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# MATHEMATICAL MODELING OF THE COLORIMETRIC PARAMETERS FOR REMOTE CONTROL OVER THE STATE OF NATURAL BIOPLATO

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*Представлені результати моделювання межкомпонентних відносин колорометричних параметрів природних біоплато. В якості вихідних даних використані космічні знімки плавнів в дельті Дунаю. Запропоновано використовувати системний колорометрический параметр, що відображає розмах значень ступеня вирівняності значень колорометричних параметрів. Виділені ознаки дозволяють дистанційно діагностувати стан біопродукційних процесів природних біоплато*

*Ключові слова: біоплато, біопродукційний процес, водоплавні птахи, граф відносин, колорометричні параметри, дистанційний контроль, траєкторія системи*

*Представлены результаты моделирования межкомпонентных отношений колорометрических параметров естественных биоплато. В качестве исходных данных использованы космические снимки плавней в дельте Дуная. Предложено использовать системный колорометрический параметр, отражающий размах значений степени выровненности значений колорометрических параметров. Выделенные признаки позволяют дистанционно диагностировать состояние биопродукционных процессов естественных биоплато*

*Ключевые слова: биоплато, биопродукционный процесс, водоплавающие птицы, граф отношений, колорометрические параметры, дистанционный контроль, траектория системы*

## 1. Introduction

The changeability of the world that the human lives in has been critically increasing. Climate changes, social upheavals, results of technical progress require prompt and adequate response. On the other hand, the progress in computer science and mathematics enable powerful means to provide such a response. The most important means to do this are the methods of mathematical modeling and related information technologies. It should be said that these means allow us to rapidly verify the working hypotheses. To test working hypotheses by statistical processing and analysis, large arrays of information have been collected and software tools have been developed.

Humanity faces the challenge of overcoming a contradiction between the following two requirements. The essence of the first of these requirements is to increase productivity of the agrarian sector of world economy. The second one relates to the necessity of maintaining the factors ensuring stability of the biosphere of our planet. These factors are linked to biodiversity, the sustainability of which requires maximum preservation of natural ecosystems. This, in turn, involves minimizing the impact of agrotechnology on natural landscapes.

In a number of cases, these problems can be solved by using agrotechnology, some essential elements of which imply minimal impact on natural ecosystems and landscapes.

An example of such agrotechnologies is the consumption of natural feed by domestic waterfowls (predominantly – ducks). The use of a natural feed base often occurs in natural and artificial reservoirs in places inhabited by waterfowls' wild relatives. Such reservoirs are often used for fish farming, melioration and for other purposes [1].

It should be said that this approach also has negative aspects, in particular, related to the emergence of new problems of biosecurity and biosafety. It is the increasing risk of disease spreading – both birds and people. As an example, "avian influenza" (Grippus avium) [2] can be named. In this case, the use of the natural feed base of waterfowls on large areas, often in hard-to-reach terrain, does not allow us to restrict medical treatment with the traditional methods of veterinary medicine. It is important that in these vast and hard-to-reach areas not only considerable resources of the natural forage base are present, but the factors of elimination of the mentioned threats to biosafety are present, too. These are the factors that provide natural self-purification of water. Such factors include massifs of semi-submerged higher aquatic plants (SSHAP), which have been used for a long time for water purification in specialized structures known as "bioplato" [3].

In the areas of terrain suitable for the household use as a natural feed base for waterfowls, there are often the thickets of SSHAP (reeds, rush, cattail), which can be used as natural bioplato. As an example of such area, one can refer to plavni (flooded areas, marshy and reedy banks) that occupy significant areas, access to which is difficult both from water and from land.

In some extreme situations, natural bioplato can be useful in overcoming serious threats to biosafety. Biosafety of drinking and other kinds of water consumption are meant here. The causes of these threats can be the destruction of sewerage and water treatment systems, as well as destruction of storages of harmful and toxic substances. These destructions may happen as a result of technogenic and natural disasters. In addition, biosafety threats can arise as a result of the untreated consumer wastewaters penetration into reservoirs. Pollution of the sources of water consumption create conditions for the development of pathogenic agents of dangerous infectious diseases.

