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ASSESSMENT OF THE ARGALI POPULATION IN KAZAKHSTAN AND FORECASTING OF ITS POPULATION USING MATHEMATICAL MODELING

Argali is a rare species whose subspecies are in a vulnerable or endangered position. The paper analyzes the structure of the argali population, considers the logistic model as a method for studying the growth of the ungulate population, which is important for tracking the current and future situation of rare species and the effectiveness of measures taken to preserve them. Using mathematical modeling, a graph of the projected number of argali in Kazakhstan has been made to assess the state of the species population. By 2100, the number of argali is expected to increase to 161239 individuals while carrying out the necessary protective measures. The maximum number and growth limit of the population is 250670 individuals. Based on the forecast, recommendations for the conservation and restoration of the population have been formulated. In general, the measures taken to protect the species allow the population to grow without slowing down the growth rate. To accelerate population growth, it is necessary to fight poaching, protect watering holes, winter feeding, put into practice compensatory economic mechanisms to prevent the development of trophy hunting and poaching, proper veterinary care of livestock with common infestations in wild ungulates.

Keywords: archar, argali, population, logistic equation, mathematical model

Introduction

Biodiversity plays a key role in providing human with the resources, ecosystem sustainability, and cultural identification. Currently, the issue of the preservation of biota is acute due to the widespread threat of extinction. Modern ecology faces a number of challenges, including forecasting the state of ecosystems under the influence of anthropogenic factors. Forecasting allows to choose the optimal strategy for the use and conservation of natural resources. In Kazakhstan, ungulates are also susceptible to extinction. They are the primary consumers on which depends the survival of birds of prey and mammals. Thus, at the beginning of the late Holocene, the aurochs (Bos primigenius) died out, in historical times – the tarpan (Equus ferus ferus), the red deer (Cervus elaphus), gazelle (Gazella subgutturosa), saiga (Saiga tatarica), onager (Equus hemionus) and argali areas were reduced [1, p. 127]. The aim of the paper is to analyze the dynamics of the Ovis ammon population by compiling its mathematical model and forecasting the number in the near future. This will help to assess the current state of the species and make recommendations for its conservation.

The range of argali (Ovis ammon Linnaeus, 1758) covers the mountains of Central and Central Asia, Southern Siberia, from Central Kazakhstan to China. The subspecies O. ammon collium in the Pavlodar region is distributed in Kazakh Uplands, Kyzyltau and adjacent ridges, in the Bayanaul National Park. Its population in the region in 2003 was 350 individuals [2, p. 41], in 2023–760 individuals. In total, there were 7000 individuals in Kazakhstan in 1970 [3, p. 29]. The average life expectancy is 12–13 years [3, p. 14]. They reach sexual maturity by 2,5–3 years old, mate at 4–5 years old. The females give birth to their first lamb at the age of 3 years. [4, p. 6]. 2/3 of the females produce offspring, fertility is 1,3 lambs per female [3, p. 73]. Mortality before one year of age for O. A. collium is 42,5 % and 70 % in the north, for O. A. karelini – 35,7 % in Tien Shan and 38,5 % in Dzungarian Alatau, for O. A. polii – 67 %, for O. A. karelini – 56,7 %. The mortality rate at the age of 4–5 years is 33%, at the age of 6 years and older – 21 % [4, p. 8]. The population in all mountain ranges is dominated by adult females – 44,28 %, males over 2 years old – 23,52, sucklings – 21 %, regular lambs 9,33 % [5, p. 50], that is, young animals – 30,33%. According to the accounting in the Tarbagatai National Park, females of the Ovis Ammon collium subspecies – 35,1 %, males – 28,3 %, sucklings – 36,4% [6, p. 237]. In the Niyaz mountain range, females – 42,3 %, males – 30,7 %, lambs – 26,9 % [7, p. 6]. The main factor of the decline in numbers is anthropogenic [8, p. 177] – 70 % of the causes of death are associated with poaching [9, p. 145], overgrazing also plays a role in habitats, which forces argali to move to high forests or graze in herds of yaks, while competition with livestock increases in winter. The main predators controlling the argali population are wolves [9, p. 141], snow leopards, sometimes leopards in Altai, foxes, lynx in Central Kazakhstan [4, p. 8]. The natural cause of death of mature males is stress from harsh environmental conditions [10, p. 174], for example, cold winters or drought. The argali living in low arid mountains have limited access to water, and when the water sources dry up, they travel long distances [4, p. 8]. Infection with endoparasites is also observed.

