UDC 574:004.942
DOI: 10.15587/1729-4061.2017.109868

MODELING OF A PROCEDURE FOR UNMASKING THE FOXES DURING ACTIVITIES ON THE ELIMINATION OF BIOSAFETY THREATS RELATED TO RABIES

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Представлені результати математичного моделювання захисного забарвлення лисиць з метою виявлення тварин на місцевості. Для моделювання використана дискретна динамічна модель. Структурно-параметрична ідентифікація моделі здійснювалася на основі цифрових знімків тварин і рослинних спільнот у місцях їх мешкання. Визначені системні колорометричні параметри, використання яких дозволило підвищити контрастність силуетів тварин на фоні фітоценозу. Це підвищення контрастності сприяє демаскуванню тварин на місцевості, що є необхідним при проведенні заходів щодо усунення загроз біобезпеки, пов'язаних зі сказом

Ключові слова: динамічні системи, дистанційне виявлення тварин, ідентифікація моделей, колорометричні параметри, сказ

Представлены результаты математического моделирования защитной окраски лисиц с целью выявления животных на местности. Для моделирования использована дискретная динамическая модель. Структурно-параметрическая идентификация модели осуществлялась на основе цифровых снимков животных и растительных сообществ в местах их проживания. Определены системные колорометрические параметры, использование которых позволило повысить контрастность силуэтов животных на фоне фитоценоза. Это повышение контрастности способствует демаскировке животных на местности, что необходимо при проведении мероприятий по элиминации угроз биобезопасности, связанных с бешенством

Ключевые слова: динамические системы, дистанционное обнаружение животных, идентификация моделей, колорометрические параметры, бешенство

1. Introduction

We can currently observe major changes in the habitat of wild animals. The reason for these changes is the impact of human civilization on the nature of the planet, which under conditions of global climatic changes in many cases result in serious biosafety threats. Elimination of a significant part of these threats is within the purview of the veterinary medicine. This may involve, in particular, the issues related to emerging of new habitats and migration routes of animals, the communities of which are potential reservoirs of dangerous infectious diseases. These diseases include rabies [1]. Its reservoir can be communities of different species of wild animals including foxes [2]. Monitoring the habitat and migration of these animals in many cases must be carried out in large areas that very often are difficult to access. This factor makes it advisable to use remote (aerospace) methods that are becoming more often applied for studying the animal life in the wild [3].

The arsenal of modern remote methods for studying the life of animals allows solving a wide range of problems. These problems are also related to the field of fundamental science and practical conservation activities. Scientific knowledge-intensive technologies, often requiring significant financial costs, are used for completion of such tasks.

One of the options is the use of devices that can register observed objects by EMR in the ranges outside the visible spectrum. Examples include application in zoology and zoogeography of infrared imagers [4] that register infrared radiation. Such solution requires a relatively higher cost of equipment. Meanwhile, there may be situations where for keeping records of animals, which are potential reservoirs of dangerous diseases, it will be required to collect a large amount of original factual information with relatively small financial costs. It should also be borne in mind that in extreme situations, involving biosafety hazards, there will be an urgent need to increase this arsenal. Moreover, the need for addressing these challenges can occur under conditions of critical time constraints.

Extreme situations may arise, in particular in connection with disruption of stability of foxes' populations. This disruption of stability of foxes' populations will be accompanied by appearance of these animals in habitats unusual for them. The appearance of foxes has recently been noticed even on the territories of large cities [5]. It should be mentioned that appearance of foxes on territories of residential areas is an aspect of increasing biosafety threats related to rabies. On the other hand, in big cities, foxes are often found in park areas, where protective coloration of these animals can effectively perform its adaptive function against the background of plant communities. On the boundaries of an urban area, there can often be plant communities, the colorometric parameters of which help disguise foxes and other wild animals.

In these situations, it would be appropriate to use relatively cheap remote methods, the example of which can be digital photography in the visible spectrum from light unmanned aerial vehicles (UAVs). Such a solution in many cases will be associated with difficulties, created by protective coloration of animals.

Thus, it is a relevant task to expand the arsenal of highly effective knowledge-intensive technologies of remote studying of habitats and migration routes of wild animals. An important aspect of this challenge is to identify traits and patterns that allow unmasking the studied animals against the vegetation background in their habitat.