In such extreme situations, there may not be enough time to construct a bioplato. In places of breeding of waterfowl, massifs of SSHAP can be used as a natural bioplato. In places where domestic waterfowls use a natural feed base, the same SSHAP massifs can be used for their wild relatives.

An important aspect of the selection of these massifs is the use of information on the nature of bioproduction processes occurring in them. The ratio of production and destruction of organic matter is of key importance. The predominance of photosynthetic products over degradation contributes to the absorption of pollution agents in water. At the same time, secondary water pollution is prevented due to dying off and subsequent decomposition of SSHAP biomass.

In the extreme situations in question, it is advisable to use remote (aerospace) methods to collect information on the nature of bioproduction processes. This is determined, in particular, by the following two factors. The first factor is the high probability of location of SSHAP massifs over large areas. The areas of these territories can be difficult to access from water or land. This factor is also important in normal situations when selecting SSHAP massifs. For example, when choosing a place to be used by waterfowls as a natural feed base in a water reservoir. The second factor is important only in extreme situations. This factor is an acute shortage of time for gathering of information necessary for making decisions.

Depending on the situation, a wide range of remote methods can be applied: from digital photography from aboard the light remotely piloted aircrafts (RPA) to the use of space photographs.

There are a number of factors that make it extremely urgent to control and correct the state of bioproduction processes in natural plant communities. These are global climate changes, critical level of human activity impact on nature, the high level of risks of technogenic disasters and even terrorist acts that create biosafety threats. Natural plant communities represent a factor that in many cases reduces the risks of such threats. The possibility of realization of this positive role of plant communities depends to a large extent on the nature of the bioproduction processes occurring in them. The same applies to SSHAP massifs, which act as natural bioplato and thus reduce the risks of biosafety threats from different types of water consumption.

The scale of these risks makes the problem of expanding of the arsenal of high-tech science intensive methods of controlling of the nature bioproduction processes in plant communities quite urgent. In this arsenal, remote (aerospace) methods become increasingly important. These methods include, in particular, the analysis of earth's surface space photographs using vegetative indices [4].

Values of vegetative indices are determined by the results of measurements of the spectral parameters of vegetation. Spectral parameters are complemented by other parameters to correct the distortions, occurring due to the physical conditions of the survey [5, 6].

Methods and means for processing the images of the earth's surface make it possible to obtain information on the state of plant communities directly at the time of registration for the use of vegetative indices. But to solve a number of problems of ensuring biosafety, it is necessary to forecast the dynamics of the state of bioproduction processes in plant communities. There is a need in approaches that allow remote registration of systemic and dynamic aspects of bioproduction processes in plant communities. Such approaches can be implemented using mathematical models of the dynamics of biological systems.

For informational support of decision-making on control and correction of the functioning of natural bioplato, methods of mathematical modeling with wide capabilities are required. These are the methods that allow a formalized description of the dynamics of the system being modeled. In this case, the actual material does not always reflect the dynamics of the simulated system in real time. Thus, a method is needed that will play the role of a tool for forming the working hypotheses. These working hypotheses relate to the form of the original vegetative indices, their effectiveness is verified during processing of images of the SSHAP massifs.

## 2. Literature review and problem statement

To obtain information on the dynamic and systemic parameters of the state of bioproduction processes in plant communities, a wide arsenal of methods of mathematical processing is used. Basically, these are the same methods that are used to analyze other living systems. The following examples of application of these methods can be given.

Models of the differential equation in quotient derivative are used to study the dynamics of gene regulation through SAM (stem apical meristems) [7]. To study the dynamics of natural and artificial systems (physiological, economic, transport) models of data such as time series are used. As an example, the use of a moving average for the analysis of time series [8]. Analysis of the dynamic aspects of such systems is of great importance due to the problem of preserving of their homeostasis. To solve this problem, trend models have been used [9]. The initial data for all methods are sequences of observations (in terms of a scalar or vector parameter), ordered by time. Although variable temporal lags are provided for some models, the sequence of observations should be preserved.

