Patterns of the reindeer (Taimyr-Evenk population) movement in dynamics during migration

V G Soukhovolsky¹, A P Savchenko², A V Kovalev¹, P A Savchenko² and A N Muravyov²

¹ Institute of Forest, Siberian Branch of the Russian Academy of Sciences, Krasnoyarsk, Russia
² Institute of Ecology and Geography, Siberian Federal University, 79, Svobodnyi prospekt, Krasnoyarsk, 660041, Russia

E-mail: soukhovolsky@yandex.ru; zom2006@list.ru; 09petro@mail.ru; sashamu@yandex.ru

Abstract. Despite the keen interest in reindeer, a number of issues in its ecology are still poorly understood. Difficulties in assessing the state of deer populations are associated with technical difficulties, the need to track individuals in the wild. In addition, most of the year they are in motion, passing from 6.5 to 9 thousand km². To assess and predict the state of populations, information is needed not only about the number, but also about the physiological state of individuals. This work is devoted to the development of indirect methods for assessing the state of reindeer based on the indicators of the migration activity of individual individuals. The use of collars with radio transmitters makes it possible to assess in detail the peculiarities of animal movement modes using numerous indicators describing the relationship between movement speed on different days. This opens up the possibility of using data to understand the state of individuals, which, ultimately, makes it possible to assess the dynamics of the abundance and stability of wild reindeer populations in general.

1. Introduction

Reindeer Rangifer tarandus (L., 1758) - one of the main representatives of the animal world of the Arctic zone. Existing in a vast area of more than 1.5 million km², animals are in motion for most of the year, passing up to 6.5 thousand km, and in some years - up to 9 thousand km [1; 2]. Despite the keen interest in reindeer, a number of issues in its ecology are still poorly understood. Data on abundance vary, and forecast estimates are extremely contradictory: from a complete loss of the commercial value of the species to a completely optimistic scenario [3; 1]. To preserve the populations of this species, detailed information is needed on the number and state of individuals in the population, as well as on the current state of the natural environment. Changes in weather characteristics, the amount of available food resources, the impact of parasites and predators, technogenic and anthropogenic impacts, and the removal of deer by hunters will lead to a change in the state of individuals and determine the future of the population. Difficulties in assessing the number of deer populations are associated with the technical difficulties in tracking individuals in the tundra: the distances over which the deer move during migration reach hundreds of kilometres, their routes of movement change, the characteristics of the natural environment in which the deer move are quite difficult to measure.

To assess and predict the state of the population, information about the physiological state of
individuals is required. It is clear that the better their physiological state, the higher the fertility of females and the survival rate of this year's broods, the lower the risk of death from attacks by predators. However, direct measurement of the physiological state of wild reindeer in the natural environment remains technically difficult to implement. This work is devoted to the development of indirect methods for assessing the state of reindeer by indicators of the migration activity of individuals.

Information on reindeer migration can be obtained using radio collars that transmit periodic data on the current location of the reindeer via satellite communication channels. Based on this data, it is possible to determine the direction of migration and its pace - the distance travelled and the average speed of movement. However, when calculating the average speed of movement from the data of radio collars, it should be borne in mind that the movement of deer is uneven - in addition to moving along the tundra, deer spend time looking for food and food, as well as rest.

2. Objects and methods

For remote observation of animals and assessment of the current speed of their movement, specialized collars with radio beacons of the Argos satellite system manufactured by ES-PAS LLC (Moscow) were used. Deer catching in 2015–2019 was carried out in the area of Lake Essey (Lake Tise-Suokh, 68°15′42″N; 103°51′32.33″E), near Lake Talakh (68°46′27″N; 103°47′49″E), near Lake Haptaarakh, 60°40′29″N; 103°9′38″E) and in the vicinity of Lake Dupkun (68°7′50″N; 99°9′30″E). Data for 2020 are taken from the general database of the Ministry of Ecology and Rational Nature Management of the Krasnoyarsk Territory. Reindeer tagging was carried out by the staff of the Taimyr Nature Reserves at the reindeer crossing points on the Kheta-Khatanga rivers (72°22′17″N; 103°13′2.38″E and 70°57′57″N; 94°36′55″E) (figure 1).

For each deer with a collar, once a day (at 00:00), the location of the individual was recorded using a radio beacon. The coordinates of the individual were used to calculate the distance between the current locations of the deer and the azimuth of the direction of movement during two adjacent days. To calculate the distance between two points and the direction of the vector of movement on the Earth's surface, we used the formulas of spherical geometry [4].