2. Literature review and problem statement

Animals communities – reservoirs of rabies, are currently the cause of many biosafety hazards [1].

A variety of animals acts as reservoirs of rabies. Paper [6] describes the same negative role of blood-sucking bats in South America. Article [7] gives analysis of geographic data of areas with a high risk of contracting rabies from blood-sucking animals for humans and cattle in the region of the Amazon in Brazil.

Biosecurity threats, connected to rabies, relate to a number of problems of veterinary medicine in cattle. In this regard, research [8] explores the problems associated with vaccinating cows.

The most important role as reservoirs of rabies is played by carnivorous mammals of Canidae family. Paper [9] specifies the role of vaccination of domestic dogs to eliminate biosafety threats in rural areas of Africa. In article [10], the features of rabies virus in Mali are described at the molecular level.

Representatives of Canidae family, which are the reservoir of rabies, also include foxes (polyphyletic group *Vulpes)*. These wild animals as increasingly often appear in urban areas [5, 11].

Reservoirs of rabies, associated with wild animals, in comparison with rabies of domestic animals cause a number of additional problems. Paper [12] examines the nature of these problems in the Serengeti National Park (Tanzania). These problems include difficulties of keeping records of animals in the wild, on vast areas of the terrain that is difficult to access. Keeping records of animals on these territories is a problem of ecology, zoology, and zoogeography not only in connection with the problem of rabies, but also with the problem of biosafety. In this regard, the role of remote methods of observing animals in the wild is becoming increasingly important. Article [13] explores the methods of determining distribution of hyenas with the help of GIS technologies and remote sensing technologies. Paper [14] describes a wide range of remote sensing technologies, related to soils, plants and animals.

At present, a large number of remote means of monitoring the life of animals in the wild have been developed. Article [15] presents description of results of studies with the help of remote methods that made it possible to find optimal migration corridors of Asian elephants in the forests. Wild animals, which are studied with the help of remote methods, include foxes as well.

Paper [16] contains results of research in spatial distribution of population of foxes in the steppes of Kazakhstan relating to the problem of determining of foci of rabies. We are talking about the danger not only for humans but also for farm animals, such as sheep.

Article [17] describes wide opportunities and prospects, offered by the use of remote methods for studying various aspects of spatial distribution and migration of populations of wild animals. These aspects are of importance in terms of biosafety problems, which are associated with emergence and spreading of foci of rabies.

Along with remote detection of animals, remote studies of plant communities in habitats of these animals are also important. Paper [18] substantiates effectiveness and prospects of application of remote methods of shrubs exploration. This type of plant communities plays a significant role in the life of a relatively small animals, including foxes.

Research [19] focuses on the use of remote methods for studying the nature of elements of steppe landscapes of Portugal that play an important role in the life of small birds. It can refer to birds, connected with foxes by predator-prey relationships.

When using remote methods, in some cases, one might encounter problems, connected with protective coloration in animals. In paper [20], for unmasking of animals, it is proposed to use systemic colorometric parameters (SCP), constructed on the basis of data about relationships between components of the RGB model of digital photography. It goes about systemic parameters that do not exist in protective coloration of animals, but which are observed in plant communities of animal habitat. These systemic parameters reflect strategies of maintaining by plant communities of their homeostasis, dynamic equilibrium, and a certain character of dynamic balance of different aspects of bioproduction processes. This refers, in particular, to the aspects related to accumulation of biomass in the process of photosynthesis, its dying out and decay. Accordingly, these systemic aspects are connected to the structure and dynamics of relationships of various plant pigments. In this case, an important role belongs to relationships of pigments that can be registered by computer analysis of the RGB model. The main role in the processes of photosynthesis is played by green chlorophyll. In addition, at the stages of vital activity of a plant community with a shift toward biomass ageing and dying out, the presence of yellow-orange pigments increases. Article [21] shows results of formalized description of RGB model of images of communities of microscopic algae with the use of discrete models of dynamic systems (DMDS). This mathematical apparatus was also used to describe the structure and dynamics of systems of various nature [22, 23].