Mathematical modeling of hydrobiocenosis is the most knowledge-intensive aspect of monitoring of large lakes. These lakes are often the most important source of fresh water for large areas. Under conditions of global warming, this source may be threatened by the loss of stability of hydrobiocenosis [10].

Mathematical methods of ecosystems description are used to determine the risk of such a threat to biosafety as the massive development of blue-green algae in drinking reservoirs [11].

For the mathematical description of the dynamics of states of different plant communities, the initial data, such as vegetative indices, must be ordered by time. Remote (aerospace) methods are widely used to obtain this information. The following examples of the use of vegetation indices can be cited.

In paper [12], vegetative indices were used for the remote study of the condition of conifers using narrow-band methods for determining the spectral characteristics of forest tracts. Similar methods were used in article [13] to study bioproduction processes in leaves. Such methods involve the use of expensive equipment, in addition, the description of the dynamics requires a series of measurements over some period of time.

In paper [14], as in the above studies, the spectral responses of desert trees were investigated. The obtained results create prerequisites for obtaining information on the nature of bioproduction processes by remote methods. In this case, it is important that this concerns large, inaccessible territories, in which the effects of global warming can manifest themselves dramatically.

Article [15] describes a large arsenal of means for remote registration of the nature of bioproduction processes in cyanobacterial communities. A possibility of the emergence of strains of these organisms that are more toxic than the known ones is a serious threat to the biosafety of drinking water supply [11], make it possible to describe the nature of bioproduction processes for a wide variety of plant communities. However, for their implementation, specific, relatively expensive equipment, which can measure in narrow bands of the spectrum, is needed. In addition, the application of the considered methods for describing dynamic aspects requires the existence of initial factual material that reflects the sequence of states of the system under study in real time. This creates serious financial and organizational problems with increasing a scale of application of these methods. Global warming and increasing human pressure on nature may create situations in which this increase in scale will be necessary.

The specified problems can be solved using mathematical methods, which allow to get a formalized description of the dynamics of the system under study based on actual material that does not directly reflect this dynamics in real time. Such a possibility is provided by the method of discrete modeling of dynamical systems (DMDS), which is already being used to study the structure of connections and dynamics of systems of very different nature [16, 17].

In a number of cases, the use of DMDS makes it possible to describe the dynamics of the system based on only one image, which registers the state of the system only at one point in time. Such a possibility is given by a technique that received the working name of resynchronization [18]. The use of resynchronization is based on a premise that states of different parts of the system under study change within a single cycle, but at the moment of registration of these states they can correspond to different phases of this cycle. Conditional steps over time of the idealized trajectory of the system (ITS) correspond to different phases of the cycle.

From a practical point of view, it is important that this model can be built on the basis of a computer analysis of components of RGB model of the image of the plant community [19], which is an advantage over using other known vegetative indices. The roles of different parts of the system are played by different sections of the SSHAP massif. This makes it possible to use as a source of the original factual material space images of the earth's surface that are freely available or digital photographs taken from aboard light RPAs. Such possibility reduces financial costs of obtaining the original factual information. The possibilities of obtaining large volumes of initial factual information also increase. Accordingly, the opportunities for the development of new, simpler to implement, vegetation indices also increase.

Consequently, it is expedient to use DMDS for the tasks of remote determination of the state of bioproduction processes in natural bioplato. At the first stage of the study, models of the dynamics of colorimetric parameters of images of natural bioplato with the help of DMDS will be constructed. The obtained models will help to formulate working hypotheses concerning the procedure of calculating the values of new vegetation indices. The role of these indices will be performed by systemic colorimetric parameters (SCP), which express certain relationships between the primary colorimetric parameters. Primary colorimetric parameters can be obtained from a computer analysis of the components of RGB model of the image of the plant community. At the second stage of the study, the working hypotheses formulated at the first stage are checked by image processing using the appropriate SCP. Initially, reference images that represent obviously different states of bioproduction processes in natural bioplato are processed. Diagnosis and prediction of the state of bioproduction processes is carried out by comparing the images of the diagnosed objects with reference images.

