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Ecological assessment of coherent relationships of the trophic system "plants-rodents-pravator" in the conditions of the aral region

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***Abstract*---**The article involves the long-term joint dynamics in the conditions of the Southern Aral Sea region of the population size of the most typical for this region system "predator-rodents-plants". It is shown that 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 the destabilized ecosystem. The classical models of the Lotka-Volter "predator-prey" type, built for a normally, steadily functioning ecosystem, turn out to be inadequate for crisis conditions.

***Keywords*---**Aral Sea area, dynamics of quantity, population, trophic connections, ecosystem, coherentness.

Introduction

Global and regional environmental changes, taking place on the planet and characterized as ecological crisis processes have brought to the fore the solution of the problems of destabilization and the dynamics of natural processes [1, 2]. Revealing the regularities of the course of crisis processes and their forecasting is of great scientific and practical importance for making decisions at the state level to mitigate them and eliminate their consequences. Tracking the self-organization of an ecosystem in crisis and, in particular, determining the point of stabilization, i.e. attractor is an actual problem. The concept of transitional dynamics is gaining more and more strength and is replacing the ideas about the linear and

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predictable nature of the dynamics of biological systems in crisis conditions [5, 6, 7, 8]. In the course of structural and functional reorganization, “coadaptive biota complexes” are formed, the development of which, according to the principles of synergetics, occurs coherently (consistently) throughout the system in the direction of one or several attractors.

For Uzbekistan, among the priority problems of crisis processes, one of the first places is occupied by the drying up of the Aral Sea. The Aral crisis, being a complex of complex ecological processes, has a specific type of dynamics, different from natural, evolutionary successions. First of all, this is a significant non-linearity and high speed of processes. In just a few decades, the water area of the sea has decreased by 83%, the grandiose reed beds, which occupied more than 600 thousand hectares in the Amudarya delta, have decreased by almost 10 times by 2004 [3], 60 species of wild animals and plants have disappeared, the number of species that are under the threat of extinction (12 species of mammals, 26 species of birds and 11 species of plants) [4]. Correspondingly, structural and functional ties are also dynamic in various communities of the ecosystem of the Southern Aral Sea region, where, by the way, the consequences of the Aral Sea crisis are manifested to the maximum.

As is known, rodents, being an important component of natural ecosystems, are widely used as model objects in ecological studies, including those that address the problems of anthropogenic transformations of the environment [10]. 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 over large areas and, therefore, can be used for bioindication of the natural environment.

Many rodent populations have cyclic dynamics. Population cycles are characterized by regularity, although they can have different amplitudes. Termination of cyclic dynamics or violation of its regularity can be considered as an example of non-stationary dynamics. A long series of observations of rodent populations made it possible to detect the massive acyclicity of rodent population processes in the forest-steppe, steppe, and desert regions of Russia, Kazakhstan, Kalmykia, and other countries [11, 12]. One of the supposed reasons for the violation of cycles is a change in climatic conditions [13] or a deterioration in the food supply [14]. For the Southern Aral Sea region, the reason for the disruption 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 food resource for rodents: species of comb (*Tamarix hispida, T.ramosissima),* karabarak *(Halosta chysbelangeriana)*, saxaul *(Haloxylon aphyllum)*, species of quinoa *(Atriplex heterosperma, A.fomini, A.tatarica),* Salsola *(Salsola dendroides)*, Sand Locust *(Ammodendron Conollyi)*, Licorice *(Glycyrrhiza glabra)*, Bassia *(Bassiahis sopifolia),* Kochia *(Kochia scoparia),* Wormwood *(Artemisia halophila)*, Cane *(Pragmites australis)* and others [15, 16].

