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Optimizing the Economic Use of Populations of Game Animals in the Region (by the Example of the Yaroslavl Region)

A.P. Kaledin[1], Yu. A. Yuldashbaev[1], A.I. Filatov[1], V.A. Demin[1], A. M. Ostapchuk[1], E.N. Anashkina[2], T.S. Kubatbekov[3]

[1]Russian State Agrarian University Moscow Timiryazev Agricultural Academy, Timiryazevskaya Street, 49, Moscow,
[2]Yaroslavl State Pedagogical University named after K.D. Ushychi, Respublikanskaya Street, 108/1, Yaroslavl
[3]Peoples' Friendship University of Russia, Miklukho-Maklaya Street, 6, Moscow

Abstract.
An algorithm for optimizing the parameters of the development of game animal populations is proposed on the basis of variant calculations using the modified Leslie matrix model using a correcting matrix. Calculations have been made to optimize the parameters of hunting animals for beaver, hare, boar, martens, fox, moose and maral populations in the Yaroslavl region, given control figures of the "Strategy for the Development of the Game Husbandry of the Russian Federation through to 2030".
Keywords: game animal populations, modified Leslie matrix model, optimization of population parameters, Yaroslavl region.

INTRODUCTION

Forecasting the headcount of game animals over time under changing parameters of the impact of endogenous and exogenous factors of habitat and economic use of the population involves optimization of indicators of economic use of game resources for achieving the desired results.

The computational constructive method and the method of mathematical modeling have become most widespread among the computational methods used in forecasting the headcount over time. The computational constructive method is based on calculating headcount using positive and regressive incremental population dynamics coefficients. The method of mathematical modeling is based on building mathematical models and model experiments of population development over time.

The models for forecasting the population development (Leslie matrix models) and economic mathematical models for optimizing the turnover of the population headcount in the context of age and gender groups were the most widespread among the models for forecasting the rational use of game resources. The population development forecasting model is a dynamic model that optimizes the structure of the population in the long term, while the economic mathematical model of the population headcount turnover optimizes the structure of the population in the context of age and gender groups at the current time.

The detailed description of the age structure leads to a class of matrix models during modeling of the dynamics of animal populations. The models of population dynamics with age structure were known as Leslie models [1]. The classical Leslie matrix models rely on the main events in the population (birth, age maturity, reproduction characteristics, life expectancy) but do not take factors of human economic activity and their impact on the population development into account. This drawback of the Leslie model is eliminated in the modified model of population dynamics calculation, the correcting matrix being its main feature. The aim of applying the corrective matrix in the classical Leslie model is to update the current vector of the population state at each point in time using the corrective vector, which is formed on the basis of natural and economic factors of the population use.

In summary, the mathematical algorithm for applying the corrective matrix is as follows: a current state vector is formed at a specific time, which is changed by the correcting vector, at each step in the formation of the population state vector [2, 3].

$X'(t_1) = LX(t_0)$
$X''(t_1) = X'(t_1) - K(t_1)$
$X'(t_2) = LX''(t_1)$
$X''(t_2) = X'(t_2) - K(t_2)$
$X'(t_n) = LX''(t_{n-1})$
$X''(t_n) = X'(t_n) - K(t_n)$

where:
$X(t_0)$ is the initial population state vector;
$X'(t_n)$ is the current vector of population development in t_n – period;
$X''(t_n)$ is the corrected vector of the population development in t_n – period;
$K = \{K(t_1), K(t_2), \dots K(t_n)\}$ is the corrective matrix.

Corrections can be made to the classical Leslie model for the forecasting of the game animal population development, based on the kill (hunt) matrix, i.e. the kill (hunt) matrix is a corrective matrix.

The kill (hunt) matrix V consists of elements V_{jt}, where index j is the index of the age group (**j**∈ **J**), and t is the index of the forecast year (**t** ∈ **T**). $\boldsymbol{V_{jt} = d_{jt} * X'_{jt}}$ $(\boldsymbol{t \in T})$.