Materials and methods

A logistic model of the Ovis ammon population was constructed using mathematical modeling. The method of differential equations is used. Population data are taken and summarized from National reports on the state of the Environment and on the use of natural resources of the Republic of Kazakhstan. The answer engine WolframAlpha was used to construct the graph.

Results and discussion

There are several basic models in population dynamics. The Malthus equation shows a model of exponential, unlimited population growth. The Ferhulst equation includes limiting factors, which will make it possible to more accurately predict population changes. The logistic equation has the form:

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right),$$

where N – population size, individuals; r – natural rate of population growth without limiting factors; K – supporting capacity of the environment, the maximum possible population size, individuals; t – number of modeling periods, the number of years of forecasting. The exact solution of the differential equation (1) is a logistic function, an s-shaped curve (logistic curve) of the following form:

$$N(t) = \frac{KN_0e^{rt}}{K-N_0+N_0e^{rt}},$$

where K – supporting capacity of the environment, the maximum possible population size, individuals; N_0 – population size at the initial time, individuals; t – number of modeling periods, number of years of forecasting. The maximum number of K must be calculated using the formula (2):

$$K = N_1\frac{N_0N_1 + N_1N_2 - 2N_0N_2}{N_1^2 - N_0N_2},$$

where N_0, N_1, N_2 – population size in time periods t_0, t_1 and t_2, respectively. At the same time, the capacity of the medium takes into account limiting factors.

If N_0 – population at time t = 0, N_1 – at time t = T and N_2 is at time t = 2T, then the natural rate of growth of the argali population can be calculated using the formula (3):

$$r = \frac{1}{T}\ln\left[\frac{1/N_0 - 1/K}{1/N_1 - 1/K}\right].$$

The average approximation error is calculated using the formula (4):

$$E = \frac{1}{n}\sum_{t=1}^{n}\frac{|\hat{y}_t - y_t|}{y_t}\cdot 100\%,$$

where n – amount of calculated and actual data for model verification (in our case, n = 8, since the period under consideration is 8 years, from 2014 to 2022); – value of the population size in year t, calculated using the Ferhulst equation; – actual value of the population size in year t.

Since data on the number of individual subspecies populations are not provided, let's assume that the number of individuals in each region is the same. So, before the age of one, the mortality rate of different subspecies is on average 51.73 %, of mature individuals – 33 %. The ratio of females, males and young will be taken as 40 %:30 %:30 %, respectively. The number of lambs born per female out of 60% is assumed to be 1.3. General data on the number from 2010 to 2022 are presented in Table 1.

Table 1 – The structure of the argali population in Kazakhstan in the period from 2010 to 2022

№	Year	Population, ind.	Number of females, ind.	Number of males, ind.	Number of lambs, ind.	Number of lambs born per female, ind.	Mortality, ind.
1	2010	13246	5298	3974	3974	4592	5115
2	2011	13597	5439	4079	4079	4714	5251
3	2012	13872	5549	4162	4207	4809	5381
4	2013	14525	5810	4358	4358	5035	5609

