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Analysis Of The Dynamics Of The Number Of Mammalian Populations In The Conditions Of The Southern Aral Sea

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Abstract

The article presents the results of research analysis of the dynamics of the number of mammalian populations in the conditions of the Southern Aral Sea Small mammals serve as bio indicators in the study of environmental conditions. Bio topic distribution, nutrition, age and sex structures were studied on the example of Microtus Ileus populations. The long-term joint dynamics of the populations of the most typical predator-prey system for this region in the conditions of the Southern Aral Sea region is investigated. It is shown that the specifics of the dynamics of natural processes in the conditions of the crisis of the Aral Sea region require the development of special simulation models taking into account the control parameters and order parameters of the destabilized ecosystem.

Keywords: Aral Sea region, population dynamics, bioindicator, predator-prey model, approximation, coherence, ecosystems.

INTRODUCTION

Currently, the ecological changes taking place on the planet and characterized as ecologically crisis processes have brought to the fore the problems of destabilization and dynamics of natural processes (Shilov et al., 2000).The identification of patterns of crisis processes and their forecasting is of great scientific and practical importance for making decisions at the state level to contain them and prevent their consequences.
For the Republic of Uzbekistan, one of the first places in a number of important problems of crisis processes is the drying up of the Aral Sea.The Aral ecological crisis, being a complex of complex natural processes, has

a specific type of dynamics, different from natural, evolutionary successions. First of all, this is a significant nonlinearity and high speed of processes. As numerous studies of the authors have shown, in just a few decades the sea area has decreased by 83%, the grandiose reed beds that occupied more than 600 thousand hectares in the Amu Darya Delta have decreased by almost 10 times by 2004 (Bakhiev et al., 2012), 60 species of wild animals and plants have disappeared, the number of species under threat has increased. threatened with extinction (12 species of mammals, 26 species of birds and 11 species of plants) (http://aral.mptf.uz/ site/aralsea.html).Accordingly, structural and functional connections are dynamic in various communities of the ecosystem of the Southern Aral Sea region, where, by the way,, The consequences of the Aral crisis are maximally manifested (Zaripov et al., 2015).

The concept of transitional dynamics is gaining more and more strength and is replacing the ideas about the linear and predictable nature of the dynamics of biological systems in crisis conditions (Briskeet. al, 2017; Ladeet.al, 2013; Folke, 2010; Schluteretal., 2012).

In the course of structural and functional reorganization, "coadaptive complexes of biota" are formed, the development of which, according to the principles of synergetics, occurs coherently (in concert) throughout the system in the direction of one or more attractors. Tracking the self-organization of an ecosystem in crisis and, in particular, determining the point of stabilization, i.e. the attractor, is an urgent task.

The population reactions of a species can reflect the dynamics of the ecosystem as a whole, therefore, the population approach, when the biology of a species has been studied sufficiently fully, can be successfully used to study the state of natural ecosystems (Ruchin, 2006). These criteria correspond to a large group of small mammals (rodents) of different species, which are the traditional model object of research on a wide range of problems of theoretical and applied ecology (Abaturov et al., 1984).

Rodents, being an important component of natural ecosystems, are widely used as model objects in environmental studies, including those that address the problems of anthropogenic transformations of the environment (Mambetullayeva, 2012). This is a large group of animals, which, due to its position in the trophic chains of ecosystems, directly perceives the pressure of certain negative environmental factors in large areas and therefore can be used to indicate the transformation of the environment.

Many rodent populations have cyclical dynamics. Population cycles are characterized by regularity, although they may have different amplitudes. Termination of cyclic dynamics or violation of its regularity can be considered as an example of non-stationary dynamics (Abaturov et al., 1984).

A long series of observations of rodent populations made it possible to detect mass acyclicity of rodent population processes in forest-steppe, steppe and desert regions of Russia, Kazakhstan, Kalmykia and other countries (Saitohetal., 2006; Cornulieretal., 2013, etc.). One of the alleged reasons for the violation of cycles is a change in climatic conditions (Biermanetal., 2006) or a deterioration of the food supply (Kausrudetal., 2008).