## 3. The study objectives and tasks

The objective of present work is to model colorimetric parameters of images of the SSHAP massifs in the breeding areas of waterfowls. This will make it possible to determine the structure of SCP, the changes in the ratios of which will signal the impending change in the states of production of live and in the accumulation of dead biomass, leading to secondary water pollution. The ability to remotely determine such SPCs optimizes control over the state of natural bioplato and over efficiency of water purification.

To achieve the set objective, the following tasks had to be solved:

– to process reference space images of the plavni in the mouth of the Danube by the method based on the results of modeling the structure and dynamics of the ratios of colorimetric parameters using DMDS;

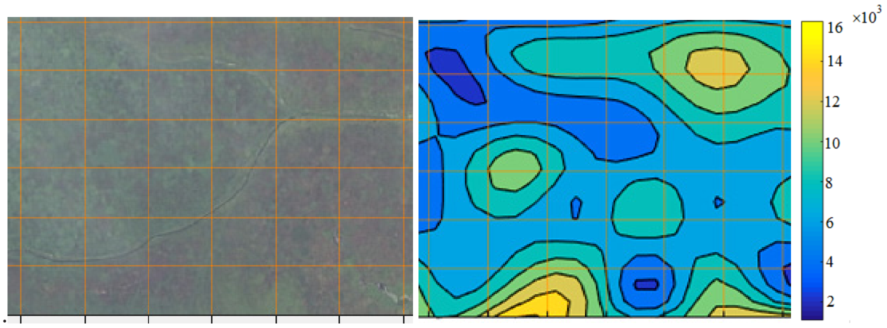
– to conduct structural and parametric modeling of the systemic colorimetric parameter reflecting the nature of the bioproduction processes of plant communities;

– to compare results of the processing of space images of the plavni at different periods of the vegetative season under the corresponding conditions of bioproduction processes in SSHAP.

## 4. Materials and methods to study the character of relation of systemic colorimetric parameters of natural bioplato

The possibilities of predicting a change in the character of bioproduction processes in SSHAP massif was investigated using cosmic images of the plavni in the mouth of the Danube [20]. A working hypothesis based on the previously obtained results of modeling the structure of relations and dynamics of colorimetric parameters of cultivated plants crops using DMDS was used to process the images [19]. In accordance with this hypothesis, the dynamics of the relations of plant pigments in similar phytocenosis must have some features of the Margalef's succession model. It is a question of the ratios of chlorophyll and yellow-red pigments, which correspond to the brightness ratios of the green and yellow-red parts of the visible spectral range in the images of SSHAP massifs. It follows from this, in particular, that different values of the colorimetric parameters may correspond to the different character of these bioproduction processes. The use of analogies with the Margalef's succession model implies the use of systemic colorimetric parameters (SCPs) that reflect certain relationships between bioproductivity and biodiversity. The prospect of using the analogies of the Margalef's succession model for the development of remote methods of nature bioproduction processes control in plant communities has been previously shown [21] on the material of crops of cultivated plants.

Within the framework of the present paper, an analogy with the Margalef's succession model was also used to find SPCs suitable for determining the state of natural bioplato. With the help of DMDS, relationship matrices, relationship graphs and idealized trajectories of the system (ITS) of relations of colorimetric parameters (CP) were constructed. As a reference, a space photograph of the plavni in the mouth of the river Danube, shown in Fig. 1, was used. The picture was taken in June 2014, in the middle of the vegetative period, when the bioproduction processes in SSHAP massifs are characterized by high intensity and marked predominance of the products over degradation. As indicated above, this state of SSHAP massif provides a high intensity of biological water purification processes. This condition also minimizes the risk of secondary water pollution – as a result of dying off and decomposition of SSHAP biomass.



*a* *b* *c*

Fig. 1. Reference image of the selected section of the Danube plavni, taken on June 6, 2014: *a* — unprocessed image; *b* — processed image; *c* — the scale of conditional colors corresponding to certain values of the mean quadratic deviation of index *C*

Based on an analysis of the type of matrices obtained and the relationship graphs, a working hypothesis was constructed relative to the type of mathematical expression, which describes a relationship between the colorimetric parameters of SSHAP massifs reflecting the character of bioproduction processes. This hypothesis was verified with the help of analysis of space photographs of the plavni [20]. Results of the processing of space photographs of the plavni at different periods of the vegetative season were compared with the corresponding states of bioproduction processes in SSHAP. Diagnosis of these conditions is necessary for the timely implementation of measures to remove biomass of SSHAP, which can cause secondary water pollution.

