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Simulation Modelling of the System "Vegetation Cover – Domestic Reindeer" in the Yamal Peninsula: Could Global Warming Help to Save the Traditional Way of Land Use?

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Abstract

Terrestrial ecosystems of the Yamal Peninsula were subjected to the impact of domestic reindeer for several decades: the reindeer husbandry was extensively developed in the traditional nomadic way during the past century and especially recently. The ecosystem dynamics was analyzed by means of computer simulations. It was shown that nomadic reindeer husbandry is the primary cause of the observed degradation of vegetative and lichens cover. Dramatic changes in both productivity and standing crop characteristics indicate the impossibility of keeping on this way of land use under the present industrial and climatic situation in the region. Warming must be fantastically rapid for improving the present situation; global warming seems to be not a sufficient factor for restoration of forage resources in Yamal.The general question we tried to answer was: if global warming (the signs of which seems to be detected since the end of 1950s) may serve as a favoring factor of indigenous manner of land use or not? In the model we supposed that production (per year) of vegetation (lichens mainly) would exponentially increase with the growth of mean ambient temperature. Several model experiments were carried on in the attempt to determine what rate of such changes would be sufficient for keeping the number of reindeer at the modern level (ca. 350000 individuals) without degradation of vegetation. The model experiments showed that these changes have to be much faster that one can reasonably imagine. Therefore, in spite of wide-spread cliché, traditional nomadic reindeer husbandry is not an example of human and vegetation coexistence in harmony at all. Even more, the existent exponential growth of domestic reindeer herds seems to be more dangerous for the natural complexes in the region, than, say, the development of oil and gas industry. The present situation requires significant corrections in ethno-cultural and economical policy in the region, and global worming would not improve the alarming situation.

Keywords: simulation; vegetation cover; reindeer husbandry; grazing pressure; trampling down, green and lichen fodder; degradation of forage resources.

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1. Introduction

This paper represents the results of a comprehensive study on the consistent patterns of the functioning (dynamics) of the shrub and northern tundra ecosystems of the Yamal Peninsula that have been subjected to long term anthropogenic impact connected with traditional reindeer breeding and are now subjected to some new influences connected with the development of the oil and gas industry. The study is based on the integration of data accumulated during several decades of investigations of Yamal ecosystems with active participation of authors. The main approach to solving this task was the use of system analysis, which implies the construction of simulation models describing interactions between the key components of tundra ecosystems of the Yamal Peninsula with their subsequent verification and analysis. Shwartz [1] once considered that such a model can be developed only on the basis of actual data on the structure and dynamics of basic components (“blocks”), composing the “core” of tundra ecosystems which include plants, lichens, small mammals, reindeer (mainly domestic), predatory mammals (arctic foxes), and birds of pray. These components are strongly interdependent; as a rule, their interrelations are nonlinear, which complicates predictability of the ecosystem dynamics [2]. Tundra ecosystems of the Yamal Peninsula might be considered as some constellation of two overlapping subsystems: natural - biogeocenosis, and anthropogenic - anthropogeocenosis, according to definition of Russian anthropologist Alekseev [3].

The latter, created by humans through involving certain natural components into the system supporting them, is typical for so called traditional (indigenous) land use. The Yamal Peninsula is unique region among Russian Transpolar regions with well developed reindeer husbandry. In contrast to the most part of Northern regions of Russia, here the numbers of domestic reindeer have considerably increased during the past century. This was accompanied by a rapid increase in the population of the Nenets who are the principal reindeer breeders in the region, in contrast to many other indigenous ethnic groups of the North [4]. For the time being the population of reindeer of the Yamal Peninsula is as large as ca. 350000 heads. Nomadic manner of traditional reindeer breeding lead to rapid degradation of forage resources, both green forage and lichens [5-7]. Comparison of the forage crops in the beginning of 1930s (data by Andreev [8]) indicated that it has dropped substantionally percent by the end of 1990s , and this process kept on swiftly develop since that time. Nowadays it might be evaluated as only 20-30% of the figure of Andreev’s studies [9].