For the Southern Aral Sea region, the reason for the violation of the cyclical dynamics of the rodent population is a sharp change in the hydro regime of the river . Amu Darya, which led to the degradation of vegetation (Table.1), in particular, plants that serve as a feed resource for rodents: species of grebe (Tamarixhispida, T.ramosissima), carabarac(Halostachysbelangeriana), saxaul(Haloxylonaphyllum), species of quinoa (Atriplexheterosperma, A.fomini, A.tatarica), salsola (Salsoladendroides), sand acacia (AmmodendronConollyi), licorice (Glycyrrhizaglabra), bassia (Bassiahissopifolia), kochia (Kochiascoparia), wormwood (Artemisiahalophila), reed (Pragmitesaustralis), etc. (Dynamics..., 2017; Kuzmina et al., 2003; Reimov, 1972, 1987).

Thus, it is possible to distinguish the "plants-rodents-predator" system as a kind of coadaptive community with trophic connections and coherence of population processes (Hendenetal., 2009). The study of connections and coherence has a special cognitive value. The cognitive nature of connections lies in the fact that if it is impossible to directly study an object, we can judge the presence or absence of certain properties of it by the behavior of objects closely related to it. Coherence in combination with the method of analogies makes it possible to detect the presence of a reaction to a strong disturbing signal of the entire structure of a dynamic system (Kolomyets, 2008).

Table 1 Dynamics of the area of tugai vegetation and the number of plant species in the lower reaches of the Amu Darya (according to Bakiev et al., 2012;Mamutova, 2006; Matzhanova et al., 2018)

Year	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009	2010-2015
Area of vegetation, thousand hectares	300	70	50	30	25	22
Number of plant species	302	183	106	62	89	73

Thus, the coherence of the behavior of the elements of a nonequilibrium self-organizing system can serve as a kind of validation measure of the results of the study of the dynamics of the behavior of individual elements of the system. Away from the bifurcation point, the behavior of system elements can also be coherent at the level of inter-element interactions, for example, the consistency of population changes in the predator-prey system due to trophic connections.
Based on the above, the study of the long-term system dynamics of the "plants-rodents-predator" community using a synergetic approach is of certain scientific interest.

MATERIALS AND METHODS

The study was carried out for the territory of the Southern Aral Sea region indicated on the map (Fig. 1).At the same time, extensive factual material collected during the period 1961-2017 by scientists specializing in ecology, zoology, botany was used. Due to the fragmentary nature and insufficient representativeness of the observational data, the spatial-temporal alignment of the series of observations was used by methods of statistical analysis of time series (Anderson, 1976).

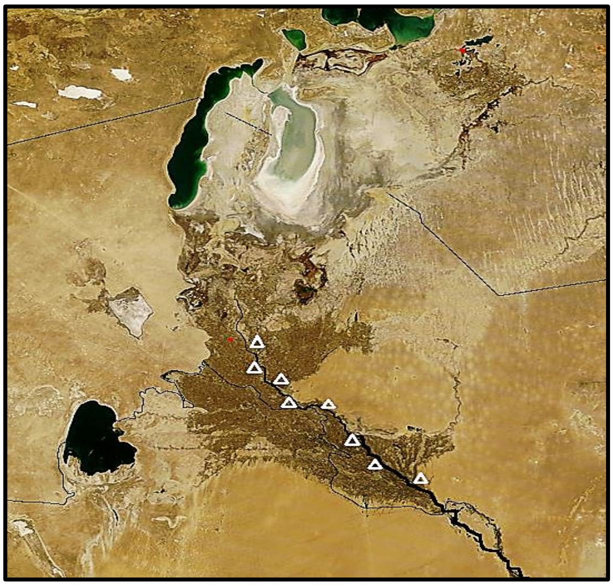

Fig. 1. Map –diagram of the research area in the region

Southern Aral Sea Region

The methodology of this study is a synthesis of several approaches: synergetic, population and simulation. The use of several mutually complementary methods allows you to study several aspects of the object under study at once. The classical predator-prey model described by the Lotka-Volterra equations (Volterra, 2004) is used to describe binary interspecific relations in the studied plant-rodent-predator system

$$\begin{cases} \frac{dx}{dt} = ax - bxy \\ \frac{dy}{dt} = -cy + dxy \end{cases} \quad (1)$$

with appropriate initial conditions

$$\begin{cases} x(0) = x_0 \\ y(0) = y_0 \end{cases} \quad (2)$$

where and is the population size of victims and predators, is the specific rate of growth of the victim population in the absence of predators, is a constant characterizing the rate of consumption by the predator population of individuals of the victim population, is the specific rate of death of predators, is a constant characterizing the rate of increase in the number of predators due to the biomass of consumed animals (Bazykin, 2003).
Taking into account the factor of intraspecific competition among predators and prey, respectively (1), the system will take the form:

$$\begin{cases} \dfrac{dx}{dt} = ax - bxy - r_1x^2 \\ \dfrac{dy}{dt} = -cy + dxy - r_2x^2 \end{cases} \quad (3)$$

