Ecology and Evolutionary Biology
2022; 7(3): 54-58
http://www.sciencepublishinggroup.com/j/eeb
doi: 10.11648/j.eeb.20220703.13
ISSN: 2575-3789 (Print); ISSN: 2575-3762 (Online)

The Use of Coherence in Studies of Biota Dynamics in the Conditions of the Aral Crisis

Elzura Pulatovna Urazimbetova*, Bibigul Saribaevna Tleumuratova

Karakalpak Scientific Research Institute of Natural Sciences, Karakalpak Branch, Academy of Sciences of the Republic of Uzbekistan, Nukus, Uzbekistan

Email address:
elzurau@gmail.com (Elzura Pulatovna Urazimbetova), bibigultleumuratova2022@gmail.com (Bibigul Saribaevna Tleumuratova)
*Corresponding author

To cite this article:
Elzura Pulatovna Urazimbetova, Bibigul Saribaevna Tleumuratova. The Use of Coherence in Studies of Biota Dynamics in the Conditions of the Aral Crisis. *Ecology and Evolutionary Biology*. Vol. 7, No. 3, 2022, pp. 54-58. doi: 10.11648/j.eeb.20220703.13

Received: August 4, 2022; **Accepted**: August 23, 2022; **Published**: September 5, 2022

Abstract: The article studies 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 of «fox-rodents-plants». It is shown that the peculiarities of dynamics of natural processes in the conditions of the Aral crisis require the development of special simulation models, taking into account the parameters of management and parameters of the order of destabilized ecosystem. Classic Lotka-Volterra models of «predator-prey», built for a normally and permanently functioning ecosystem, are inadequate for crisis conditions. The coherence of the behaviour of elements of an unbalanced self-organizing system can serve as a measure of verification of the results of the investigation of the behaviour of individual elements of the system. Consistency of population changes in the system of «predator-prey», caused by trophic bonds far from the point of bifurcation, the behavior of the system elements and the level of interelement interactions can be coherent. We propose a method of reconstructing series of observations missing data on multi-year population dynamics of one species, by linking this species to another well-studied species, which is a very effective method of structuring source data in mathematical modeling of natural processes. Response functions, analogy method and consistency of species abundance dynamics are used, which is especially manifested in the positions of synergy in a crisis. Coherence coefficients are introduced for the speed and tempos of change of population numbers, which are calculated as correlation coefficients of the first and second derivatives, respectively, approximating the dynamics of population, because coherence of processes is characterized by consistency in their speed and coincidence of special points.

Keywords: Southern Aral Sea, Multi-year Population Dynamics, Predator-Prey Model, Coherence, Approximation, Data Series Recovery, Discrepancy

1. Introduction

The local and global ecological changes occurring on the planet and characterized as ecologically crisis processes have brought to the forefront ecosystem research the problems of destabilization and dynamics of natural processes [1, 2]. Revealing the patterns of the course of crisis processes and their prediction is of great scientific and practical importance for making decisions at the state level to contain them and prevent their consequences.

The population responses of a species can reflect the dynamics of the ecosystem as a whole, so the population approach, when the biology of the species is studied sufficiently fully, can be successfully used to research the state of natural ecosystems [3]. These criteria are corresponds by a numerous group of small mammals (rodents) of different species, being the traditional model object of researches a wide spectrum of problems of theoretical and applied ecology. Rodents, being an important component of natural ecosystems, are widely used as model objects in ecological studies, including those that affect the problems of anthropogenic transformations of the environment [4]. This is a numerous group of animals, which, due to its position in the trophic chains of ecosystems, directly perceives the pressure of those or other 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. The termination of cyclic dynamics or the violation of its regularity can be considered as an example of non-stationary dynamics. A long series of observations of rodent populations has allowed to discover a mass acyclicity of rodent population processes in forest-steppe, steppe, and desert regions of Russia, Kazakhstan, Kalmykia, and other countries [5, 6]. One of the alleged reasons for the disruption of the cycles is a change in climatic conditions [7] or a deterioration in the food supply [8].

For the Southern Aral Sea region, the reason for the violation of the cyclic 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, in particular plants serving as a food resource for rodents [9, 10].

Dynamics of the number of rodents also reflects time series of the number of fox skins handed over by hunters, for which rodents are the main food resource [11]. Thus, it is possible to distinguish the system "fox-rodents-plants" as a certain coadaptive community possessing trophic relations and coherence of population processes.

The study of relations and coherence has a special cognitive value. The cognitiveness of relations is that when it is impossible to study an object directly, 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 method of analogy, allows us to detect the presence of a response to a strong perturbing signal of the whole structure of the dynamical system. In other words, the results of studies of the dynamics of individual ecosystem elements can be comparable and mutually ratifiable.