2. Substantiation and description of the model

The simulation model of the interaction between domestic reindeer and tundra forage resources represented a discrete event system, which was realized by means of the licensed software for simulation modelling based on JAVA platform “Anylogic University 6.0” (©”XJTechnologies ltd.”) [10]. The following dependent variables were calculated at each step of simulation experiments (one year): the lichen and green forage reserves, the food mass consumed by the reindeer, and the effect of mechanical damage vegetation (trampling down). Driving variables were reindeer numbers and climatic conditions (mean ambient temperature and humidity. The simplified scheme of the living part of the ecosystem is presented below (Fig.1).

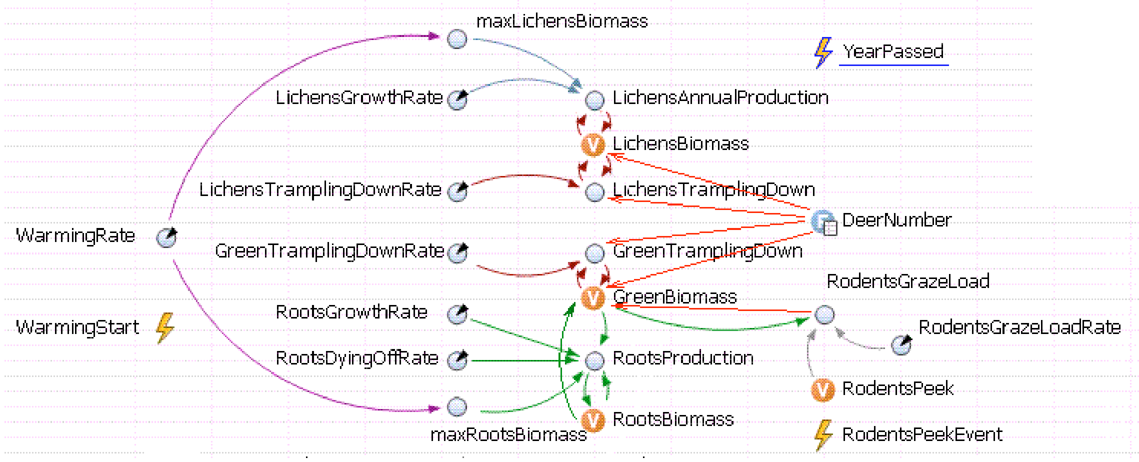

Fig.1. Simplified scheme of the model algorithm for the ecosystem (maximal fodder biomass is dependent on climatic conditions).

Climatic changes might be regarded as the most influencing factor for growth rate of lichens - one of the most important part of reindeer diet: the more favorable are temperature and humidity conditions, the more rapid is restoration rate of lichens. This is confirmed by comparison of growth rates of lichens in taiga zone of Northern Finland where mean ambient temperature is about 0°C, while in the Yamal it is about -8.4°C. [11].