$r_1, r_2 -$ the coefficient of intraspecific competition between prey and predator (Volterra, 2004). Equations (3) with initial conditions (2) are a Cauchy problem for a system of nonlinear ordinary differential equations, which is solved by the Runge-Kutta method.
To quantify the binary coherence of the long-term dynamics of the populations of the components of the "plants-rodents-predator" system, an approximation of the time series of data (actual and model) was first carried out (Bratus et al., 2010). We have introduced the coefficients of coherence of the rate of changes in the number of populations (CPR) and rates (CTP), calculated as correlation coefficients, respectively, of the first and second derivatives of the equations approximating the dynamics of populations.

RESULTS AND DISCUSSIONS

The population of Microtus Ilaeus is one of the few species in the mammal fauna of the Southern Aral Sea region. In the lower reaches of the Amu Darya, the vole inhabits mainly kulaks, damp areas with dense vegetation of reeds, cattails, tamarisk, sedges, periodically flooded with water [2, p.731,3,p.84, 4, p.35]. It is also found in moistened areas of tugai, along the banks of river channels, collectors, as well as in irrigated fields. According to Reimov (1987), in 1970-1975, the number of this species increased sharply, in some places by 100 catches /day, the incidence was 10-15% or 15-20 copies. per 1 ha .
The vole feeds on aquatic and wetland vegetation, which also emphasizes the close connection of this species with the near-water habitat. It also eats the underground parts of aquatic and wetland plants (reeds, cattails, reeds, sedges, etc.). When analyzing the contents of stomachs (58 copies), as well as "feeding tables" that are found at the entrances to burrows (92 copies), it was found that many species of voles also enter the summer feed of various cereals – 20%, 60.5% of the stomach is filled mainly with green parts of plants, the rest (15.5%) – remains of underground parts of plants (Fig.2).

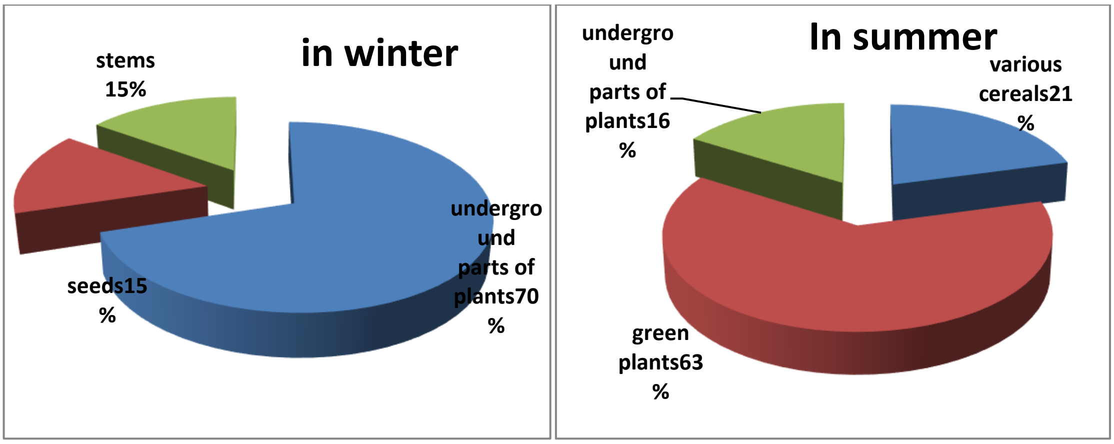

Fig. 2. The ratio of the MicrotusIlaeus diet depending on from the season of the year
As our research has shown, the breeding time of Microtusilaeus in the Amu Darya Delta varies depending on the ecological situation in different years. The external manifestations of rutting in voles are hardly noticeable. However, due to some greater activity of males, during this period they fall into traps / traps more often than females (see Fig. 3)

The study of the age structure, as one of the main characteristics of the population, is of paramount importance, because it reflects the dynamics and mechanism of population regulation. In turn, the age composition determines the subsequent reproduction and population size. The gender and age structure also varies by year and season. The sex ratio in the litter is close to 1:1.