Based on the above, the research of long-term system dynamics of "fox-rodents-plants" community using synergetic approach is of certain scientific interest. The principle of isomorphism allows to transfer theoretical results of this research (regularities, trends of system development in conditions of ecological crisis) to other subsystems of biota of Southern Aral Sea region, and possibly to ecosystems of other crisis regions.

In this article aggregated, in a first approximation the long-term population dynamics is considered of the most typical in the Southern Aral Sea region community "fox-rodents-plants" with an emphasis on the coherence of the behavior of its elements is considered.

2. Materials and Methods

The study was conducted for the territory of South Aral Sea region. At the same time extensive factographic material collected during the period 1961-2017 by scientists specializing in ecology, zoology, and botany was used. Due to the fragmentary and insufficient representativeness of the observation data, spatial and temporal alignment of the observation series by methods of statistical analysis of time series was applied [12].

The methodology of this research is a synthesis of several approaches: synergetic, population-based and imitation. The use of several mutually complementary methods allows you to study several aspects of the object under research 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. A synergistic approach is needed to assess coherence and predict population dynamics. Imitation models are indispensable when promptly detected by numerical experiments of patterns of behavior of the object of study in various conditions.

To quantify the binary coherence of the long-term population dynamics of the components of the "fox-rodents-plants" system, we first approximate the time series of data [13]. Since the coherence of processes is characterized by consistency in their speed and the coincidence of points of peculiarities, we have introduced the coherence coefficients of the speed of changes in population size and tempos, calculated as the correlation coefficients, respectively, of the first and second derivatives of the approximating population dynamics of equations.

3. Results and Discussion

Analysis of data natural researches of the number of rodents (*Microtus Ilaeus*) and foxes (*Vulpes Vulpes*) per 1 ha (hectare) (Table 1) shows essential fluctuations for rodents and relative stability for foxes. The variety of methods and the absence of a unified spatio-temporal system monitoring naturally reduces the correctness of model results, as evidenced by essential discrepancies.

Table 1. *Residuals between the data of field studies and model data of the dynamics of the population of fox and rodents.*

Years	Rodents		Fox	
	Data of natural researches	Model data value	Research data of the nature	Model data value
1960-1969	17.20	17.20	8.30	8.30
1970-1979	13.14	13.14	6.14	6.14
1980-1989	2.23	11.03	5.38	4.55
1990-1999	0.68	9.76	3.60	3.37
2000-2009	4.35	8.93	2.25	2.50
2010-2019	3.95	8.37	1.81	1.85

The standard deviation between the data of natural researches and the value of the model data of rodents is $\rho_{rod} \approx$

5.7 and the foxes $\rho_{fox} \approx 0.34$.

The interrelation between the number of rodents and foxes by year is characterized by a high correlation both in actual and model data (respectively $k_{act} \approx 0.78$ and $k_{mod} \approx 0.99$).

The graphical representation of the simulation results (Figure 1) clearly demonstrates the consistency of the long-term dynamics of the number of foxes and rodents. We see that the waning in the number of both populations occurs almost synchronously, since the dependence of the population of foxes on the number of rodents leads to the fact that the dynamics of foxes adjusts to the dynamics of rodents.

The model clearly simulates the violation of the cyclical nature of natural fluctuations in the population size characteristic of rodents, which in reality manifests itself in a gradual attenuation of fluctuations. There are also objective prerequisites for the variability of the number of rodent populations, taking into account the spatial localization of zones with varying degrees of anthropogenic mosaicism of the animal habitat.