Paper [24] explores possibilities of using remote methods for determining risk factors for development of certain diseases. These factors include the nature of vegetation as well. In this case, analysis of behavior of biological systems with complicated structure is based on a systemic approach [25–29]. Research [25] presents the structure of feature semantic spaces, reflecting an organized representation of variability of obesity process. Prediction of development of postoperative pain in patients with injuries to limbs with the use of a systemic approach is shown in [26]. In paper [27], the authors substantiated splitting of the system of parameters into content units in the process of examining risk factors for development of the crisis in family relations. Article [28] describes prediction of recurrent myocardial infarction based on the methodology of the verbal decision analysis. In [29], the approach to predicting the development of atopic dermatitis in children with the use of discrete modeling of dynamic systems was offered. The proposed approach is based on comparison of values of clinical signs of a child with an idealized trajectory of behavior of a biological system.

Application of comparatively simple and cheap light UAV with relatively cheap equipment for digital photography allows registration of colorometric parameters in broad spectrum bands. The components of the RGB model of the obtained image correspond to registered parameters. This registration makes it difficult to get enough contrasting images of animals with protective coloration. These difficulties can be overcome by means of finding systemic aspects of protective coloration with the use of mathematical modeling. Based on the results of modeling, which was carried out with the help of DMDS, working hypotheses about the form of SCP were formulated in work [30]. On the basis of the specified working hypotheses, the authors developed procedures for processing fish images against the background of such relatively simple freshwater communities of microscopic algae. These procedures allow unmasking fish, which has protective coloration. Similar procedures can be used for unmasking of foxes. However, it is possible that protective coloration of higher animals imitates some features of SCP of plant communities in habitats of these animals. On the other hand, changes in protective coloration of higher animals are relatively small in comparison with dynamics of colorometric parameters of specified phytocenoses. This makes it possible to find subtle differences that unmask animals. Thus, finding differences of colorometric parameters of protective coloring of foxes and phytocenoses in habitats of these animals is a relevant problem. Image processing with the use of SCP allowed increasing the contrast range of images, obtained using relatively simple and cheap equipment, and unmasking animals against a vegetation background.

This result will allow improvement of efficiency and reduction of costs for activities aimed at elimination of biosafety hazards, associated with rabies. It is implied that the use of SCP will simplify and cheapen unmasking of animals (in the case under consideration – foxes) that are potential reservoirs of rabies. Such unmasking will make it possible to promptly determine habitats and migration routes of these animals, which is an essential aspect of organizing activities for elimination of the specified biosafety hazards.

3. The aim and objectives of the study

The aim of present research is the formalized description of systemic aspects of dynamics of relationships of colorometric parameters and search for subtle distinctions in digital images of protective coloration of foxes and plant community in the habitat of these animals. The use of these subtle distinctions will improve conditions of unmasking of these animals against the background of vegetation habitat. This unmasking will allow enhancing efficiency of detection of habitats and migration routes of these animals, which is a necessary condition of information support of decision making on elimination of biosafety hazards related to rabies. We mean, in particular, to enhance effectiveness of the methods for unmasking, implemented with the use of light drones.

To accomplish the set goal, the following tasks had to be solved:

– to determine the feature space where it is possible to separate regions of values, which differ protective coloration of foxes from colorometric parameters of plant communities;

– using these regions of values, to implement the procedure of image processing for foxes' detection against the background of plant communities in habitats of these animals;

– using the procedure of image processing, to offer approaches to unmasking of animals against vegetation background in their habitat; this unmasking is intended to enhance effectiveness of means of keeping records, inter alia, of remote spatial distribution of animals, used to plan activities for elimination of biosafety hazards, related to spreading of rabies.

4. Materials and methods for studying systemic aspects of dynamics of relationships of colorometric parameters of plant communities and protective coloration of foxes

In extreme situations, requiring rapid response, light UAV with equipment for digital photography are used for remote monitoring. These approaches are based on mathematical modelling of dynamics of colorometric parameters of plant communities with the help of DMDS. As it was mentioned earlier in [11, 12], DMDS allow us somewhat decrease requirements for actual source material. In particular, they offer opportunities of working with the material, colorometric parameters of which can be obtained only by computer analysis of the RGB model of digital photography.