5	2014	14737	5895	4421	4421	5109	5691
6	2015	15710	6284	4713	4713	5446	6067
7	2016	15979	6392	4794	4794	5539	6171
8	2017	16802	6721	5041	5041	5825	6489
9	2018	17065	6826	5120	5120	5916	6590
10	2019	17954	7182	5386	5386	6224	6934
11	2020	18465	7386	5540	5540	6401	7131
12	2021	18863	7545	5659	5659	6539	7285
13	2022	19730	7892	5919	5919	6840	7620

When calculated with an interval of 6 years (2010, 2016 and 2022), the supporting capacity will take a negative value. Since the total number of the covered period is 12 years, the years with equal intervals of 4 years are taken as a basis: 2014, 2018 and 2022. Let's find the supporting capacity according to equation 2:

$$17065 \cdot \frac{14737 \cdot 17065 + 17065 \cdot 19730 - 2 \cdot 14737 \cdot 19730}{17065^2 - 14737 \cdot 19730} = 250670{,}0391 \approx 250670.$$

This means that the maximum number and growth limit for this population is 250670 individuals. Next, we find the population growth rate according to equation 3:

$$\frac{1}{4} \ln \left[\frac{1/14737 - 1/250670{,}0391}{1/17065 - 1/250670{,}0391} \right] = 0{,}0391.$$

Let's look at the accuracy of population forecasting, using 2021 as an example, where t = 7:

$$\frac{250670{,}0391 \cdot 14737 e^{0.0391 \cdot 7}}{250670{,}0391 - 14737 + 14737 e^{0.0391 \cdot 7}} = 19024{,}3951 \approx 19024.$$

Let's look at the accuracy of population forecasting, using 2015 as an example, where t = 1:

$$\frac{250670{,}0391 \cdot 14737 e^{0.0391 \cdot 1}}{250670{,}0391 - 14737 + 14737 e^{0.0391 \cdot 1}} = 15228{,}7895 \approx 15229.$$

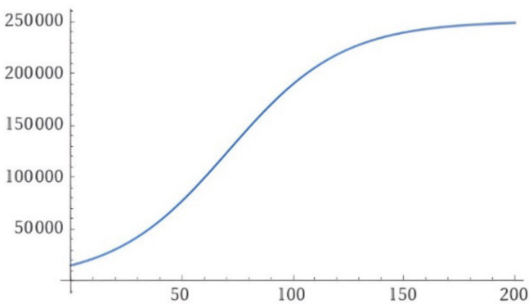
According to the logistic model, in 2015 the number of argali should reach 15229 individuals (in fact, 15710 individuals), and in 2021–19024 individuals (in fact, 18863 individuals). Let's calculate the average approximation error according to equation 4:

$$E = \frac{0{,}0679}{8} \cdot 100\% = 0{,}8489\% \approx 0{,}85\%.$$

The value of the average approximation error of up to 5% indicates a well-chosen model of the equation. Thus, the logistic model is well suited for predicting the number of argali. Let's calculate the population size by 2100 (t = 86):

$$\frac{250670{,}0391 \cdot 14737 e^{0.0391 \cdot 86}}{250670{,}0391 - 14737 + 14737 e^{0.0391 \cdot 86}} = 161238{,}6195 \approx 161239.$$

Thus, by 2100, the argali population may amount to 161239 individuals. Having the predicted data, we will make a graph of the population size:



Graph 1 – Projected number of argali

In the last 20 years, the number of argali has been growing, but the population growth rate has been somewhat slowed down and at the moment the number of individuals in the territory is small. The projected number presented is possible only with proper protection of argali and their habitats, otherwise the number of individuals may decrease to 8,5 thousand individuals as in 2008 [11, p. 8].

Conclusion

The conservation and restoration of the ungulate population, including argali, are important tasks for Kazakhstan, requiring the cooperation of government agencies, scientific institutions and the public. A logistic mathematical model of the argali population made it possible to estimate the dynamics of their numbers under current conditions. Based on the data obtained, it is important to conclude that the measures taken to protect the species allow the population to grow without slowing down the growth rate.