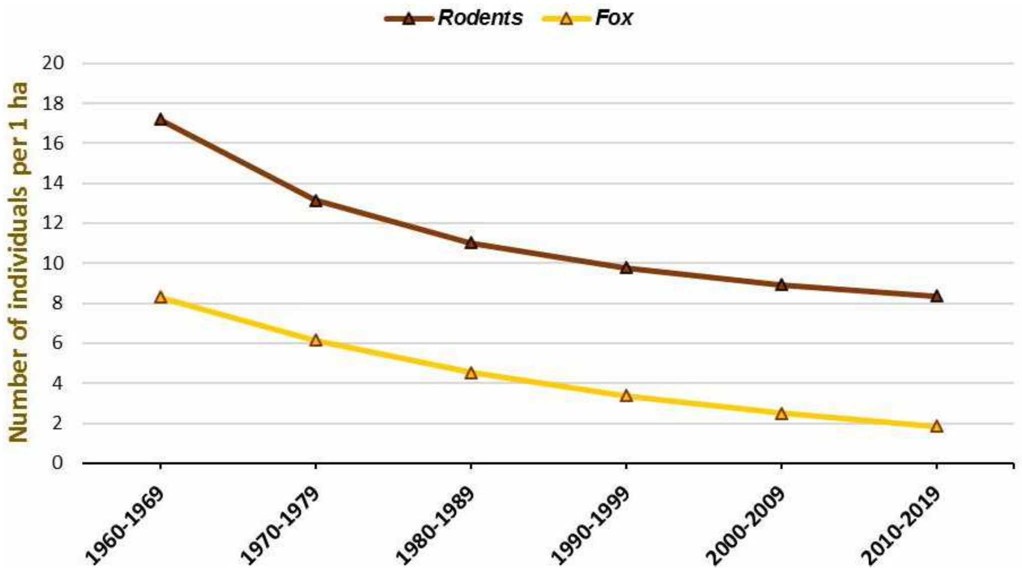

***Figure 1.** Dynamics of the population size of rodents and foxes based on the results of modeling.*

In contrast to the interspecific relations "fox-rodents", the correlation between the numbers of plants and rodents is high both for model data ($k_{mod} \approx 0.98$), and for actual data ($k_{act} \approx 0.94$).

The joint dynamics of the number of components of the binary relations "predator-prey", as well as in the case of interspecific relations "fox-rodents" is agreed (Figure 2). Note that the Lotka-Volterra “predator-prey” model, focusing on imitating the dependence of the “predator's” dynamics on the “prey” trajectory, “underestimates” the number of rodents, so that the number of rodents per 1 ha for the decade 2010-2019. declines from 8.37 in case "fox-rodents" to 5.79 for the "rodents-plants" relations.

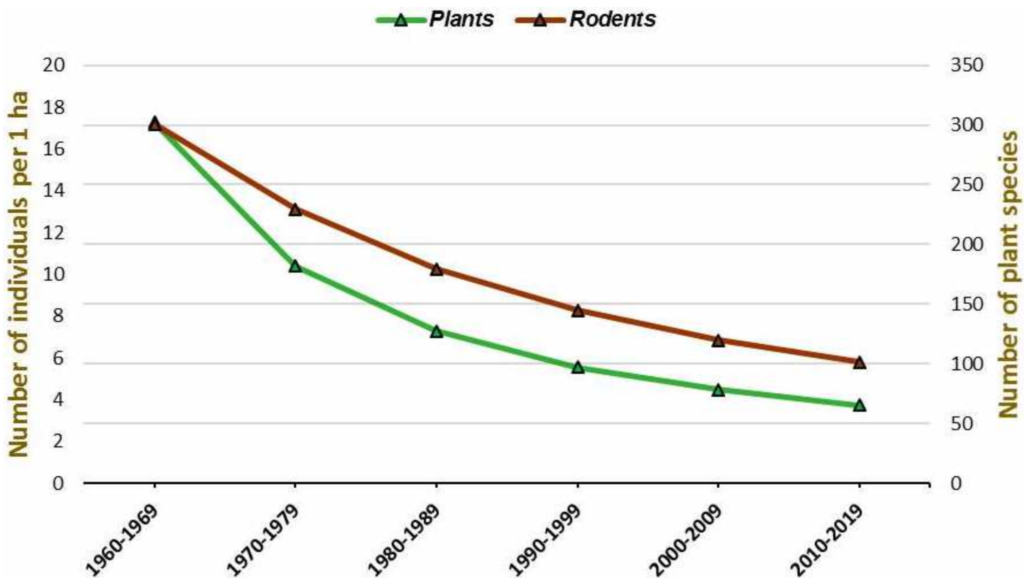

***Figure 2.** Dynamics of the number of plant species and rodents according to the results of modeling.*

In Figure 2, we also observe a violation of the cyclicity of fluctuations in the population size.

On the whole, based on the simulation results, it can be concluded that the classical Lotka-Volterra "predator-prey" [14, 15] model is too simple to describe the long-term dynamics of the population size an ecosystem located in difficult crisis conditions. Let us present, for comparison, the graphs of the dynamics of the population size of the considered system "fox-rodents-plants" (Figure 3), constructed from the actual data.