The distance between the two points according to the data of radio beacons was interpreted as the average speed of the deer movement per day. The average speed of movement may depend on the state of the individual, the availability of food resources, the landscape of the area along which the route passes. It should also be borne in mind that deer are herd animals and the average speed of movement of an individual may depend on the state of other individuals in the herd (just like the speed of movement of a squadron as a whole depends on the presence of vessels with a minimum speed of movement).

3. Methods for indirect assessment of the reindeer state

To assess the processes of movement of individuals in each of these periods, let us consider the hypothesis of using a strategy that consists in alternating the stages of running, feeding and resting. When using this strategy, there must be a correlation between the speeds of movement of the deer on individual days. So, if the strategy “run for a day - rest for a day” is used, then there should be a negative correlation between the speeds of movement of an individual on adjacent days, which in the model of movement can be expressed by the order of autoregression $k = 1$ (Markov process). More complex variants of such a strategy, expressed in a less frequent alternation of movement and rest, can be described by autoregressive functions of higher orders $k > 1$, characterizing the dependence of the distance $L(i)$ covered on day $i$ (in fact, this is the average daily speed of movement) on the distances $L(i-j)$ passed in the previous $k$ days:

$$L(i) = a_0 + \sum_{j=1}^{k} a_j L(i-j)$$

(1)

where $a_0 - a_k$ are coefficients, $k$ is the autoregressive order, which characterizes the significance of the relationship between the current and $k$ previous values of the time series $\{L(i)\}$. Note that for $k > 1$, the spectrum of the time series of average daily speeds will be cyclic with a period depending on the values of the coefficients of equation (1) [5].
Figure 1. Migration routes of reindeer from calving and summering areas to wintering ground, according to the results of tagging with collars with radio transmitters: A – 2015-2019; B – 2020; Color of the tracks in figure A – years, in figure B – individual reindeer tracks.
If the time series of velocities of the deer is known from the data of radio beacons, then the values of \( L(i-j) \), will be known in equation (1), but the order of autoregression \( k \) and the values of the coefficients \( a_0 - a_k \) are unknown. To estimate the order of autoregressive it is possible to use partial autoregressive function (PACF) [6-8]. The autoregressive order will be equal to the number of PACF coefficients whose values exceed the PACF standard errors. With a known order of autoregression, equation (1) can be considered as a linear regression equation for the unknown coefficients \( a_0 - a_k \). The problem of finding such coefficients is well known [9; 10].

The correctness of equation (1) can be estimated by the value of the determination coefficient \( R^2 \), which characterizes the fraction of the variance of the variables \( L(i) \), described by equation (1), and the significance according to the t-test of the coefficients \( a_0 - a_k \).

4. Results and discussion

In figure 1, as an example, we give a partial autoregressive function (PACF) for a reindeer with collar 33340 migrating north in 2019. Figure 2 shows that the autoregressive order for the northward migration period is \( k = 4 \) days. Using the value of \( k \) and a series of data on the average daily speed of movement, it is possible to calculate the coefficients of the autoregressive equations connecting the speeds of movement on adjacent days.

![Figure 2. PACF for the reindeer migration period with collar 33340 in 2019: 1 - PACF value, 2 - PACF confidence interval.](image)

Table 1 shows the coefficients of the AR-equation of motion of deer No. 34340 during its migration to the north.

**Table 1.** Coefficients of the AR equation (1) of movement of individual No. 34340 to the north in 2019.

| Variables | Coefficients | Std.Err. | t-test | p-level  |
|-----------|--------------|----------|--------|----------|
| \( L_0 \) | 2.294        | 0.967    | 2.37   | 0.0239   |
| \( L(i-4) \) | -0.675      | 0.185    | -3.65  | 0.00092  |
| \( L(i-3) \) | 1.509        | 0.354    | 4.27   | 0.000164 |
| \( L(i-2) \) | -1.832       | 0.344    | -5.33  | 0.000008 |
| \( L(i-1) \) | 1.796        | 0.173    | 10.41  | 0.000000 |
| \( R^2 \) | 0.89         |          |        |          |
| \( F \) | 63.2         |          |        |          |

As can be seen from table 1, all coefficients of equation (1) are significant at a level not lower than \( p < 0.024 \). Equation (1) for the movement of deer No. 34340 explains almost 90% of the variance of the variable under consideration. The coefficient of the variable \( L(i-1) \) has a positive value, and the greater the distance covered in day \( (i-1) \), the more the deer will walk in day \( i \). The coefficient of the variable \( L(i-2) \) has a negative sign, that is, the greater the distance travelled in day \( (i-2) \), the less distance
L(i) travelled in day i. Thus, this deer is characterized by alternating movement speeds. In figure 3 the series of data are compared: average daily velocities obtained using a radio collar, and the model series according to the AR (4)-equation for the movement of deer No. 34300 to the north.