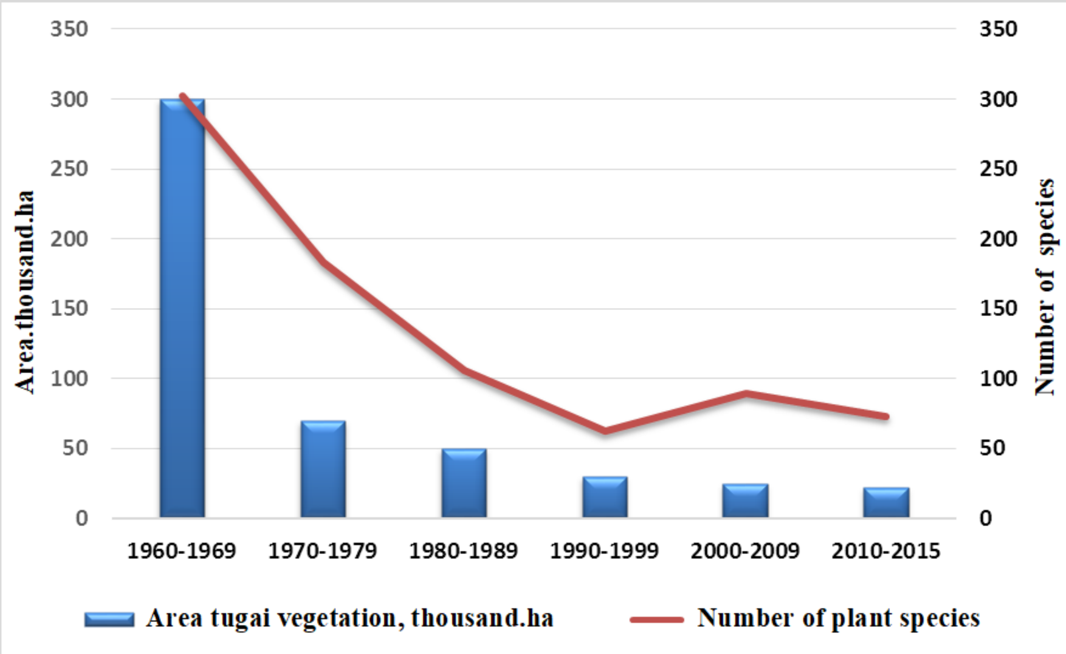


Fig.1. Dynamics of the area of tugai vegetation and the number of plant species in the lower reaches of the Amu Darya [3, 17, 18]

The cognitivity 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 in it by the behavior of objects closely related to it. Coherence, in combination with the analogy method, makes it possible to detect the presence of a reaction to a strong perturbing signal of the entire structure of a dynamic system. In other words, the results of studies of the dynamics of individual elements of an ecosystem can be comparable and mutually ratifiable.

Thus, the coherence of the behavior of the elements of a non-equilibrium self-organizing system can serve as a kind of validation measure for the results of studying the dynamics of the behavior of individual elements of the system. Based on the foregoing, the study of the long-term systemic dynamics of the “fox-rodents-plants” community using a synergistic approach is of particular scientific interest.

Material and Research Methods

A synergistic approach is needed to assess coherence and predict population dynamics. Simulation models are indispensable for the rapid identification through numerical experiments of the patterns of behavior of the object of study in various conditions. The study was carried out for the territory of the South Aral Sea region indicated on the map (Fig. 2).

At the same time, extensive factual material was used, collected over the period 1961-2017 by scientists specializing in the field of ecology, zoology, botany. In view of the fragmentation and insufficient representativeness of the observational data, spatiotemporal alignment of the observation series was used by the methods of statistical analysis of time series [20].

Fig.2. Map-scheme of the research area in the region of Southern Aral Sea

The methodology of this research is a synthesis of several approaches: synergistic, population and simulation. The use of several mutually complementary methods allows you to study several aspects of the object under study at once. Thus, the population approach is used to identify and interpret the ecological features of the population dynamics of the components of the “fox-rodents-plants” system.