The RGB models of obtained digital images of plant communities are analyzed. Protective coloration of foxes causes problems for keeping their records against the background of phytocenosis. Paper [30] shows how the fish can be unmasked against the background of algae. To do this, the idealized trajectory of the system (ITS) is constructed with the help of DMDS; this trajectory represents the cycle of changes in a plant community of the values of certain colorometric parameters associated with plant pigments. While constructing ITS, the technique that received the working name of rechronization was used in some cases [21, 30]. This technique rests on the assumption that different parts of the studied system (for example, different parts of the plant community) change within one cycle, but at the moment of registration of the system's state are in different phases of this cycle. Cycle phases correspond to conditional steps of ITS. To find the SCP, which unmask an animal against the background of the vegetation community, the ITS form, constructed for the plant community, is analyzed. As a result of analysis of the character of convergence degrees of maximum values of original colorometric parameters, observed in ITS, the working hypothesis on the kind of the specified SCP is formulated. It is supposed that designation of gradation of values of this SCP with a particular conditional color will make it possible to identify the animal's silhouette against the background of vegetative community. Paper [30] presented results of verification of such hypothesis, performed in this way, which can be considered satisfactory at the preliminary stage of the research.

Along with ITS, which was constructed for a plant community, it is proposed to construct an idealized trajectory, which can be designated with a working term of idealized pseudo trajectory of the system (IPTS) – for protective coloration of animals. IPTS does not reflect any cycle of changes in colorometric parameters in real time, as dynamism of protective coloration of most animals is significantly inferior to the dynamism of colorometric parameters of a plant community. During the growing season, dynamism of protective coloration of most animals (in particular, foxes) does not exist at all. But protective coloration of animals can imitate distribution of different relationships of values of colorometric parameters of a plant community. We imply the allocation, which occurs because phases of dynamics of colorometric parameters of a plant community mismatch in time.

Comparing the nature of such distribution for specified ITS and IPTS, we can formulate a working hypothesis regarding the procedure for determining the SCP form.

Let us represent trajectories of ITS and IPTS as matrices. Let the number of components be equal to N, the number of levels – to K, the length of trajectory of ITS – T_1, the length of trajectory IPTS – T_2.

Trajectory of ITS will be presented as:

$$\begin{bmatrix} A_1(1) & A_1(2) & \dots & A_1(T_1) \\ A_2(1) & A_2(2) & \dots & A_2(T_1) \\ \vdots & \vdots & \ddots & \vdots \\ A_N(1) & A_N(2) & \dots & A_N(T_1) \end{bmatrix}, \quad (1)$$

where $A_k(j)$ is the value of the k-th component at moment j (we assume that the trajectory begins from moment t=1).

Similarly, trajectory of IPTS will be presented in the form of:

$$\begin{bmatrix} B_1(1) & B_1(2) & \dots & B_1(T_2) \\ B_2(1) & B_2(2) & \dots & B_2(T_2) \\ \vdots & \vdots & \ddots & \vdots \\ B_N(1) & B_N(2) & \dots & B_N(T_2) \end{bmatrix}, \quad (2)$$

where $B_k(j)$ is the value of the k-th component at moment (we also assume that the trajectory begins from moment t=1).

Let assume that there is a function $\phi(x, y)$ of two arguments. For two components with numbers μ and ν, we will designate

$$C_{\max} = \max_t \varphi(A_\mu(t), A_\nu(t)), C_{\min} = \min_t \varphi(A_\mu(t), A_\nu(t)),$$

$$Z_{\max} = \max_t \varphi(B_\mu(t), B_\nu(t)), Z_{\min} = \min_t \varphi(B_\mu(t), B_\nu(t)). \quad (3)$$

We believe that statement Q is true if at least one of inequalities is satisfied:

$$C_{\max} \neq Z_{\max},$$

$$C_{\min} \neq Z_{\min}. \quad (4)$$

Otherwise, statement Q is false.

Let us assume that as a result of processing of reference digital images of a plant community, maximum and minimum values of function $\phi(x, y)$ for some parameters x and y were obtained: $V_{\max}$ and $V_{\min}$. We will designate similar values of function $\phi(x, y)$ for protective coloration of animals as $A_{\max}$ and $A_{\min}$.

We believe that statement M is true if at least one of inequalities is satisfied:

$$V_{\max} \neq A_{\max},$$

$$V_{\min} \neq A_{\min}. \quad (5)$$

Otherwise, statement M is false.