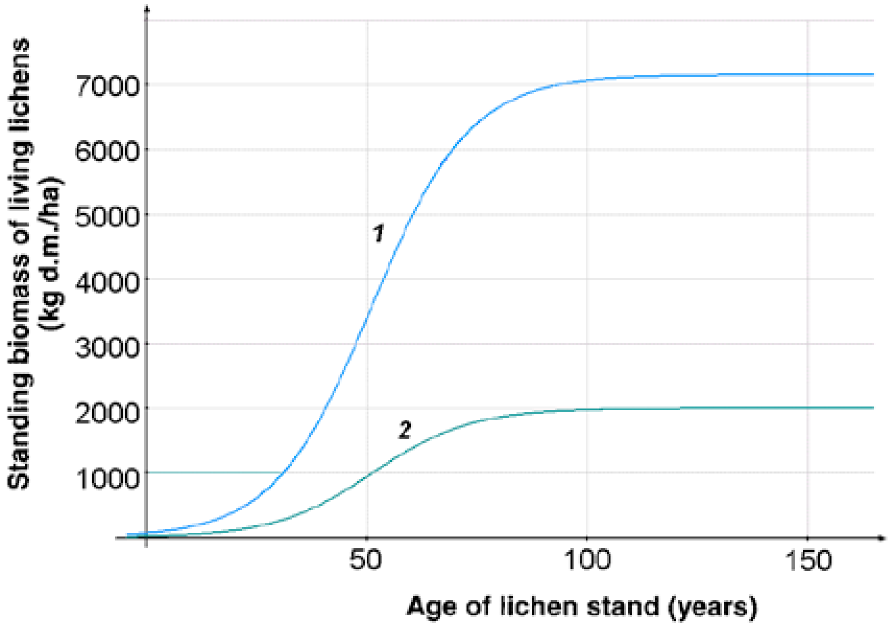

Fig.2. S-shaped dynamics of lichen stands restoration: 1 – the logistic curve well enough describing the data on lichens restoration after forest fires in dry pine forests of Finland [13]; 2 – the logistic curve of growth of lichen forage reserve in the Yamal Peninsula.

The model described lichens production by classical Verhulst's *S*-shaped growth equation (Fig.2):

$$P_L = g_L*L_y*(1 - L_y / L_{max}), \quad (1)$$

where P_L is the annual production, L_y is the lichen reserve in the current year (y), L_{max} is the maximum possible amount of the reserve in the given geographic zone (so called "carrying capacity); g_L is a coefficient reflecting the specific annual production observed at small values of the reserve in the absence of limiting factors (the "starting production"). Analysis of published data on lichen biomass production in different regions of the reindeer breeding zones [12-14]) as well as our own observations on the natural restoration of lichens in Yamal [15] showed that the maximum specific production of lichens (g_L/L) was approximately the same in all cases (4.5–5.0% of the biomass reserve). On the other hand, the L_{max} varied under different climatic conditions (it was about 3.5 times higher in the taiga zone of Finland compared to the region of Yamal). It seems reasonable to suppose that it is carrying capacity (L_{max}) which changes with changes in climatic conditions rather than g_L which are about equal under different conditions (g_L = 0.09). Andreev [8] estimated the mean annual food demand of a reindeer as 1.25 and 2.5 t of lichen and green forage respectively. We took these estimates as basic assumptions for foraging load when developing the model:

$$F_L = 1.25*N_y, \quad (2)$$

$$F_G = 2.5*N_y, \quad (3)$$

where F_L and F_G are food loads (t/year) on the lichens (L) and green forage reserves (G) respectively, and Ny is the number of reindeer in the year y. Andreev's[8] calculations also took into account unproductive (mechanical) loss of foraging reserves. It is known that that unproductive loss rapidly increases with decreasing amount of pasture food [16-18]. Therefore, we assumed that the loss of resources due to trampling down was directly proportional to the numbers of reindeer and inversely proportional to the food reserves:

$$T_L = t_L* N_y/ L_y, \quad (4)$$

$$T_G = t_G*N_y/ G_y, \quad (5)$$

where T_L and T_G are the losses due to trampling down of lichen (L_y) and green (G_y) forage, respectively; t_L and t_G are the coefficients of the effect of this factor on lichen and green food; N_y is the number of reindeer in the year y. When calculating the proportionality coefficients ($t_L = 1375*10^4$ and $t_G = 1625*10^5$), we proceeded from the ratios between trampled down and grazed food reserves assumed by Andreev [8] and his estimates of the lichen and green forage resources.