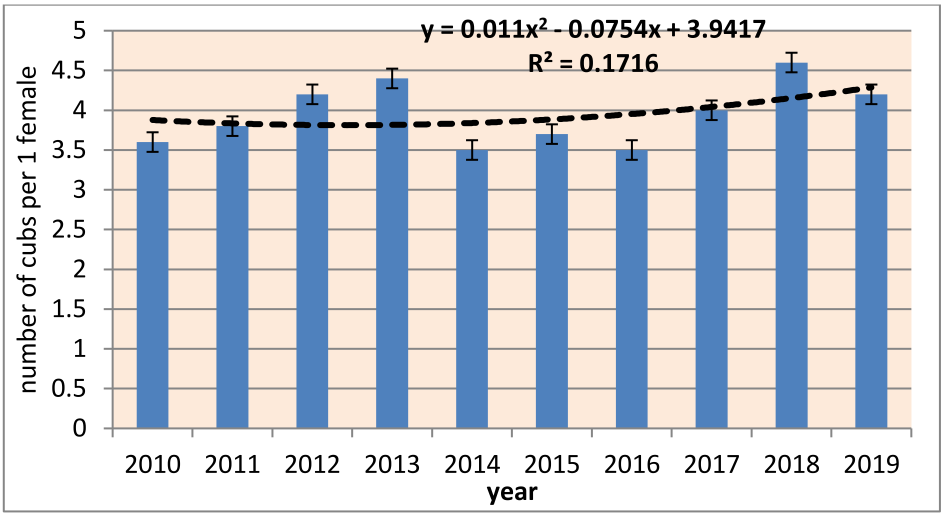

Fig. 3. Dynamics of fertility of the Microtus Ilaeus population in the lower reaches of the Amu Darya (2010-2019)

Based on statistical processing of the materials, it was found that males significantly predominate in the spring period in the catches (58.9%), in summer and autumn the sex ratio in the population is leveled (51.5% of males and 48.5% of females), in winter there are more males again (53.8%) (Fig.4).

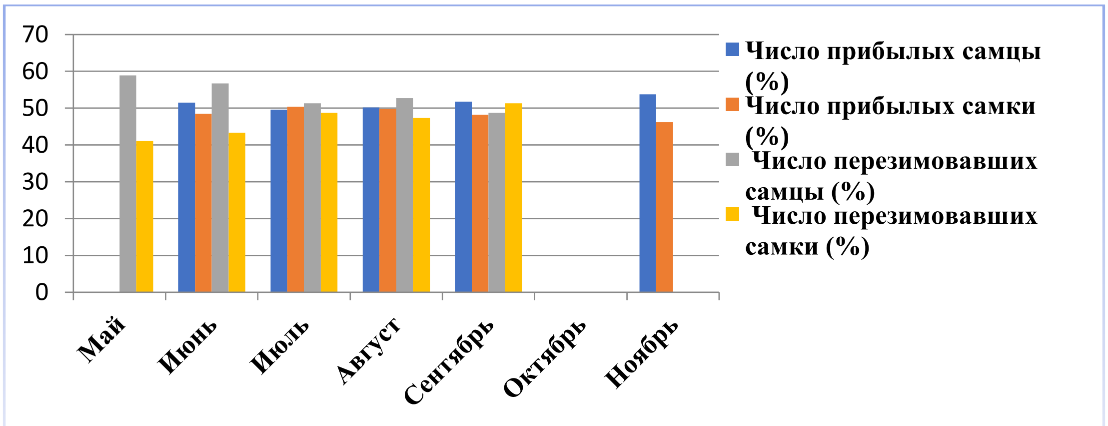

Fig. 4. Dynamics of sex and age structure of Microtus Ilaeus populations in the lower reaches of the Amu Darya (%)

The study of the age structure of Microtus Ilaeus populations makes it possible to assess the biological uniqueness and the specific role of individual generations in the reproduction of species. As observations show, fingerlings born in July and later represent an autumn late-maturing generation with a longer life cycle, slow growth and development.