The working hypothesis at the first stage of its formulation is presented by a Boolean function

$$Q \Rightarrow M. \quad (6)$$

Hypothesis specification will make it possible to determine dimensionality of the feature space, which can be found in region of values of SCP, allowing unmasking foxes against the background of plant communities in habitat of these animals. These SCP are the coordinates of such feature space. During image processing, various regions of values can be highlighted with different gradations of conditional colors. This method for unmasking an animal is presented in [22], but without comparison with IPTS: only the character of matching the steps with maximum values of colorometric parameters in ITS is analyzed to build a working hypothesis.

For better results, it is advisable to build a working hypothesis using the above procedure by comparing the form of ITS and IPTS. As a result, the SCP that can be used for unmasking animals are proposed. Then the working hypothesis is preliminarily validated by analysis of distribution of values, measured for a plant community and protective coloration of animals in the feature space, the coordinates of which are specified SCP. In this case, regions of values of more typical ITS or IPTS are determined. In image processing, the segments, SCP values of which belong to different regions, are designated by different conditional colors. This enables us to create the contour of an animal against the background of a plant community in the image that was processed.

The ultimate aim of the approaches, proposed in this article, is not to replace remote technologies, currently used in zoology, zoogeography and ecology. These technologies are supposed to be supplemented with new methods of information processing, in particular, of images. We mean the information that has already been received through such high-tech methods as satellite methods or through comparatively simpler and cheaper methods that can be widely used in extreme situations. An example of such relatively simple and cheap methods is digital photography from light UAVs.

Formalized description of systemic aspects of dynamics of relationships between colorometric parameters of plant communities and distribution of relationships, which are similar to colorometric parameters of protective coloration of foxes, was carried out by construction of corresponding ITS and IPTS. They were constructed with the use of rechronization technique with the help of DMDS modification, which used the approach based on extended interpretation of the Liebig law and Spearman correlation [13]. The view of the reference images is presented in Fig. 1, 2.

Fig. 1. Reference image of protective coloration of foxes

Fig. 2. Reference image of plant community in the habitat of foxes

Based on computer analysis of components of the RGB model, values of the following colorometric parameters were determined:

R/(R+G+B) corresponds to the share of red pixel component and number of carotenoids and other yellow-orange pigments in plant biomass, as well as to the old and dead part of this biomass.

G/(R+G+B) corresponds to the share of green pixel component and amount of chlorophyll in plant biomass, as well as photosynthetically active alive young part of this biomass.

(R+G)/(R+G+B) corresponds to total amount of dead and alive, old and young plant biomass.

R/G corresponds to indicator of pigment diversity of a plant community, to "yellow-green index".

By image processing, working hypothesis, formulated based on comparison of the view of the specified ITS and IPTS, was verified.

The technique of image processing is reduced to the following algorithm. Based on comparison of the trajectories of ITS and IPTS, the classification procedure is built. The image is divided into sections, for each of which the values of colorometric parameters of the RGB model are determined. Depending on obtained parameter values, the sections of a processed image fall into one of two classes: (i) sections that are superimposed on a recognized object, and (ii) sections, which do not intersect the object. Rectangles, obtained by splitting of the original image by a rectangular grid, are used as such sections in our study. In principle, the shape of sections can be different (triangular, polygonal, with curved boundaries), if a more detailed object recognition is required.

Once classification procedure has been designed, split rectangles in the synthesized (processed) image are highlighted with different colors, which will give a visual image of the recognized object during image generation. Thus, at the output of the numerical processing procedure we obtain a dichroic image, monochrome rectangles of which have the color corresponding to the class of this section.

Image processing in this research was carried out in package Image Processing Toolbox of the MATLAB software.

5. Obtained results of systemic aspects of dynamics of relationships of colorometric parameters of plant communities and protective coloration of foxes

As a result of the use of DMDS and rechronization, we constructed IPTS for protective coloration of foxes and ITS for plant communities in habitats of these animals. The original actual material included reference digital photos, the view of which is presented in Fig. 1, 2. Obtained ITS and IPTS are presented in Table 1, 2. Colorometric parameters, described in chapter "Materials and methods", play the role of the components of the system. The rows of the table correspond to the system components, the values of which are expressed in conventional scores (1 – low, 2 – medium, 3 – high), and the columns represent conditional steps in time. Maximum values for each colorometric parameter for this trajectory of the system are written in bold.

