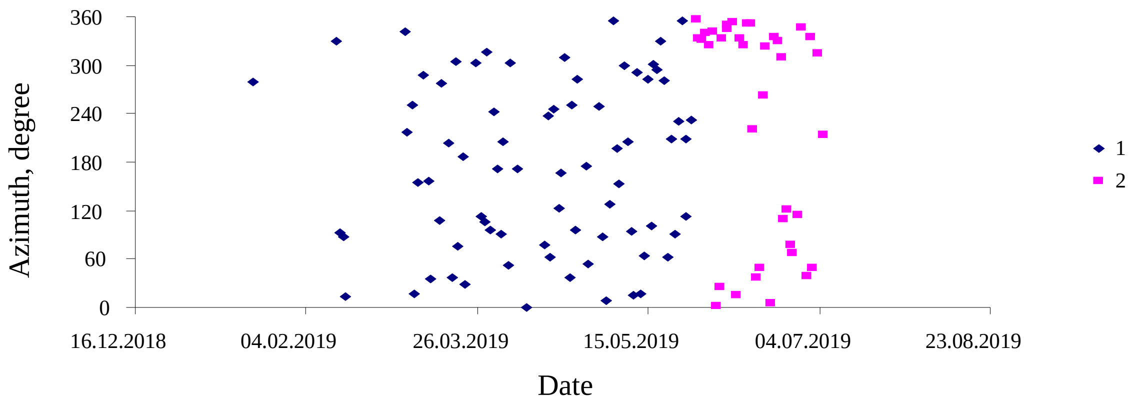

Figure 1. The graph of daily movement azimuth values for a deer with a collar No.34340: 1 – random walk, 2 – migration to the north.

Two periods of movement may be identified for this individual: random walk until 05/27/2019 and migration to the north after this date and until 07/25/2019. Using these dates, it is possible to show changes in the movement speed in these periods (figure 2).

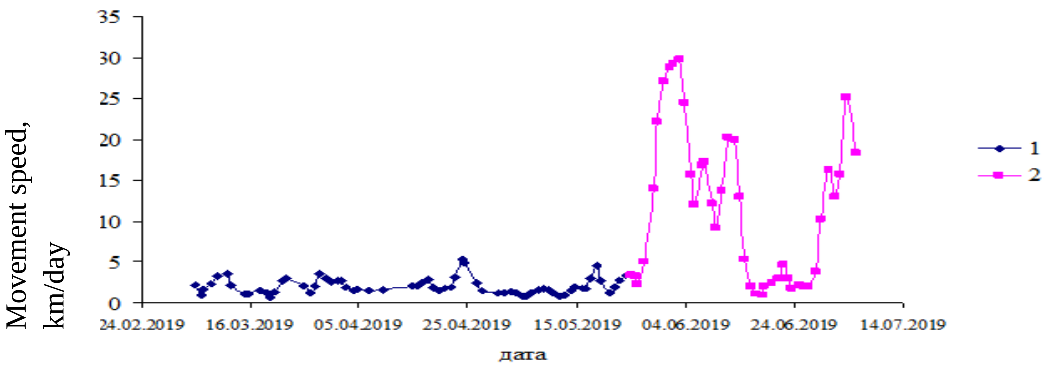

Figure 2. The movement speed of the individua the observation period: 1 – random walk; 2 – migration to the north.

As can be seen, the characteristics of the migration speed during these periods vary significantly. An important characteristic of the physiological capabilities of an individual is a change in the characteristics of movement - acceleration or deceleration of the movement speed. As an integral indicator characterizing changes in speed, a phase portrait of the movement dynamics in the plane is used {v(i), a(i, i+1) = v(i+1)-v(i) (figure 3).