To describe binary interspecies relations in the studied system “fox-rodents-plants”, the classical model “predator-prey” is used, which is described by the Lotka-Volterra equations

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

with appropriate initial conditions

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

where x and y – the population size of prey and predators, a – the specific growth rate of the prey population in the absence of predators, b — a constant characterizing the rate of prey population consumption by the population of predators, c – the specific mortality rate of predators, d – a constant characterizing the rate of increase in the number of predators due to the biomass of consumed prey [21, 22]. Taking into account the factor of intraspecific competition among predators and prey, respectively (1), the system will take the form:

$$\begin{cases} \dfrac{dx}{dt} = ax - bxy - r_1 x^2 \\ \dfrac{dy}{dt} = -cy + dxy - r_2 y^2 \end{cases} \quad (3)$$

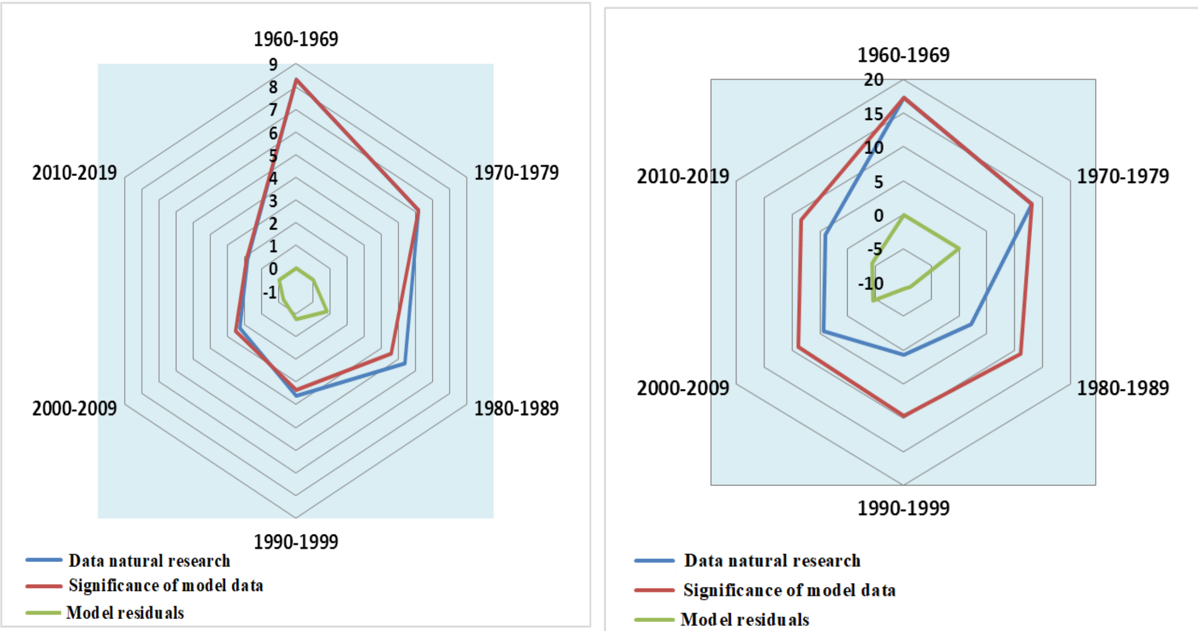
where r_1, r_2 – coefficient of intraspecific competition between prey and predator [23]. Equations (3) with initial conditions (2) represent the Cauchy problem for a system of nonlinear ordinary differential equations, which is solved by the classical 4th order Runge-Kutta method [24].

To quantify the binary coherence of the long-term dynamics of the populations of the components of the “fox-rodents-plants” system, the time series of data (actual and model) were first approximated. Since the coherence of processes is characterized by the consistency in their speed and the coincidence of singularity points (extrema, inflections, etc.), we introduced the coherence coefficients for the speed of change in the population size (CSP) and the tempo (CTP), calculated as the correlation coefficients, respectively, of the first and second derivatives of the approximating dynamics of populations of equations.

Results and Discussion

In model (2) - (3) for binary relationships “fox-rodents”, the following input data are used: initial values $x_0 = 17,2;\ y_0 = 8,3$, parameters $a = 0,02;$ $b = 0,0003;\ c = 0,03;\ d = 0,00004;\ r_1 = 0,003;\ r_2 = 0,0001$.