As a result of correction of the population headcount matrix to the current kill by the kill matrix, a matrix of headcount is obtained, taking hunt into account, each vector of which is calculated by years of forecasting:

$\boldsymbol{X''_{jt} = X'_{jt} - V_{jt}}$ $(\boldsymbol{t \in T})$

Let us optimize the economic use of populations of game animals in the region (by the example of the Yaroslavl region, Table 1).

Variant calculations changing the parameters of the corrective matrix allow to optimize these parameters taking the final settings for population development into account.

Let us consider a modified Leslie matrix model with a corrective kill matrix at different kill rates using the example of the beaver population in the Yaroslavl region (Tables 2, 3).

The "Strategy for the Development of the Game Industry of the Russian Federation through to 2030" declares "an increase in the number of main types of game animals at least twice compared with their actual number in the base 2013, while maintaining a balance aimed at sustainable use of all types of game animals in natural ecological systems" as the main result of the implementation of the planned measures [4].

According to the "Strategy for the Development of the Game Industry...", the target figure for beaver in the Yaroslavl region is 46.5 thous. heads by 2030. Interpolation of the variant calculations obtained based on the modified model allows to determine the average optimal level of beaver kill in the Yaroslavl region, which is 7.7%.

Let us perform calculations for the hare population, according to the proposed algorithm (Table 4).

Table 1 Dynamics of the number of game animals in the Yaroslavl region in 2007-2016

Years	Game animals, heads						
	Beaver	Hare	Boar	Marten	Fox	Moose	Maral
2007	10,470	23,670	8,700	2,060	5,232	18,470	200
2008	12,370	29,840	9,201	3,850	6,740	17,697	243
2009	16,280	22,720	10,350	4,600	3,080	16,994	310
2010	17,600	16,130	10,940	3020	6,580	20,423	340
2011	19,119	15,938	10,434	3276	8,856	21,833	407
2012	20,839	17,260	11,207	2,833	6,377	18,500	445
2013	23,233	19,499	9,833	2,839	5,337	20,318	507
2014	21,325	24,195	5,267	4071	5,517	20,534	631
2015	21,775	8,709	2,436	3,427	2,167	24,603	563
2016	22,702	25,269	2,557	3,438	2,781	19,055	512

Table 2 Source information on the beaver population

Population indicators	Age groups				
	animals 0-1 year old	animals 2-3 years old	animals 4-8 years old	animals 9-11 years old	12 years old and older
Percentage of natural death, %	45	25	12	10	3
Share of males, %	49	51	50	49	48
Size of single females, %		30	10	15	25
Average number of young beavers born, heads		1.9	2.7	2.5	2

Table 3 Forecasting the beaver population in the Yaroslavl region at different kill rates, thous. heads

Years of forecasting	Options of the Leslie model by kill percentage					Best option
	2%	5%	7%	10%	15%	7.70%
2017	28.0	27.4	26.5	25.1	28.0	27.2
2018	29.7	28.5	26.7	23.8	29.7	28.1
2019	30.7	28.8	26.1	22.0	30.7	28.2
2020	32.8	30.2	26.5	21.0	32.8	29.3
2021	36.2	32.5	27.6	20.7	36.2	31.3
2022	38.9	34.2	28.1	19.9	38.9	32.7
2023	41.5	35.8	28.4	19.1	41.5	33.9
2024	44.7	37.7	29.0	18.4	44.7	35.5
2025	48.2	39.8	29.6	17.7	48.2	37.2
2026	51.9	41.9	30.2	17.1	51.9	38.9
2027	55.8	44.1	30.8	16.4	55.8	40.6
2028	60.0	46.5	31.4	15.8	60.0	42.5
2029	64.6	49.0	32.0	15.2	64.6	44.4
2030	69.5	51.6	32.6	14.6	69.5	46.4

Table 4 Forecasting the hare population in the Yaroslavl region at different kill levels, thous. heads

Years of forecasting	Options of the Leslie model by kill percentage			Best option
	30%	35%	40%	37.15%
2017	27.4	26.5	21.2	22.2
2018	28.5	26.7	23.4	25.7
2019	28.8	26.1	21.8	25.1
2020	30.2	26.5	22.7	27.3
2021	32.5	27.6	21.7	27.4
2022	34.2	28.1	22.1	29.2
2023	35.8	28.4	21.6	29.9
2024	37.7	29.0	21.6	31.4
2025	39.8	29.6	21.3	32.4
2026	41.9	30.2	21.3	33.8
2027	44.1	30.8	21.0	35.0
2028	46.5	31.4	20.9	36.5
2029	49.0	32.0	20.7	37.8
2030	51.6	32.6	20.6	39.4

According to the "Strategy for the Development of the Game Industry...", the target figure for hare in the Yaroslavl region is 39.0 thous. heads by 2030. Interpolation of the variant calculations obtained based on the modified model allows to determine the average optimal level of hare kill in the Yaroslavl region, which is 37.15%.