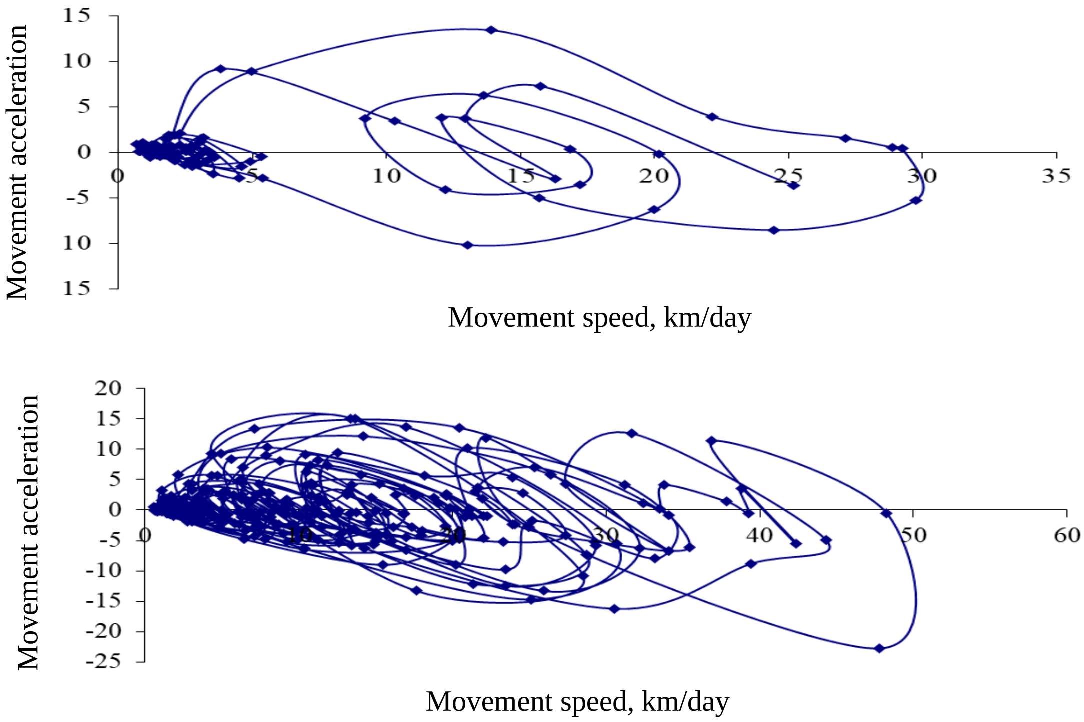

Figure 3. Movement phase portraits of the deer with collars No. 34340 and No. 61941.

The right extreme values of V (i) in the phase portrait characterize the maximum speed, the left extreme values of v (i) - the minimum. The maximum value of a (i, i + 1) reflects the maximum shift in speed during the day, and this value is important for understanding the physiological capabilities of an individual. The minimum value of the movement acceleration corresponds to the mode of sharp movement braking and can be associated both with the transition to the feeding mode and a sharp change in the state of the movement paths. Comparing the phase portraits of two individuals, it can be concluded that the range of movement speeds and the maximum value achievable by the individual speed for deer No. 61940 is almost 70% higher than for individual No. 34340.

A characteristic of the movement mode of an individual may be the distribution density function of movement speed. Certainly the distribution density function will depend on the characteristics of the movement mode, but the general distribution density function will carry information about the nature of the individual's movement and its capabilities (figure 4). An important characteristic of the movement of an individual may be the distribution function of the extreme speed values. Considering a certain function, the distribution of local maxima of the values of this function (that is, values that are more than two adjacent values) is characterized by the following function:

$$1 - F(x) = \ln(-\ln(p(i)) = A - Bx(i) \quad (3)$$

where p(i) – relative rank of the local maximum ranked by its value x (i), A and B – some constants. The value A characterizes the minimum value of the local maximum, the value B characterizes the probability of a certain value appearing in the function of the local maximum.

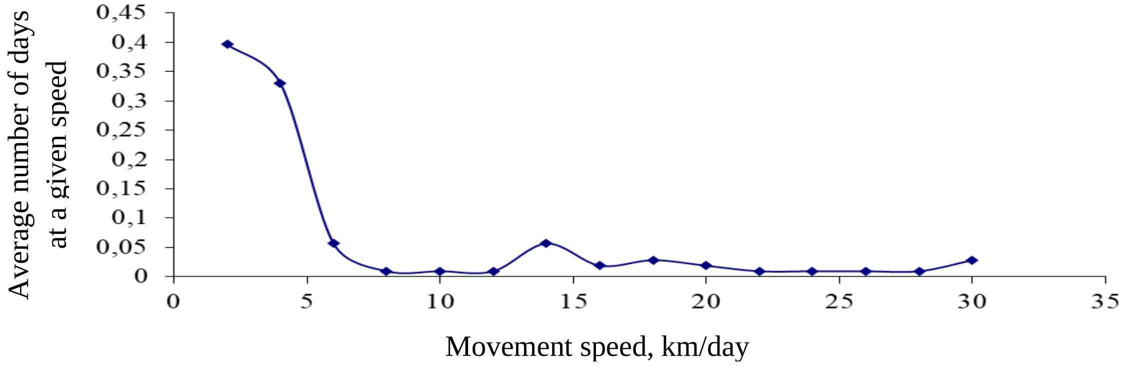

Figure 4. The density distribution function of movement speed of the deer No.34340.