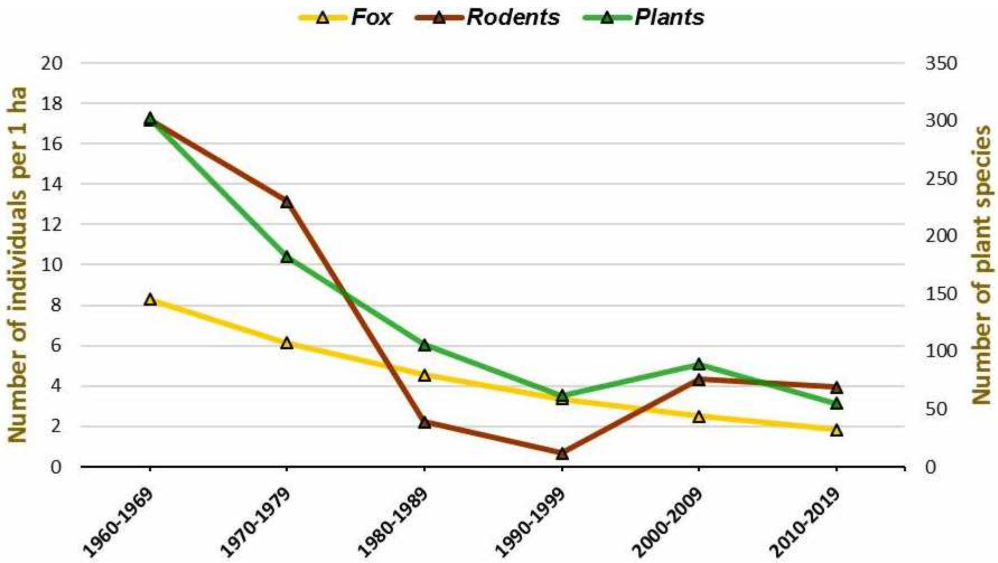

Figure 3. *Dynamics of the population size of the "fox-rodents-plants" system based on natural data.*

Significant discrepancies with model data do not allow us to consider the Lotka-Volterra "predator-prey" model as adequate for describing the real interspecific relations and population size in the regions of ecological disasters. Since under the conditions of a crisis changes the entire structure of the ecosystem, including trophic relations, the minimum requirement for the applicability of indicated model to describe long-term population dynamics is the nonstationarity of all coefficients. This requires separate studies to determine these coefficients as functions of time.

In view of the multidimensional influence of the Aral crisis, greatly 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 the crisis [16]. This requires the development of complex simulation models based on fairly representative factual material. In turn, this requires an established monitoring system and databases with built-in software for systematization and data processing. All this, unfortunately, is absent in the Southern Aral Sea region, which significantly reduces the effectiveness of environmental research.

To identify patterns of long-term population dynamics, long series of relevant factual data are needed. In this research, we had sufficiently 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). Recovery of a number of data from natural researches in such a situation is possible with the use of the response function on the number of rodents, the method of analogies and the coherence of the dynamics of the number of these two species, especially manifested according to the provisions of synergetics in a crisis. For this purpose, the above described PSC (population speed coherence) and PTC (population tempos coherence) were calculated for the "fox-rodents-plants" system (Table 2):

Table 2. *Values of the coherence coefficients of the speed (PSC) and tempos (PTC) of dynamics of the population size.*

Years	Speed			Tempos		
	Plants	Rodents	Fox	Plants	Rodents	Fox
1960-1969	-20.32	-0.57	-1.24	2.88	0.04	0.33
1970-1979	-8.07	-0.28	0.19	0.21	0.02	0.01
1980-1989	-6.97	-0.16	-0.13	0.28	0.01	-0.04
1990-1999	-0.82	-0.10	-0.30	0.85	0.004	0.02
2000-2009	4.39	-0.07	0.05	-0.28	0.002	0.03
2010-2019	-19.57	-0.05	-0.26	-5.35	-0.001	-0.14
	PSC	0.54	0.74	PTC	0.71	0.91

The high values of PSC and PTC justify the reliability of the restored series of data 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 interrelations between the two species, the higher the reliability of the reconstructed data series.

4. Conclusion

Based on the results of the study, the following conclusions were made:

1) It was revealed that the dynamics of the number of components of the binary relations "predator-prey", as in the case of interspecific relations "predator-rodents" is consistent. If the emphasis is placed on simulating the dependence of the dynamics of the "predator" on the trajectory of the "prey "in the" predator-prey " model of Lotka-Volterra, the number of rodents decreases.
2) Significant discrepancies with model data do not allow us to consider the Lotka-Volterra “predator-prey” model as adequate for describing real interspecific relations and population size in regions of ecological disasters. Since the entire structure of the ecosystem, including trophic relationships, changes under conditions of an ecological crisis, the minimum requirement for the applicability of this model to describe long-term population dynamics is the nonstationarity of all coefficients.

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