Let us perform calculations for the boar population, according to the proposed algorithm (Table 5).

According to the "Strategy for the Development of the Game Industry...", the target figure for boar in the Yaroslavl region is 9.83 thous. heads by 2030. Interpolation of the variant calculations obtained based on the modified model allows to determine the average optimal level of hare kill in the Yaroslavl region, which is 40.03%.

Let us perform calculations for the marten population, according to the proposed algorithm (Table 6).

Table 5 Forecasting the boar population in the Yaroslavl region at different kill levels, thous. heads

Years of forecasting	**Options of the Leslie model by kill percentage**			**Best option**
	35%	**40%**	**45%**	**40.03%**
2017	9.8	9.1	8.3	9.08
2018	10.2	8.7	7.3	8.68
2019	11.4	8.9	6.9	8.93
2020	12.2	8.8	6.2	8.82
2021	13.5	9.0	5.9	9.02
2022	14.7	9.1	5.4	9.06
2023	16.1	9.2	5.0	9.17
2024	17.6	9.3	4.6	9.24
2025	19.3	9.4	4.3	9.34
2026	21.1	9.5	4.0	9.43
2027	23.1	9.6	3.7	9.52
2028	25.3	9.7	3.4	9.61
2029	27.7	9.8	3.2	9.71
2030	30.3	9.9	2.9	9.80

Table 6 Forecasting the marten population in the Yaroslavl region at different kill levels, thous. heads

Years of forecasting	**Options of the Leslie model by kill percentage**				**Best option**
	30%	**35%**	**40%**	**44%**	**36.95%**
2017	5.1	4.7	4.3	4.0	4.6
2018	5.1	4.4	3.7	3.1	4.1
2019	6.1	4.8	3.8	2.9	4.4
2020	6.6	4.9	3.6	2.5	4.3
2021	7.6	5.3	3.5	2.3	4.5
2022	8.6	5.5	3.4	2.0	4.6
2023	9.9	5.9	3.4	1.8	4.8
2024	11.2	6.2	3.3	1.6	4.9
2025	12.8	6.6	3.2	1.5	5.0
2026	14.6	7.0	3.1	1.3	5.1
2027	16.6	7.4	3.1	1.2	5.3
2028	19.0	7.8	3.0	1.0	5.4
2029	21.6	8.3	2.9	0.9	5.6
2030	24.6	8.7	2.8	0.8	5.7

According to the "Strategy for the Development of the Game Industry...", the target figure for marten in the Yaroslavl region is 5.68 thous. heads by 2030. Interpolation of the variant calculations obtained based on the modified model allows to determine the average optimal level of hare kill in the Yaroslavl region, which is 36.95%.

Let us perform calculations for the fox population, according to the proposed algorithm (Table 7).

Table 7 Forecasting the fox population in the Yaroslavl region at different kill levels, thous. heads

Years of forecasting	**Options of the Leslie model by kill percentage**				**Best option**
	30%	**35%**	**40%**	**44%**	**40.85%**
2017	3.2	3.0	2.8	2.54	2.7
2018	4.4	3.8	3.2	2.70	3.1
2019	5.6	4.5	3.5	2.70	3.4
2020	7.5	5.6	4.1	2.86	3.8
2021	9.7	6.7	4.5	2.90	4.2
2022	12.9	8.2	5.1	3.03	4.7
2023	16.8	10.0	5.7	3.10	5.2
2024	22.1	12.2	6.4	3.22	5.8
2025	29.0	14.9	7.2	3.31	6.4
2026	38.1	18.2	8.2	3.42	7.1
2027	50.0	22.1	9.2	3.52	7.8
2028	65.7	27.0	10.3	3.64	8.7
2029	86.3	32.9	11.6	3.75	9.7
2030	113.4	40.2	13.1	3.87	10.7

According to the "Strategy for the Development of the Game Industry...", the target figure for fox in the Yaroslavl region is 10.67 thous. heads by 2030. Interpolation of the variant calculations obtained based on the modified model allows to determine the average optimal level of hare kill in the Yaroslavl region, which is 40.85%.