If there are zones with no feed resources on the migration route, then it can be assumed that all deer moving through this area should increase their speed in order to quickly get into more abundant food areas. In this case, the correlation functions between the time series of movement speeds should have maxima in territories with a low abundance of feed. If on the way of the deer there are natural obstacles, then the speed of the deer will fall (figure 5).

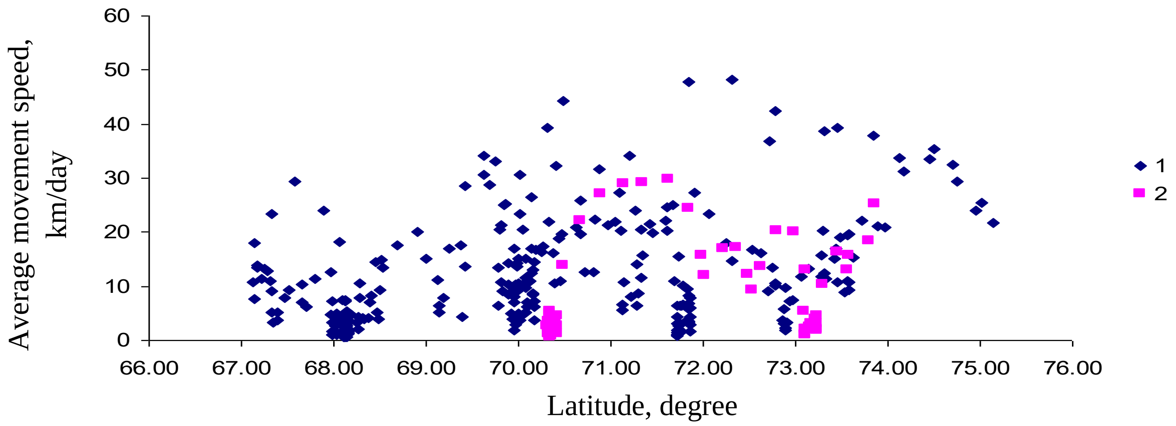

Figure 5. Relationship between the speed of the deer and their location (in latitude): 1 – deer No. 61941, 2 – deer No. 34340.

In addition to the latitudinal dependence of the speeds of movement, which is most identified in high latitudes (places of calving and summer feeding); sections of lower speeds are characterized by the presence of swamps and floodplains, which indicates their role as geographical barriers to the migration of reindeer.

4. Conclusions

A brief review of the analysis of data obtained from deer equipped with satellite transmitters showed that the use of radio collars enables to evaluate in detail the features of the deer migration modes using numerous indicators describing the connections between movements on different days, and opens up the possibility of using these indicators to assess the state of individuals, and through these indicators to assess the dynamics of the number and stability of populations and subpopulations of reindeer. Certainly, when conducting regular monitoring of the movement regime using radio collars, it is necessary to automate the calculation process, starting with data collection, further processing and obtaining generalized conclusions from the analysis. For this purpose, a special software package is required, including an interface that allows the operator to control the calculation process. Additional information on the status of biomes along the paths of deer movement and weather data makes it possible to further clarify the patterns of movement of individuals.

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References

[1] 2019 *Materials of the working meeting on the conservation of the Taimyr (Taimyr-Evenki) population of wild reindeer* (Krasnoyarsk:WWF)
[2] Savchenko A P, Sukhovolskiy V G, Savchenko P A, Muravyov A N, Dubintsov S A, Karpova N V and Tarasova O V 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **421** 052004
[3] Kolpashchikov L A and Mikhaylov V V 2015 Problems of protection and rational use of wild reindeer of the Taimyr population in modern socio-economic conditions *APEC* **1** 17-29
[4] Tishkov A A, Belonovskaya E A, Vaysfeld M A, Glasov P M, Krenke A N and Tertitskiy G M 2018 Greening the tundra as a driver of modern dynamics of the Arctic biota *Arctic: ecology and economics* **2(30)** 31-42
[5] Tishkov A A and Krenke A N 2015 Greening the Arctic in the 21st Century as an effect of synergism of global warming and economic development *Arctic: ecology and economics* **4(20)** 32-3
[6] Box G and Jenkins G 1974 *Time Series Analysis. Forecasting and Control* **1** 406
[7] Kendall M G and Stewart A 1976 *Multivariate Statistical Analysis and Time Series* (Moscow: Nauka) p 73