Analysis of data from field studies of the number of populations of rodents (*Microtus Ilaeus*) and foxes (*Vulpes Vulpes*) (individuals per 1 ha) (Table 2) shows significant fluctuations for rodents and relative stability for the fox. A variety of methods and the absence of a unified space-time monitoring system naturally reduces the correctness of the model results, as evidenced by significant discrepancies.



A. B.

Fig.3. Discrepancies between data from field studies and model data on population dynamics Rodents (A) and foxes (B)

The middle quadratic deviation between the data of field studies and the value of the model data of rodents is

$\rho_{rodent} \approx 5,7,$ a fox $\rho_{fox} \approx 0,34$

The relationship between the number of rodents and foxes over the years is characterized by a high correlation both according to the actual and model data (respectively and и).

$$k_{factual} \approx 0,78 \quad k_{model} \approx 0,99$$

The graphical representation of the simulation results (Fig. 2) clearly demonstrates the consistency of the long-term dynamics of the abundance of foxes and rodents. We see that the decrease in the number of both populations occurs almost simultaneously, 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 imitates the violation of the cyclicity of natural fluctuations in the population size characteristic of rodents, which in reality manifests itself in the gradual damping of fluctuations. There are also objective prerequisites for the variability in the number of rodent populations, taking into account the spatial localization of zones with varying degrees of anthropogenic mosaicity of the animal habitat.

The relationship that develops between plants and herbivores can also be seen as a predator-prey relationship. For the "rodents-plants" relationship, the following input data are accepted in the model: initial conditions $x_0 = 302;\ y_0 = 17,2$, parametres $a = 0,0014;\ \ b = 0,0019;\ \ c = 0,005;\ \ d = 0,0001;\ \ r_1 = 0,0001;$ $r_2 = 0,003$.

In contrast to the interspecies relations "fox-rodents", the correlation between the abundance of plants and rodents is high, as for the model data ($k_{model} \approx 0,98$), as well as for factual data ($k_{factual} \approx 0,94$).

The joint dynamics of the number of components of the binary relationship "predator-prey", as well as in the case of interspecific relations "fox-rodents" is consistent. It should be noted that Lotka-Volterra's "predator-prey" model, focusing on simulating the dependence of the "predator" dynamics on the "prey" trajectory, "underestimates" the number of rodents, so that the number of rodents per 1 *ha* for the decade 2010-2020 decreases from 8.37 in the case of "fox-rodents" to 5.79 for the relationship "rodents-plants".

To reveal patterns of long-term dynamics of population numbers, long series of relevant actual 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). 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 the coherence of the dynamics of the number of these two species, which is especially manifested according to the provisions of synergetics in a crisis.

For this purpose, the above-described CSP and CTP for the "fox-rodents-plants" system were calculated (Fig. 4):