While modeling the dynamics of colorimetric parameters of massifs of SSHAP with the help of DMDS, the method of resynchronization was used [18]. The use of resynchronization implies a change in the state of different parts of the system under study (different parts of the registered SSHAP massif in the plavni at the same time in a space photograph) within the same cycle. However, at the moment of registration (digital photography) of these states, they can correspond to different phases of this cycle.

## 5. Modeling the character of relation of colorimetric parameters of natural bioplato

At the first stage of the work, matrices and graphs of relations were constructed, as well as ITS reflecting the structure of relations and dynamics of colorimetric parameters. The matrices were constructed using DMDS and resynchronization based on the material presented in Fig. 1, the reference image of a SSHAP massif. The colorimetric parameters expressed by the relations of elements of the RGB model and associated with certain aspects of the bioproduction processes were:

G/(R+G+B) – a parameter reflecting the amount of green pigment of chlorophyll, which affects the level of photosynthetic products;

R/(R+G+B) – a parameter reflecting the amount of orange-red pigments, the increase in values of which can be considered as a sign of growth in the dead plant biomass system;

G/(R+G) – a parameter reflecting the ratio of the amount of chlorophyll to the total amount of different plant pigments, associated with the balance of young biomass carrying out active photosynthesis and with the old, dying-off biomass;

R/G – a parameter reflecting, similar to the "yellow-green index" of the Margalef's succession model, the biochemical pigmented diversity of the system;

R, G and B – are the average of the red, green, and blue values of the elements of a pixel in the digital image selected for processing.

As a result of the performed analysis, two variants of the matrices of the ratios of the above colorimetric parameters were constructed, which are presented in Table 1, 2. For each of the matrices, the graphs of relations were created shown in Fig. 2, 3. To reflect the dynamics of changes in the values of colorimetric parameters, ITS were constructed, presented in Table 3, 4.

Table 1

First variant of the matrix of ratios of colorimetric parameters

| Colorimetric parameters | R/(R+G+B) | G/(R+G+B) | G/(R+G) | R/(G) |
|---|---|---|---|---|
| R/(R+G+B) | [0; 0] | [+; –] | [–; –] | [0; 0] |
| G/(R+G+B) | [+; –] | [0; 0] | [0; 0] | [0; 0] |
| G/(R+G) | [–; –] | [0; 0] | [0; 0] | [–; +] |
| R/(G) | [0; 0] | [0; 0] | [–; +] | [0; 0] |

Table 2

Second variant of the matrix of ratios of colorimetric parameters

| Colorimetric parameters | R/(R+G+B) | G/(R+G+B) | G/(R+G) | R/(G) |
|---|---|---|---|---|
| R/(R+G+B) | [0; 0] | [+; –] | [0; 0] | [0; 0] |
| G/(R+G+B) | [+; –] | [0; 0] | [0; 0] | [–; –] |
| G/(R+G) | [0; 0] | [0; 0] | [0; 0] | [+; –] |
| R/(G) | [0; 0] | [–; –] | [+; –] | [0; 0] |

An analysis of the structure of the ratio matrices (Table 1, 2) indicates the significant role of the "plus-minus" relations between the parameters G/(R+G+B) and R/(R+G+B) in maintaining the homeostasis of the reference SSHAP massif. This allows us to make the first step in forming a working hypothesis regarding the type of expression for the calculation of SCP. In the first step, it is proposed to use mathematical expressions for the "plus-minus" relations between the values of the parameters G/(R+G+B) and R/(R+G+B). Registering the values of the proposed SCP makes it possible to highlight the sections of SSHAP with a different character of bioproduction processes.