Table 1

View of idealized trajectory of the system of colorometric parameters of plant community in the habitat of foxes

Indicator	Number of conditional step in time							
	1	2	3	4	5	6	7	8
R/(R+G+B)	1	2	**3**	**3**	**3**	2	1	1
G/(R+G+B)	1	1	1	2	**3**	**3**	**3**	2
G/(R+G)	1	2	**3**	**3**	**3**	2	1	1
R/G	1	**2**	**2**	**2**	**2**	1	1	1

Table 2

View of idealized pseudo trajectory of the system of colorometric parameters of protective coloration of foxes

Indicator	Number of conditional step in time							
	1	2	3	4	5	6	7	8
R/(R+G+B)	1	1	1	**2**	**2**	**2**	**2**	1
G/(R+G+B)	1	2	**3**	**3**	**3**	2	1	1
G/(R+G)	1	1	1	**2**	**2**	**2**	**2**	1
R/G	1	1	1	2	**3**	**3**	**3**	2

As $\phi(x, y)$,we use the following function of colorometric parameters

$$\varphi(x,y) = x - y. \qquad (7)$$

Such a form of the function was selected because it enables us to formulate a working hypothesis in the simplest form (which is a positive aspect in accordance with the principle of "Okkama razor").

By obtained trajectories of ITS and IPTS, we will determine values of C_{min}, C_{max}, Z_{min} and Z_{max} for all possible pairs of colorometric parameters according to (3). Then we will determine if statement Q is true according to (4) (Table 3).

Table 3

Table of values Q for trajectories, presented in Table 1, 2

Pair of parameters		Ends of intervals				Q
x	y	C_{min}	C_{max}	Z_{min}	Z_{max}	
R/(R+G+B)	G/(R+G+B)	–2	2	–2	1	true
R/(R+G+B)	(R+G)/(R+G+B)	0	0	0	0	false
R/(R+G+B)	R/G	0	1	–1	0	true
G/(R+G+B)	(R+G)/(R+G+B)	–2	2	–1	2	true
G/(R+G+B)	R/G	–1	2	–2	2	true
(R+G)/(R+G+B)	R/G	0	1	–1	0	true

For using of maximum visual form of data representation in subsequent work, it is advisable to select a planar feature space and, accordingly, two pairs of colorometric parameters.

In accordance with biological sense of the studied processes, to consider the working hypotheses in more detail, the following pairs of colorometric parameters were selected: R/(R+G+B) and G/(R+G+B), as well as (R+G)/(R+G+B) and G/(R+G+B). These pairs were also selected because the maximum interval between values of C_{max} and C_{min} was observed for them, which contributes to diagnostic procedures with the use of feature space. Then, according to (7), we will determine the form of function $\phi(x, y)$:

$$\phi\left(\frac{R}{R+G+B},\frac{G}{R+G+B}\right)= \\ =\frac{R}{R+G+B}-\frac{G}{R+G+B}=\frac{R-G}{R+G+B},$$

$$\phi\left(\frac{R+G}{R+G+B},\frac{G}{R+G+B}\right)= \\ =\frac{R+G}{R+G+B}-\frac{G}{R+G+B}=\frac{R}{R+G+B}.$$

Obtained expressions (R+G)/(R+G+B) and R/(R+G+B) can be subsequently used as SCP. Fig. 3 shows two-dimensional feature space, in which selected SCP plays the role of coordinates. In this feature space, it is possible to have statistically reliable splitting of regions of values that belong to colorometric parameters of plant communities in habitats of foxes and protective coloration of these animals.

In Fig. 3, region with SCP values ((R–G)/(R+G+B)< <0.087&R(R+G+B)<0.47) corresponds to dynamics of relationships of colorometric parameters of plant communities in habitats of foxes. The rest of the space is more characteristic for distribution of colorometric parameters of protective coloration of foxes.