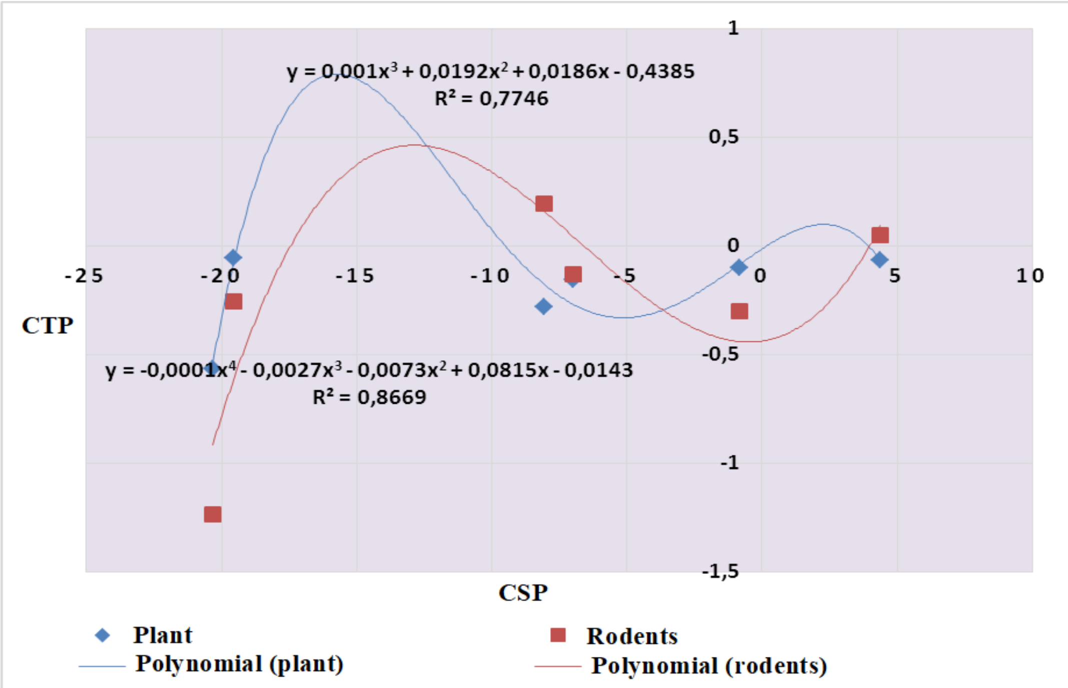


Fig.4. Values of velocity coherence coefficients (CSP) and tempo (CTP) of population dynamics “plant-rodents-predator”

The high values of CSP and CTP substantiate the reliability of the reconstructed data series on the dynamics of the number of foxes used in the simulation. Obviously, the more accurate the scientific information about the nature of the observed relationships between the two types, the higher the reliability of the restored data series.

Thus, we note that the specifics of the dynamics of natural processes in the conditions of the Aral Sea ecological crisis require the development of special simulation models, taking into account the control parameters and order parameters of a destabilized ecosystem. Classical Lotka-Volterra “predator-prey” models built for a normally, steadily functioning ecosystem turn out to be inadequate for crisis conditions. The results showed that the dynamics of the abundance of components of the binary relationship “predator-prey”, as in the case of interspecific relations “predator-rodents” is consistent. Significant discrepancies with model data do not allow us to consider the Lotka-Volterra “predator-prey” model as adequate for describing real interspecific relationships and population sizes in regions with an unstable ecological situation.

References

1. Kuznetsov A.S. Energy potential of landscape and geomorphological systems / A.S. Kuznetsov // Nature and society: a look from the past into the future: mater. XVII scientific conference of young geography of Sibir and the Far East. – Irkutsk: Publishing House of Institut of geography, 2011. – Pp. 31–32.

2. Shilov A., Chabovsky A.V., Isaev S.I., Neronov V.V. The dynamics of the community and population of rodents in the semi-deserts of Kalmykia under conditions of reduced pressure on pastures and humid climate // Information of Academy Sciences: Seria Biology. – 2000. – No. 3. – pp. 332-344.
3. Bakhiev A.B., Treshkin S.E., Mamutov N.K. The study of plant resources of the Southern Aral and their rational use in the conditions of Anthropogenic desertification. // In the collection of IV International scientific-practical conference "Problems of rational use and protection of biological resources of the Southern Aral Sea". – Nukus: Ilim. – 2012. – P. 35.
4. http://aral.mptf.uz/site/aralsea.html
5. Briske D. D., Illius A. W., Anderies J. M. Nonequilibrium ecology and resilience theory. In: Rangeland systems. Springer, Cham. – 2017. – 197–227 pp.
6. 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.
7. 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.
8. 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.
9. Ruchin A.B. Ecology of populations and communities. M., 2006. – 352 p.
10. Mambetullaeva S.M. Determination of ecological criteria for rationing the anthropogenic load on the fauna of mammals in the lower reaches of the Amu Darya // Actual problems of biology, ecology and soil science. Materials of Republican scientific-practical conference. Tashkent, 2008. – Pp. 85–87.
11. 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.
12. 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.
13. 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.
14. 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.
15. Reimov R. Rodents of the South Aral Sea. – Tashkent: AS. –1987. – 125 p.
16. Reimov R. Experience of ecological and morphophysiological analysis of the mammalian fauna of the Southern Aral Sea. – Nukus: Karakalpakstan. – 1972. – 412 p.
17. Mamutov N. Pasture resources of the South Aral Sea region and problems of their rational use // Foreign conference of "Problems of rational use and protection of biological resources of the southern Aral Sea. – Nukus. – 2006. – P.15.