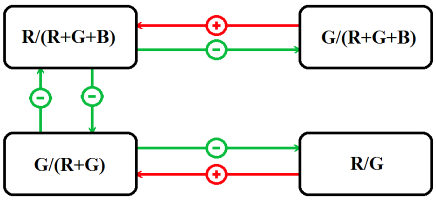


Fig. 2. First variant of the relation graph of colorimetric parameters. Red arrow — direct relationship between the parameters, green — reverse one

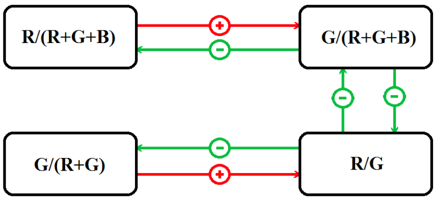


Fig. 3. Second variant of the relation graph of colorimetric parameters. Red arrow — direct relationship between the parameters, green — reverse one

An analysis of the structure of relation graphs shown in Fig. 2, 3 allows us to confirm and lay out the specifics of the proposed assumption. In the course of analysis, it is necessary to highlight amplifying deviations contours (ADC) and weakening deviations contours (WDC) that are present in the graphs. In both variants of the relation graph, there are WDCs based on the "plus-minus" relations. These WDCs connect the parameters G/(R+G+B) and R/(R+G+B). In the graph shown in Fig. 2, ADC is formed by the "minus-minus" relations between the parameters R/(R+G+B) and G/(R+G). In the graph shown in Fig. 3 ADC is formed by relations of the same type between the parameters G/(R+G+B) and R/G. The presence of WDC weakens the destabilizing effect of ADC. Also, both variants of the relation graphs include WDCs functioning due to the "plus-minus" relations between the parameters G/(R+G) and R/G.

Table 3

First variant of idealized trajectory of the system

| Colorimetric parameters | Conditional time steps | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| R/(R+G+B) | 1 | 1 | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 2 | 1 | 1 |
| G/(R+G+B) | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 1 | 1 | 1 | 2 |
| G/(R+G) | 3 | 3 | 3 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 |
| R/(G) | 3 | 2 | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 3 | 3 | 3 |

Table 4

Second variant of idealized trajectory of the system

| Colorimetric parameters | Conditional time steps | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| R/(R+G+B) | 3 | 2 | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 3 | 3 | 3 |
| G/(R+G+B) | 3 | 3 | 3 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 |
| G/(R+G) | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 1 | 1 | 1 | 2 |
| R/(G) | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 2 | 1 | 1 |

Results of the performed analysis show that it is preferable to use a mathematical expression describing relations of the parameters G/(R+G+B) and R/(R+G+B) as SCP. The "plus-minus" relations connecting them, for example, in the case of the "predator-prey" Lotka-Volterra model [16], imply the alternation of the maxima of the values of the components of the system connected by these relations. In the framework of the problem under consideration, the degree of proximity or remoteness of these maxima is important, which affects the magnitude of the spread of the values of the ratio of the corresponding parameters. The "plus-minus" relations between the parameters G/(R+G+B) and R/(R+G+B), which support the homeostasis of the system, are superimposed on other intercomponent relations forming ADC that act against the homeostasis. To detail the character of dynamics and determine the degree of convergence of the maximum values of these parameters, the shape of both variants of the ITS presented in Table 3,4 has been analyzed. In both versions of ITS, there is a significant degree of mutual remoteness of the maxima of the values of the majority of CPs (with the exception of the parameters G/(R+G+B) and G/(R+G) used in mathematical modeling).

Such a significant degree of mutual remoteness of the maxima of the CP values gives certain grounds for supplementing the working hypothesis with the provision on that the value of Shannon index (H), calculated using formula (1), can be used as SCP:

$$H = -\sum_{i=1}^{k} P_i \cdot \log_2 P_i, \quad (1)$$

where $P_i$ is the share of the $i$-th colorimetric parameter value in the total value of all colorimetric parameters; $k$ is the number of colorimetric parameters.

By analogy with the Margalef's succession model [20], considerable mutual remoteness of the CP maxima can be used as a diagnostic attribute of the character of bioproduction processes in the community of SSHAP. In this case, low values of the Shannon index can serve as an expression for the considerable mutual remoteness of the maxima.