Let us perform calculations for the moose population, according to the proposed algorithm (Table 8).

Table 8 Forecasting the moose population in the Yaroslavl region at different kill levels, thous. heads

Years of forecasting	**Options of the Leslie model by kill percentage**				**Best option**
	3%	**5%**	**8%**	**10%**	**6.15%**
2017	20.9	20.5	19.8	19.41	20.25
2018	22.4	21.5	20.2	19.30	20.99
2019	24.1	22.6	20.5	19.22	21.79
2020	25.9	23.9	21.0	19.22	22.73
2021	28.4	25.5	21.8	19.50	24.04
2022	31.1	27.5	22.7	19.86	25.54
2023	34.2	29.6	23.6	20.25	27.15
2024	37.5	31.7	24.5	20.59	28.79
2025	40.9	33.9	25.4	20.86	30.42
2026	44.8	36.4	26.4	21.20	32.23
2027	49.1	39.0	27.4	21.54	34.15
2028	53.8	41.9	28.5	21.89	36.19
2029	58.9	44.9	29.6	22.24	38.34
2030	64.5	48.2	30.7	22.59	40.61

According to the "Strategy for the Development of the Game Industry...", the target figure for moose in the Yaroslavl region is 40.60 thous. heads by 2030. Interpolation of the variant calculations obtained based on the modified model allows to determine the average optimal level of hare kill in the Yaroslavl region, which is 6.15%.

Let us perform calculations for the maral population, according to the proposed algorithm (Table 9).

Table 9 Forecasting the maral population in the Yaroslavl region at different kill levels, thous. heads

Years of forecasting	**Options of the Leslie model by kill percentage**				**Best option**
	3%	**5%**	**8%**	**10%**	**6.65%**
2017	0.6	0.6	0.5	0.52	0.54
2018	0.6	0.6	0.6	0.52	0.56
2019	0.6	0.6	0.6	0.52	0.58
2020	0.7	0.6	0.6	0.52	0.60
2021	0.8	0.7	0.6	0.52	0.63
2022	0.8	0.7	0.6	0.53	0.66
2023	0.9	0.8	0.7	0.54	0.70
2024	1.0	0.9	0.7	0.55	0.74
2025	1.1	0.9	0.8	0.56	0.78
2026	1.2	1.0	0.8	0.57	0.82
2027	1.3	1.0	0.8	0.58	0.87
2028	1.4	1.1	0.9	0.59	0.91
2029	1.6	1.2	0.9	0.60	0.96
2030	1.7	1.3	1.0	0.61	1.01

According to the "Strategy for the Development of the Game Industry...", the target figure for maral in the Yaroslavl region is 1.01 thous. heads by 2030. Interpolation of the variant calculations obtained based on the modified model allows to determine the average optimal level of hare kill in the Yaroslavl region, which is 6.65%.

Matrix models are in fact balance models where the reflection of the object function aimed at a certain extremum (optimality criterion) is associated with additional procedures. This paper proposes an algorithm for optimizing (determining) the parameters for developing a population of game animals in order to achieve the desired results. In the economic practice of using the game animal populations, questions arise on the intensity of kill when a given population reaches a certain period of the population development. In the context of multifactor influence on the population development (different initial headcount, age and gender structure, gender ratio, conservation factors and yield of young animals), direct calculation is associated with some difficulties.

The modified Leslie matrix model underlies the proposed algorithm for optimizing the parameters of the game animal population. Variant calculations on the dynamics of the game population development, with the subsequent interpolation of the model parameters at the chosen interval in which the given result is located, allow to find the best parameter of the model (population).

As such, the best parameters of economic use of the game animal population (kill) can be found in order to achieve the desired results for the population development in the long term.

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