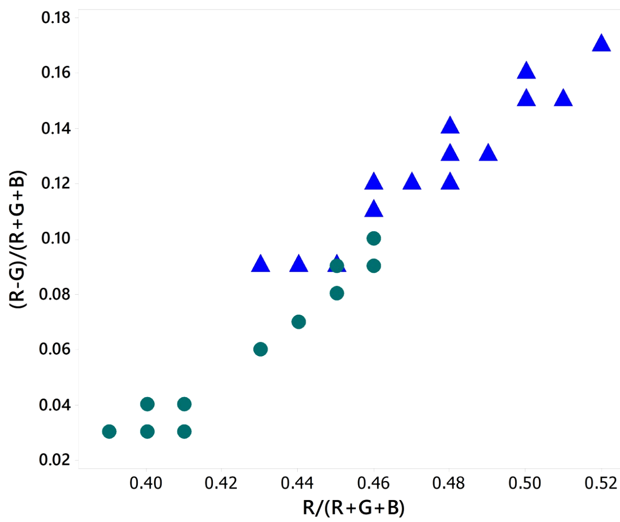

Fig. 3. Diagram of scattering of values of systemic colorometric parameters in coordinate system (R–G)/(R+G+B) and R/(R+G+B). ▲ – points, corresponding to image of protective coloration of foxes; ● – points, corresponding to image of phytocenosis in habitat of foxes

This distinction of feature space lies at the basis of procedure of classification of sections of the analyzed image. Depending on SCP values, each section of the image refers to one of these regions. Sections, corresponding to plant communities, are painted black, the other parts – white.

Location of foxes' brood, presented in Fig. 4, is not difficult to determine. But it is quite difficult to solve the same problem for the image shown in Fig. 5. The image, shown in Fig. 5, was obtained through artificial reduction of sharpness and contrast range of the image, shown in Fig. 4.

Fig. 4. Original unprocessed image of foxes' brood against background of grassy plant community

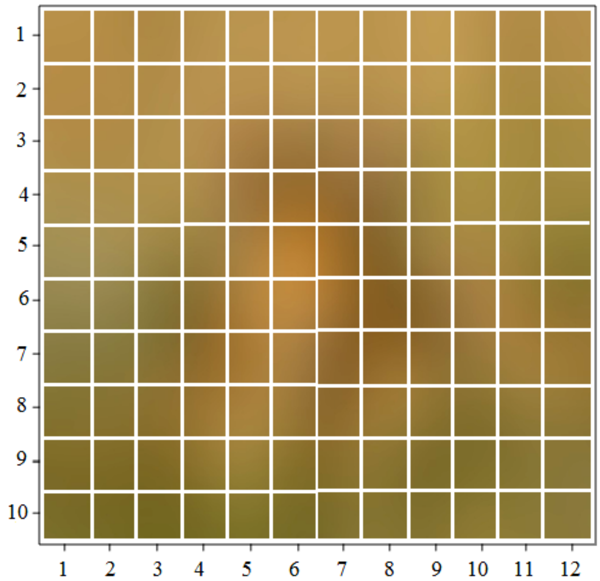

Fig. 5. Image of foxes' brood against background of grassy plant community subject to artificial deterioration of sharpness and contrast range

For unmasking of foxes, the image (Fig. 5) was divided into 120 identical sections. For each image section, parameters of the RGB model were determined and SCP value was calculated. Then each image section was assigned to one of two possible classes and painted with the corresponding color. Results of such processing are shown in Fig. 6.

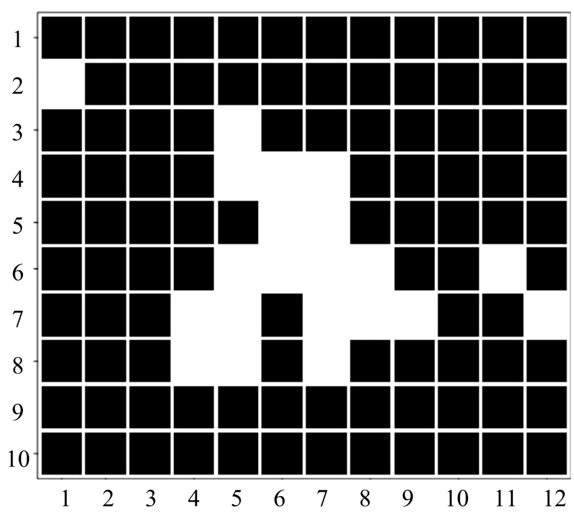

Fig. 6. Results of processing the image of snapshot of foxes' brood with artificial computer deterioration of sharpness

In the processed image, the sections, painted white, formed the outline of foxes' broods against the background of a grassy vegetation community (Fig. 6). This outline has much higher contrast range than the image, shown in Fig. 5, the contrast and sharpness of which were artificially degraded. On the other hand, this outline is less detailed than the original image, shown in Fig. 4. Under specific circumstances of using these image processing techniques, contrast range may appear more important that detailing. Such conditions can be found, in particular, in extreme situations described above.