In the model (2)-(3) for the binary relationship "rodents-predator", the following input data are used: initial values of parameters. Analysis of data from field studies of the number of rodents (MicrotusIlaeus) and foxes per 1 ha (Vulpes Vulpes) (Table.2) shows significant fluctuations for rodents and relative stability for a predator. The variety of methods and the absence of a single spatio-temporal monitoring system naturally reduce the correctness of the model results, as evidenced by significant inconsistencies.

Table 2 Discrepancies between the data of field studies and model data on the dynamics of fox and rodent population**s**

Year	*Microtus Ilaeus*		Discrepancies	*Vulpes Vulpes*		Discrepancies
	Field research data	The value of model data		Field research data	The value of model data	
1960-1969	17,20	17,20	0,00	8,30	8,30	0,00
1970-1979	13,14	13,14	0,00	6,14	6,14	0,00
1980-1989	2,23	11,03	-8,80	5,38	4,55	0,83
1990-1999	0,68	9,76	-9,08	3,60	3,37	0,23
2000-2009	4,35	8,93	-4,58	2,25	2,50	-0,25
2010-2019	3,95	8,37	-4,42	1,81	1,85	-0,04

The standard deviation between the data of field studies and the value of the model data of rodents is p_gryz≈5.7, and foxes p_lis≈0.34.The relationship between the number of rodents and foxes by year is characterized by a high correlation both according to actual and model data (respectively, k_fak≈0.78 and_mod≈0.99).

Graphical representation of the simulation results (Fig.5) clearly demonstrates the consistency of the long-term dynamics of the number of foxes and rodents. We see that the decrease in the number of both populations occurs almost synchronously, since the dependence of the fox population on the number of rodents leads to the fact that the dynamics of foxes adjusts to the dynamics of rodents.The model clearly simulates a violation of the cyclical nature of natural fluctuations in the population of rodents, which in reality manifests itself in a gradual attenuation of fluctuations..

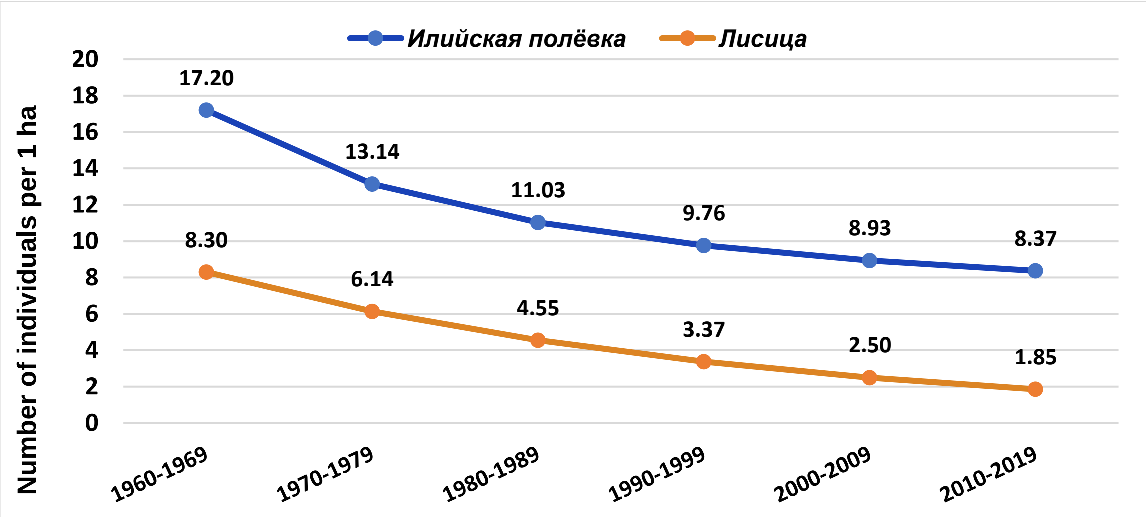

Fig.5. Dynamics of rodent and fox populations based on simulation results

The relationship that develops between plants and herbivores can also be considered as a predator-prey relationship. For the "plants-rodents" relationship, the following input data are accepted in the model: initial conditions, parameters $a = 0.0014,\ b = 0.0019,\ c = 0.005,\ d = 0.0001,\ \lambda_1 = 0.0001,\ \lambda_2 = 0.003$.