18. Matzhanova H.K., Orel M.M. Vegetative resources of the Southern Aral Sea and the possibilities of their use // Journal “Bulletin of the Karakalpak branch of AS RUz”. – Nukus, 2018. – No. 1. – P. 30–36.
19. 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.
20. Anderson T. Statistical analysis of time series. - M., Mir, 1976. - 756 p.
21. Zaripov Sh.Kh., Abzalilov D.F., Kosterina E.A. Problems of mathematical ecology and the Maxima package // Textbook. – Kazan: Publishing House of Kazan Federal University, 2015. – 120 p.
22. Chu A.R., Mikhailov M.D. Study of the mathematical model “predator-prey” taking into account intraspecific competition and habitat in a two-dimensional approximation // XIX Siberian Conference on Parallel and High-Performance Computing. Tomsk, October 10–12, 2017: collection of articles. Tomsk, 2017. – Pp. 78–85.
23. Chu A.R., Mikhailov M.D. Study of the mathematical model “predator-prey” taking into account intraspecific competition // All-Russian Youth Scientific Conference “All Facets of Mathematics and Mechanics”: collection of articles / ed. A.V. Starchenko. Tomsk: Publishing House of Tomsk State University, 2016. – Pp. 118–124.
24. Kalitkin N.N. Numerical methods. The main edition of the physical and mathematical literature of the publishing house “Science”, M., 1978. – 512 p.
25. Tleumuratova B.S. Mathematical modeling of the impact of transformations of the South Aral Sea ecosystem on soil and climatic conditions. / Dissertation of doctor of science, Tashkent, 2018.
26. Abaturov B.D., Sokolov V.E. Mammals as a component of ecosystems. M.: Science. 1984. – 286 p.
27. A. D. Bazykin, Nonlinear Dynamics of Interacting Populations. Moscow-Izhevsk: Institute of Computer Technologies, 2003. – 368 p.
28. Bratus A.S., Novozhilov A.S., Platonov A.P. Dynamic systems and models of biology. M.: FIZMATLIT, 2010. – 320 p.
29. Volterra V. Mathematical theory of the struggle for existence / ed. Yu.M. Svirezheva. M.: Nauka, 1976. – 286 p.
30. Dynamics and potential of the natural environment of Karakalpakstan / N.K. Aimbetov, B.S. Tleumuratova, S.M. Mambetullaeva and others, Karakalpak Scientific Research Institute of Natural Sciences of the Karakalpak Branch of the Academy of Sciences of the Republic of Uzbekistan. – Nukus: Ilim, 2017. – 251 p.
31. Kolomyets E.G. Local mechanisms of global changes in natural ecosystems. – M.: Science. 2008. – 427 p.
32. Kuzmina Zh.V., Treshkin S.E. Assessment of the impact of the South Karakalpak main collector on the Badai-tugai reserve // Arid ecosystems. – 2003. – Volume 9. – Pp. 93–105.
33. Mambetullaeva S.M. Characterization of the spatial structure of populations of small mammals in the lower reaches of the Amu Darya // Journal “Postgraduate student and competitor”, M., Russia, 2012, No. 2. – Pp. 47–48.
34. Okulova N.M., Kataev G.D. Interrelations between the “Predator and Red-backed Vole” in Vertebrate Communities of the Lapland Reserve // Zoology journal, 2007. – T. – No. 8. – Pp. 989-998.

35. Liu J., Dietz T., Carpenter S. R., Alberti M., Folke C., Moran E., Ostrom E. Complexity of coupled human and natural systems // Science. – 2007. – V. 317. – № 5844. – P. 1513–1516.
36. Nishanov A. K., Akbaraliev B. B., Satimovich S. B., Kamarbekovich A. O., & Khudaybergenovich T. S. An algorithm for classification, localization and selection of informative features in the space of politypic data // Webology. – 2020. – V. 17. № 1. – P. 341–364.