Figure 3. Field data series of average daily velocities (1) and model series (2) for the movement of deer No. 34300 to the north.

For longer migration rows (from February to December 2019) of a reindeer with collar No. 61941, three stages of migration processes can be distinguished: random wandering in the winter-spring period without a clear direction of movement; migration to the north and random wandering in the autumn-winter season (figure 4).

Figure 4. Speeds of movement of an individual during the observation period of 2019: 1 - random walk in spring, 2 - migration to the north, 3 - random walk in autumn.

For each of the stages of movement of an individual, an individual AR (k) - autoregressive model was considered. For this, the autoregression order of spring random (trophic) movements was determined from the values of the partial autoregressive function (figure 5).

Figure 5 shows that the equation of motion is of order 5. Table 2 shows the results of calculations of the AR- equation for this period.
Figure 5. PACF for movement of reindeer with collar No. 61941 in spring.

Table 2. Calculation of the AR-equation for the movement of a deer with a collar No. 61941 in the spring.

| Variables | Coefficients | Std.Err. | t-test | p-level |
|-----------|--------------|----------|--------|---------|
| L_0       | 0.442        | 0.332    | 1.34   | 0.185100|
| L(i-5)    | 0.417        | 0.091    | 4.61   | 0.000013|
| L(i-4)    | -0.885       | 0.156    | -5.68  | 0.000000|
| L(i-3)    | 1.089        | 0.169    | 6.44   | 0.000000|
| L(i-2)    | -1.245       | 0.158    | -7.86  | 0.000000|
| L(i-1)    | 1.522        | 0.093    | 16.33  | 0.000000|
| R^2       | 0.86         |          |        |         |
| F-test    | 109.7        |          |        |         |

Figure 6 shows graphs of changes in a number of field data and a model range for a deer with collar No. 61941.

Figure 6. Dynamics of movement velocities of a series of field data (1) and model series (2) for a deer with collar No. 61941 in the spring.

As can be seen from table 2, the alternation of the signs of the coefficients of the AR-equation in this case is the same as in table 1. The coefficient of determination for the model of this stage is also very high ($R^2 = 0.86$), and the coefficients of the equation are significant.

It is possible to compare the characteristics of the movement of reindeer in the spring with collars No. 34340 and 61941. As can be seen from tables 4 and 5, for deer with collar No. 61941 all coefficients
are significantly higher than for deer with No. 34340. Thus, the characteristic of coefficient \( a(i-1) \), which is responsible for the influence of the movement speed on the previous day on the current movement speed is 1.52, while for a deer with collar No. 34340 this value is 1.25. This value can be interpreted as the possibility of increasing the speed on adjacent days, which may depend on the physiological state and the availability of food for the deer.

For the stage of migration of reindeer No. 61941 to the north (to the place of calving), the PACF describes autoregression of the order of 5 (figure 7).

![Figure 7. PACF for a time series of velocities of deer No. 61941 when migrating north.](image_url)

Table 3 shows the characteristics of the AR (5)-equation for deer No. 61941.

**Table 3.** Calculation of the AR-equation for the movement of a deer with a collar No. 61941 during migration to the north.

| Variables | Coefficients | Std.Err. | t-test | p-level |
|-----------|--------------|----------|--------|---------|
| \( L_0 \) | 0.890        | 0.735    | 1.21   | 0.231001|
| \( L(i-5) \) | 0.453        | 0.116    | 3.89   | 0.000265|
| \( L(i-4) \) | -0.765       | 0.211    | -3.62  | 0.000638|
| \( L(i-3) \) | 0.804        | 0.238    | 3.38   | 0.001310|
| \( L(i-2) \) | -1.109       | 0.213    | -5.20  | 0.000003|
| \( L(i-1) \) | 1.529        | 0.118    | 12.97  | 0.000000|

R\(^2\) 0.88

F-test 80.5

Figure 8 compares the full-scale and model values of the series of average daily speeds of movement of a reindeer with collar No. 61941 when moving to the north.

![Figure 8. Dynamics of the movement velocities of a series of field data (1) and a model series (2) for deer No. 61941 in 2019 when moving south to the wintering area.](image_url)
The PACF of the time series of velocities during the return of deer No. 61941 to the south is shown in figure 9.