In contrast to the interspecific relations "rodents-predator", the correlation of the number of plants and rodents is high both for model data (k_mod≈0.98) and for actual data (k_fak≈0.94).Note that the Lotka-Volterra predator-prey model, focusing on simulating the dependence of the dynamics of the predator on the trajectory of the victim, "understates" the number of rodents, so that the number of Microtus Ilaeus individuals per 1 ha for the decade 2010-2022. it is reduced from 8.37 in the case of "rodents-predator" to 5.79 for the "plants-rodents" connection.According to the results of the study, we observe a violation of the cyclical fluctuations in the number of rodent populations (Fig.6).

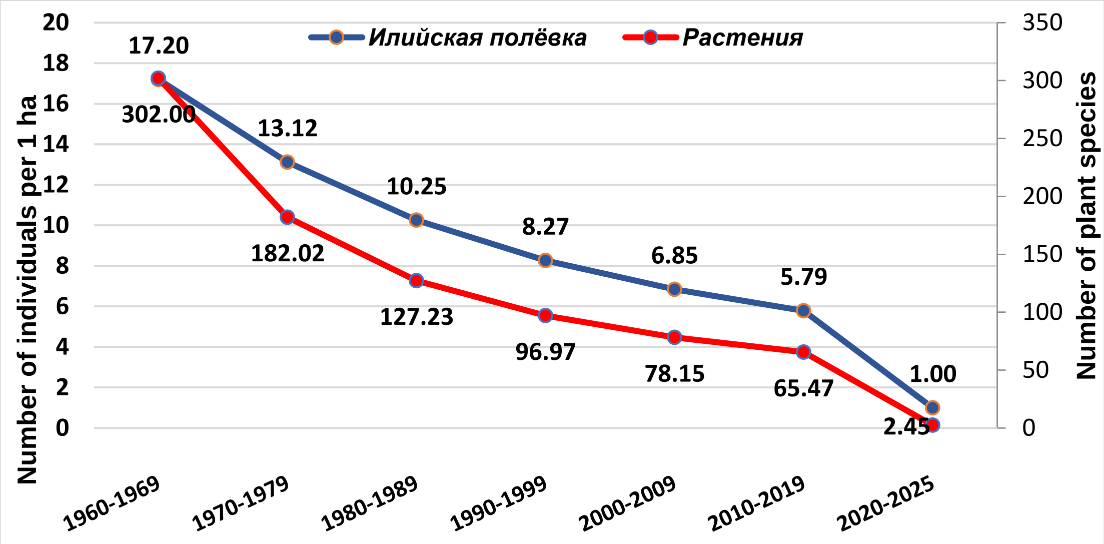

Fig. 6. Dynamics of the number of plant species and Microtus Ilaeus according to the simulation results

Significant discrepancies with the model data do not allow us to consider the Lotka-Volterra predator-prey model adequate for describing real interspecific relationships and the number of populations in the regions of environmental disasters. Since the entire structure of the ecosystem, including trophic relationships, changes in the conditions of crisis, the minimum requirement for the applicability of this model to describe long-term population dynamics is the non-stationarity of all coefficients (Okulova, 2007). This requires separate studies to determine these coefficients as functions of time.

Thus, taking into account the multidimensional impact of the Aral ecological crisis, which significantly changed the structure of the ecosystem of the Southern Aral Sea region as a whole, modeling of natural processes in this region, including population dynamics, in our opinion, should be systematic, taking into account the specificity of the dynamics of elements of the natural environment in a crisis (Tleumuratova, 2018). To identify patterns of long-term population dynamics, long series of relevant factual data are needed. In this study, we had fairly representative information on rodents and plants. The data on the fox turned out to be fragmentary and did not fully cover the entire modeling period (1961-2019). The restoration of a number of data from field studies in such a situation is possible using the response function to the number of rodents, the method of analogies and coherence of the dynamics of the number of these two species, especially manifested according to the provisions of synergetics in a crisis (Chu et al., 2016). For this purpose, the KSP and KTP described above were calculated for the "plants-rodents-predator" system (Table 3):

Table 3 The values of the speed coherence coefficients (CPR) and The rate (KTP) of population dynamics