Thus, the changes in the lichen reserve may be expressed by the balance equation:

$$L_{y+1} = L_y - F_L - T_L + P_L \quad (6)$$

where L_y and L_{y+1} are the lichen reserves in the current (y) and next (y+1) years, respectively; F_L and T_L are the same as in Eqs.(2) and (4) respectively; and P_L is the annual production of the lichen reserve which is close to zero in the mature state of lichen cover in condition of pasture load absence. In the model the annual production of green forage plants was assumed to be proportional to the reserve of their underground organs (roots and rhizomes). On the basis of general considerations we assumed the production of the reserve of underground components in our model to depend on the mass of photosynthesizing organs (the live aboveground plant biomass). In accordance with some published data [19] the specific rate of loss of perennials in green plants was taken to be constant. Thus, the model employed the following algorithm for calculation of green forage crops:

$$P_R = g_R*(G_y - F_G - T_G)*(1 - R_y/R_{max}), \qquad (7)$$

$$R_{y+1} = R_y + P_R - d_R*R_y \qquad (8)$$

$$G_{y+1} = g_G*R_{y+1} \qquad (9)$$

where P_R is the annual growth of perennial organs (roots and rezones herbaceous plants and aboveground parts in shrubs); G_y and G_{y+1} are the productions of the photosynthesizing organs in the current and next years; F_G is the trophic load; T_G is the loss due to trampling down; R_y and R_{y+1} are the masses of perennial organs of plants (mainly the underground organs of herbaceous plants) in the current and next years respectively, $R_{\max}$ is the maximum possible value of this mass (carrying capacity); g_R = 10, d_R = 0.2 and g_G = 0.2 are the coefficients of relative production and loss respectively, taken from literature sources including some early attempts of ecological modelling [19-21].

The model also took into account the effect of periodically increasing foraging pressure of rodents on the vegetation. The results of long term observations have shown that rodent population outbreaks occur with a period of 3–4 years correspondingly to the trend first demonstrated by Elton [22] and repeatedly confirmed since then. According to literature data, lemmings could remove up to 50-70% of standing crop in the years of their peaks (the phenomenon of “lemmings hay” proves this); see [23] and [24]. That is why we subtracted half of aboveground biomass (G_y) from the second factor of Eq.(7) for the years of peak numbers of small rodents. The results of the first stage of modeling allowed us to reconstruct the forage plant resources dynamics in the case of the observed reindeer population growth. The trajectory of the dynamic curve which started from the point determined by the state of vegetation during the 1930s, ended at the point corresponding to the current state (which was not specified in the modeling procedure) (Fig.3a), at that the constant since 1930s reindeer number preserves the vegetation from degradation (Fig.3b); this facts confirms the acceptability of the functional dependences used for the model development [9].

3. Simulation experiments

We simulated increase in the mean annual temperature which possibly might gain the level which is observed in Fennoscandia. We learned the frequently quoted figures [25] pointing that mean global warming since 1980 gained 0,5°C, i.e. 0.16°C per year. It is easy to calculate that according to the difference in mean annual temperatures in Yamal and Fennoscandia it would lead to increase of carrying capacity for lichens in Yamal to 16% if temperature here would be raised for 1°C. We have carried out 6 simulation experiments supposing that increase of ambient temperature in time may be either linear or exponential under different scenarios of reindeer numbers dynamics. Simulation of linear warming showed that if the rate of it is such slow as it is observed since 1980s, degradation of forage resources is also inevitable in spite would reindeer numbers keep to grow extensively or it would be fixed at the modern level. Intensification of linear increase in temperature a six time would not prevent future crush (Fig.3c). The only simulated possibility for restoration of forage reserves for domestic reindeer husbandry is fantastic exponential increase in temperature at the Yamal Peninsula not less than a six times comparing to the present figure (Fig.3d).