To accelerate population growth, it is necessary to observe measures to protect the species and its habitats. The most important measure for the reproduction of Ovis ammon is the fight against poaching. In arid places, it is necessary to protect watering holes and organize winter feeding. It is necessary to introduce compensatory economic mechanisms into practice to prevent the development of trophy hunting and poaching; proper veterinary care of livestock with common invasions in wild ungulates.

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ҚАЗАҚСТАНДАҒЫ АРҚАР ПОПУЛЯЦИЯСЫНЫҢ ЖАҒДАЙЫН БАҒАЛАУ ЖӘНЕ МАТЕМАТИКАЛЫҚ МОДЕЛЬДЕУ АРҚЫЛЫ САНДАРДЫ БОЛЖАУ

Арқар сирек кездесетін түр, оның кіші түрлері осал немесе жойылып кету қаупі төнген. Жұмыста арқар популяциясының құрылымы талданады, сирек түрлердің қазіргі және болашақтағы жағдайын және оларды сақтау бойынша қабылданған шаралардың тиімділігін бақылау үшін маңызды тұяқтылар популяциясының өсуін зерттеу әдісі ретінде логистикалық модель қарастырылады. Математикалық модельдеуді пайдалана отырып, тұяқтылардың популяциясының жағдайын бағалау үшін Қазақстандағы арқарлардың болжамды санының кестесі құрастырылған. 2100 жылға қарай табиғатты қорғау бойынша қажетті шараларды жүзеге асырған жағдайда арқарлар саны 161 239 бас өседі деп күтілуде. Популяцияның максималды мөлшері мен өсу шегі – 250 670 жеткен. Болжау негізінде сандарды сақтау және қалпына келтіру бойынша ұсыныстар жасалды. Жалпы, түрді қорғауға бағытталған шаралар популяцияның өсу қарқынын бәсеңдетпей өсіруге мүмкіндік береді. Популяцияның өсуін жеделдету үшін браконьерлікпен күресу, суармалы жерлерді қорғау, қысқы азықтандыру, жабайы тұяқтыларға трофикалық аңшылық пен браконьерліктің дамуын болдырмаудың өтемдік экономикалық тетіктерін тәжірибеге енгізу және үй жануарларын жарақаттанғанда дұрыс ветеринариялық күту қажет.

Кілтті сөздер: архар, аргали, популяция, логистикалық теңдеу, математикалық модель.

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ОЦЕНКА СОСТОЯНИЯ ПОПУЛЯЦИИ АРХАРА В КАЗАХСТАНЕ И ПРОГНОЗИРОВАНИЕ ЧИСЛЕННОСТИ С ПОМОЩЬЮ МАТЕМАТИЧЕСКОГО МОДЕЛИРОВАНИЯ

Архар – редкий вид, подвиды которого находятся в уязвимом или находящимся под угрозой исчезновения положении. В работе проведен анализ структуры популяции архаров, рассмотрена логистическая модель как метод исследования роста численности популяции копытных, что имеет значение для отслеживания нынешнего и будущего положения редких видов и эффективность предпринятых мер по их сохранению. С помощью математического моделирования построен график прогнозируемой численности архара в Казахстане для оценки состояния популяции вида. К 2100 году ожидается увеличение численности архара до 161239 особей при выполнении необходимых охранных мероприятий. Максимальная численность и предел роста популяции составляет 250670 особей. На основе прогнозирования составлены рекомендации по сохранению и восстановлению численности. В целом, принятые меры по охране вида позволяют популяции расти, не сбавляя темпы прироста. Для ускорения роста численности необходимы борьба с браконьерством, охрана водопоев, зимние подкормки, внедрение в практику компенсаторных экономических механизмов для предотвращения развития трофейной охоты и браконьерства, должное ветеринарное обслуживание домашнего скота с общими инвазиями у диких копытных.

Ключевые слова: архар, аргали, популяция, логистическое уравнение, математическая модель.

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