Years / Speed	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009	2010-2019	**KSP**
Plants	-20,3150	-8,0650	-6,9650	-0,8150	4,3850	-19,5650	
Microtus Ilaeus	-0,5660	-0,2823	-0,1582	-0,1013	-0,0660	-0,0538	0,5390
VulpesVulpes	-1,2354	0,1921	-0,1304	-0,3009	0,0466	-0,2579	0,7355

Years / Pace	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009	2010-2019	**KTP**
Plants	2,8775	0,2125	0,2775	0,8525	-0,2825	-5,3475	
Microtus Ilaeus	0,0406	0,0185	0,0079	0,0042	0,0028	-0,0012	0,7045
VulpesVulpes	0,3320	0,0108	-0,0435	0,0155	0,0344	-0,1404	0,9064

High values of KSP and KTP justify the reliability of the reconstructed series of data on the dynamics of the number of foxes used in modeling. Obviously, the more accurate the scientific information about the nature of the observed relationships of the two types, the higher the reliability of the reconstructed data series.

CONCLUSION

1. In indigenous habitats, the number of Microtus Ilaeus is more stable and its fluctuations are less sharp, smoothed, and in transformed ones, on the contrary, the population of animals is extremely unstable and

experiences sharp fluctuations in numbers over the years and especially seasons. Due to this, the population as a whole acquires the necessary dynamism and integrated resistance to the effects of adverse environmental factors.

2. The specifics of the dynamics of natural processes in a crisis (in this case, the Aral crisis) require the development of special simulation models taking into account the control parameters and order parameters of a destabilized ecosystem. The classic "predator-prey" Lotka-Volterra models built for a normally, sustainably functioning ecosystem turn out to be inadequate for crisis conditions.

3. When there is a shortage of data on the long-term dynamics of the abundance of a species, the proposed method of reconstructing the series of observations on the relationships of this species with another well-studied species is a fairly effective method of structuring input data for mathematical modeling of natural processes.

REFERENCES

1. Абатуров Б.Д., Соколов В. Е. Млекопитающие как компонент экосистем. М.: Наука.– 1984. – 286 с.
2. Андерсон Т. Статистический анализ временных рядов.- М., Мир, 1976.- 756 с.
3. Базыкин А. Д. Нелинейная динамика взаимодействующих популяций. Москва-Ижевск: Институт компьютерных технологий, 2003. - 368 с.
4. Бахиев А.Б., Трешкин С.Е., Мамутов Н.К. Изучение растительных ресурсов Южного Приаралья и их рациональное использование в условиях Антропогенного опустынивания. // В сб. IV Международной научно-практической конференции «Проблемы рационального использования и охрана биологических ресурсов Южного Приаралья». – Нукус: Илим.– 2012.– С.35.
5. Братусь А.С., Новожилов А.С., Платонов А.П. Динамические системы и модели биологии. М.: ФИЗМАТЛИТ, 2010.- 320 с.
6. Вольтерра В. Математическая теория борьбы за существование. М.: Наука, 2004. 288 с.
7. Динамика и потенциал природной среды Каракалпакстана / Н.К. Аимбетов, Б.С. Тлеумуратова, С.М. Мамбетуллаева и др., Каракалпакский научно-исследовательский институт естественных наук Каракалпакского отделения Академии наук Республики Узбекистан. –Нукус: Илим, 2017 – 251с.
8. Ешчанова С.Ш. Экологические особенности популяций мелких млекопитающих тугайных экосистем Южного Приаралья // Universum: химия и биология. 2022.- Москва.- Выпуск: 2(93).- с.16-21. DOI - 10.32743/UniChem.2022.93.3. 13205
9. Зарипов Ш.Х., Абзалилов Д.Ф., Костерина Е.А. Задачи математической экологии и пакет Maxima //Учебное пособие. –Казань: Изд–во Казанского федерального университета, 2015. – 120 с.
10. Коломыец Э.Г. Локальные механизмы глобальных изменений природных экосистем. М.:Наука.- 2008. - 427 с.
11. Кузьмина Ж.В., Трешкин С.Е. Оценка влияния Южно-Каракалпакского магистрального коллектора на заповедник Бадай-тугай//Аридные экосистемы.– 2003.– Том 9.– С.93–105.
12. Мамбетуллаева С.М. Характеристика пространственной структуры популяций мелких млекопитающих в низовьях Амударьи // Журнал «Аспирант и соискатель», М., Россия, 2012, № 2, стр. 47-48.
13. Мамутов Н. Пастбищные ресурсы Южного Приаралья и проблемы их рационального использования //Тез. докл. Межд. конф. «Проблемы рационального использования и охрана биологических ресурсов южного Приаралья. – Нукус. –2006.– С.15.
14. Матжанова Х.К., Орел М.М. Растительные ресурсы Южного Приаралья и возможности их применения//Журнал «Вестник Каракалпакского отделения АНРУз».- Нукус, 2018.- №1.- 30-36 с.
15. Окулова Н.М., Катаев Г.Д. Взаимосвязи «Хищник – красно-серая полевка» в сообществах позвоночных животных Лапландского заповедника // Зоол. журн. 2007.-Т.86.- № 8.- С. 989-998.
16. Реймов Р. Опыт экологического и морфофизиологического анализа фауны млекопитающих Южного Приаралья – Нукус: Каракалпакстан.–1972. – 412 с.
17. Реймов Р. Грызуны Южного Приаралья.– Ташкент: ФАН. –1987. – 125 с.
18. Ручин А.Б. Экология популяций и сообществ. М., 2006.- 352 с.
19. Тлеумуратова Б.С. Математическое моделирование влияния трансформаций экосистемы Южного Приаралья на почвенно-климатические условия //Дисс…докт., Ташкент, 2018.