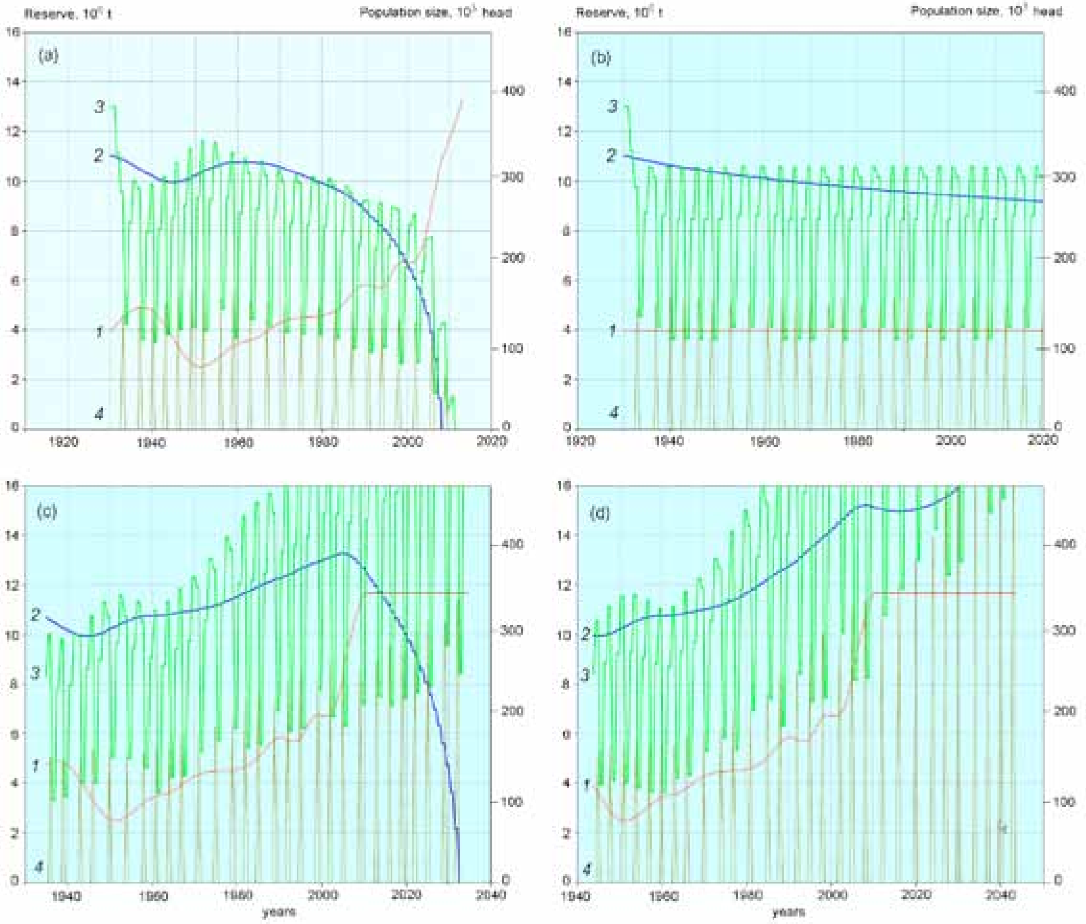

Fig.3. Simulated dynamics of plant forage reserves in Yamal: (a) the scenario of the actual extensive growth of the domestic reindeer population (verification of the model); (b) the scenario where the initial reindeer population size (120000 head) remained constant throughout the period studied; (c) the scenario of linear increase in temperature a six time faster than observed with reindeer number fixed at the modern level; (d) the scenario of exponential increase in temperature a six time faster than observed with reindeer number fixed at the modern level; (1) reindeer population size, 1000 head; (2) lichen forage reserve, 106 t; (3) green forage reserve, 106 t; (4) forage loss to rodents, 106 t.

4. Conclusion

Although any model is a simplification and gives only a rough picture of actual situation which partly accounts for the heuristic role of simulation, the verification of the model has generally confirmed its validity. The play with simulated changes in ambient temperature indicated that extensive (nomadic) reindeer breeding already lead to the very possibility of its continuation and this type of land use is quite disastrous. Probably, the restoration potential of forage resources in the Yamal is already critical. This shows that the whole system of reindeer breeding has to be strongly corrected.

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