6. Discussion of results of mathematical modeling of relationships of colorometric parameters of plant communities and protective coloration of foxes

Presented results are of practical importance for solution of a number of complex issues of ecology, biosafety, and veterinary medicine, the relevance of which increases significantly in the face of global climate change. We mean the problems, associated with disruption of stability of animal populations, in particular foxes, which can be potential reservoirs of rabies. Disruption of stability of populations is accompanied by a change in the boundaries of areas of habitat of these animals. This change in many cases occurs on vast areas, which often include hard-to-reach terrains. In this regard, remote (aerospace) methods are used in order to monitor changes in specified habitats. When using these methods, we may face difficulties associated with protective coloration in animals. Fairly complex and expensive equipment can be applied in order to overcome these difficulties. As an example, we can take equipment that registers radiation of the body of warm-blooded animals in the infrared region of the spectrum. The price of equipment, which is used for monitoring wild animals in the visible spectrum region, is also quite high. The reason for this is high requirements for optical parameters of this equipment. Meeting these requirements makes it possible, in particular to increase contrast range of an image of animals with protective coloration.

In extreme situations, related to constant appearance of new potential hotbeds of rabies, it may prove impossible to use this high-quality equipment on required large scale. In such extreme situations, it may be necessary to mobilize the entire available arsenal of technical means of remote ecological monitoring. We are talking about the means of registration of habitats and migration routes of animals – potential reservoirs of rabies. Devices for digital photography, which are included in the equipment of fairly simple and inexpensive drones (UAVs), can play a significant role in this arsenal. However, contrast range of photographs may be negatively influenced by conditions of shooting (bad lighting, fog, dust, etc.). Images of animals with protective coloration are not contrast enough in such photographs.

The proposed approach to solution of this problem is special computer image processing. This approach is based on results of mathematical modeling of patterns of protective coloration of foxes using DMDS. The image, obtained as a result of such processing (Fig. 6), has its shortcomings compared to the reference image (Fig. 4). One of these shortcomings is lower detail elaboration (one can see only the white rough silhouette of the foxes' brood on a black background). But in comparison with artificially degraded image (Fig. 5), the processed image is more contrast.

Improvement of contrast range and detail elaboration is the objective for subsequent research. In this case, degree of such detail elaboration, which would be sufficient to solve definite practical problems, can be relatively low. In this regard, it is worth making one comment. The proposed approach is not intended to replace existing methods of remote registration of animals on the ground. This approach should only supplement these methods in the above mentioned extreme situations.

7. Conclusions

1. We carried out formalized description of systemic aspects of distribution of segments of protective coloration of foxes that imitates dynamics of relationships of colorometric parameters of plant communities in habitats of these animals. As a result, the form of UPC, analysis of which allows unmasking foxes against the backdrop of phytocenosis, was determined. Such SCP include relationships (R+G)/(R+G+B) and R/(R+G+B). It was established that in a two-dimensional feature space, coordinates of which are the separated SCP, region with SCP values $((R-G)/(R+G+B)<0.087\&R/(R+G+B)<0.47)$ corresponds to the image of plant communities in habitat of foxes. The rest of the feature space is more characteristic of protective coloration of foxes.

2. Separated regions of values made it possible to conduct binary classification of sections of the analyzed image. As a result of implementation of this classification, the authors correctly detected location of foxes' brood against background of plant communities in the image, the sharpness and contrast range of which were deliberately artificially degraded.

3. Using the designed image processing procedure, the approach to unmasking animals against the vegetation background in their habitat was proposed. This unmasking allows an increase in effectiveness of detection methods, in particular, remote methods, methods of spatial distribution of animals – potential reservoirs of rabies. Similar methods can be used for planning activities for elimination of biosafety hazards, related to spreading of this dangerous infectious disease.

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