20. Чу А.Р. Михайлов М. Д. Исследование математической модели "хищник-жертва" с учетом внутривидовой конкуренции // Сб. статей Всероссийской молодежной научной конференции "Все грани математики и механики".-Томск.-2016.-С.118-120.
21. Шилов А., Чабовский А.В., Исаев С.И., Неронов В.В. Динамика сообщества и популяции грызунов полупустынь Калмыкии в условиях снижения нагрузки на пастбища и увлажнения климата// Известия АН: Сер. Биол. - 2000.- № 3. - с. 332-344.
22. Bierman S. M., Fairbairn J. P., Petty S. J., Elston D. A., Tidhar D., Lambin X. Changes over time in the spatiotemporal dynamics of cyclic populations of field voles (*Microtusagrestis* L.) // The American Naturalist. – 2006. – V. 167. – № 4. – P. 583-590.
23. Briske D. D., Illius A. W., Anderies J. M. Nonequilibrium ecology and resilience theory. In: Rangeland systems. Springer, Cham. – 2017. – 197-227 pp.
24. Cornulier T., Yoccoz N. G., Bretagnolle V., Brommer J. E., Butet A., Ecke F., Huitu O. Europe-wide dampening of population cycles in keystone herbivores // Science. – 2013. – V. 340. – № 6128. – P. 63-66.
25. Folke C., Carpenter S., Walker B., Scheffer M., Chapin T., Rockström J. Resilience thinking: integrating resilience, adaptability and transformability // Ecology and Society. – 2010. – V. 15. – № 4. – P. 20.
26. Henden J. A., Ims R. A., Yoccoz N. G. Nonstationaryspatio-temporal small rodent dynamics: evidence from long-term Norwegian fox bounty data // Journal of Animal Ecology. – 2009. – V. 78. – № 3. – P. 636-645.
27. Kausrud K. L., Mysterud A., Steen H., Vik J. O., Østbye E., Cazelles B., Stenseth N. C. Linking climate change to lemming cycles // Nature. – 2008. – V. 456. – № 7218. – P. 93-98.
28. Lade S. J., Tavoni A., Levin S. A., Schlüter M. Regime shifts in a social-ecological system // Theoretical Ecology. – 2013. – V. 6. – № 3. – P. 359-372.
29. Schlueter M., Mcallister R. R., Arlinghaus R., Bunnefeld N., Eisenack K., Hoelker F., Stöven M. New horizons for managing the environment: A review of coupled social-ecological systems modeling // Natural Resource Modeling. – 2012. – V. 25. – № 1. – P. 219-272.
30. Saitoh T., Cazelles B., Vik J. O., Viljugrein H., Stenseth N. C. Effects of regime shifts on the population dynamics of the grey-sided vole in Hokkaido, Japan // Climate Research. – 2006. – V. 32. – № 2. – P. 109-118.
31. http://aral.mptf.uz/site/aralsea.html)