![Figure 9. PACF of the time series of the return of deer No. 61941 to the south.](image)

Table 4 shows the coefficients of the AR - (5) -equations for this time series of average daily rates.

**Table 4.** Coefficients of AR - (5) -equations for the time series of average daily speeds of movement of the reindeer 61941 to the south.

| variables | coefficients | Std.Err. | t-test | p-level |
|-----------|--------------|----------|--------|---------|
| L0        | 0.887        | 0.750    | 1.18   | 0.241   |
| L(i-5)    | 0.461        | 0.119    | 3.87   | 0.000300|
| L(i-4)    | -0.773       | 0.216    | -3.57  | 0.000761|
| L(i-3)    | 0.810        | 0.242    | 3.35   | 0.001468|
| L(i-2)    | -1.118       | 0.217    | -5.18  | 0.000004|
| L(i-1)    | 1.533        | 0.121    | 12.71  | 0.000000|
| R²        | 0.88         |          |        |         |
| F - test  | 75.9         |          |        |         |

Let us compare the coefficients of the AR-equations for different individuals in the same period of migration. Deer No. 61941 during migration to the north moves at a speed that is twice as high as the speed of movements (wanderings), and deer No. 34340 during migration to the north at a speed five times higher than the speed during spring wanderings. The coefficients $L_{(i-1)}$ and $L_{(i-2)}$ of the AR-equations for deer No. 61941 during wandering and migration, which estimate the influence of the speeds of the previous two days on the current speed of an individual, are close in values. The differences in the average speeds of movement can be associated with the random or trophic movement of the individual in the spring. The coefficients of the AR-equation for deer No.34340 in different periods of seasonal movements are characterized by large differences for different periods of movement. So the influence of the speed of the previous day during migration to the north is one and a half times stronger than during spring trophic movements. In this case, the changes in the speed of movement in the spring and the average speed of movement will be less than during directed migration to the north.

Studies show that even during the winter months, reindeer are in motion, but they are different from the movements associated with migration. However, even during this period, extended in time, for example, the autumn cycle begins in the third decade of July and ends in November, animals (herds, groups), which are in different physiological states, can participate, which naturally leaves an imprint on a rather complex picture of seasonal movements of wild reindeer.
5. Conclusion
The analysis showed that the use of radio collars makes it possible to assess in detail the peculiarities of
the modes of movement of deer using numerous indicators describing the relationships between the
speed of movement 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 reindeer subpopulations.

Acknowledgements
This work was supported by LLC “Arctic Scientific Centre” within the framework of research under an
agreement between PAO NK Rosneft and LLC “Arctic Scientific Centre” on the topic “Assessment of
the sustainability of Arctic ecosystems based on the study of the dynamics of the state of key species”.

References
[1] Savchenko A P, Sukhovolskiy V G, Savchenko P A, Muravyov A N, Dubintsov S A, Karpova N V
and Tarasova O V 2019 IOP Conf. Ser.: Earth Environ. Sci. 421 052004
[2] Salman1 A L, Savchenko A P, Grebel G, Okhlopkov I M, Savchenko P A, Dubintsov S A,
Soukhovolsky V G and Muravyov A N 2019 IOP Conf. Ser.: Materials Science and Engineering 734
(2020) 012011 doi:10.1088/1757-899X/734/1/012011
[3] Bonadar M G and Kolpashchkov I A 2018 Estimation of the abundance and summer distribution
of the Taimyr wild reindeer population in 2017 Scientific works of the Federal State Budgetary
Institution “Taimyr United Directorate of Nature Reserves” Norilsk APEK vol 2 29-45
[4] Vincenty Th 1975 Direct and Inverse Solutions of Geodesics on the Ellipsoid with application of
nested equations Survey Review XXIII (176) 88–93
[5] Anderson T W 1971 Statistical Analysis of Time Series (N.Y.: Wiley) p 704
[6] Box G E P and Jenkins G M 1970 Time Series Analysis: Forecasting and Control (San Francisco:
Holden-Day) p 784
[7] Box G E P, Jenkins G M, Reinsel G C and Ljung G M 2015 Time Series Analysis: Forecasting
and Control (N.Y.: Wiley) p 712
[8] Brockwell P J and Davis R A 2016 Introduction to Time Series and Forecasting (Springer Texts
in Statistics) (Berlin: Springer) p 439
[9] Wei W 2006 Time Series Analysis: Univariate and Multivariate Methods (Boston: Pearson)
p 614
[10] Shumway R H and Stoffer D S 2017 Time Series Analysis and Its Applications: With R Examples
(Springer Texts in Statistics) (Berlin: Springer) p 202