However, the differences in the dimensionality of CP used can create difficulties that reduce the attractiveness of this approach to the formation of SCP. In addition, the most noticeable remoteness of the maxima is the most pronounced in two pairs of characteristics, and the use of Shannon index to determine the degree of alignment in a pair of attributes looks as an unjustified complication.

The close dimensionality of CP used stipulates the choice of creating a formalized description of the relation of the values of the parameters G/(R+G+B) and R/(R+G+B), for example, the degree of their alignment. An analysis of Table 3, 4 indicates the presence of maximally wide set (expressed in imaginary points) of the degree of equalization of the values of these CPs in both versions of ITS. Therefore, the mathematical expression for the calculation of SCP should reflect the range of the values of the alignment degree of the values of the parameters G/(R+G+B) and R/(R+G+B).

The values of this magnitude, which performs the role of SCP, can be marked on different parts of the image of a SSHAP massif by the corresponding conditional colors. The analysis of the digital photos processed in this way will provide information on the distribution in space and time of different states of bioproduction processes in the SSHAP massifs.

In accordance with the hypothesis formulated at the first stage of the work, at the second stage, the values of the mean quadratic deviation of the values of index C, determined from formula (2), were used as SCP:

$$C = \frac{|R-G|}{R+G+B}, \quad (2)$$

where $R$, $G$, $B$, respectively, are the percentage of red, green and blue pixel elements.

As a result of conducting the second stage of present work, we obtained processed images of the plavni areas, which can be used as natural bioplato for eliminating biosafety threats. When processing the images, their sections were marked with conditional colors corresponding to the mean quadratic deviation of the values of index C (Fig. 1, *c*).

Photographs of the same section of the Danube plavni were selected for processing during vegetative season. The images obviously differ by the character of ratio of the processes of photosynthetic production, the accumulation of dead biomass and its destruction.

The images taken in June (Fig. 1), March (Fig. 4), August (Fig. 5) and September (Fig. 6, 7), 2014 were processed.

Comparison of unprocessed images does not allow us to clearly register the indicated change in states. In the processed images, it is very much pronounced.

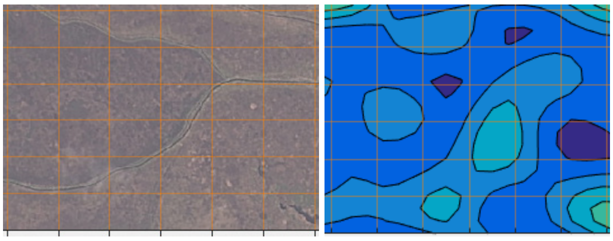

*a* *b*

Fig. 4. Reference image of the section of the Danube plavni taken on March 11, 2014: *a* – unprocessed image; *b* – processed image

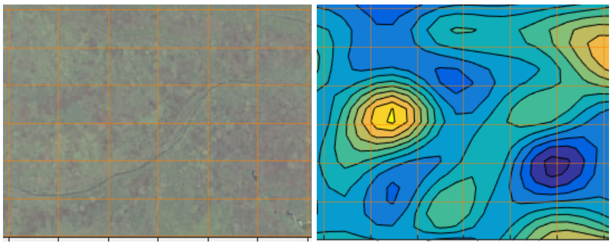

*a* *b*

Fig. 5. Image of the section of the Danube plavni taken on August 25, 2014: *a* – unprocessed image; *b* – processed image

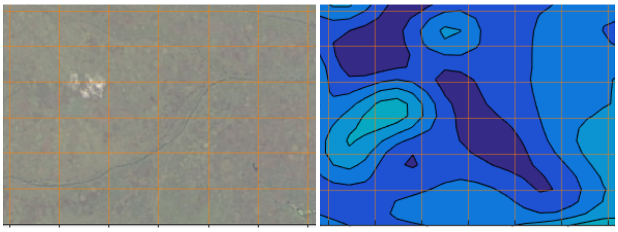

*a* *b*

Fig. 6. Image of the section of the Danube plavni taken on September 10, 2014: *a* – unprocessed image; *b* – processed image

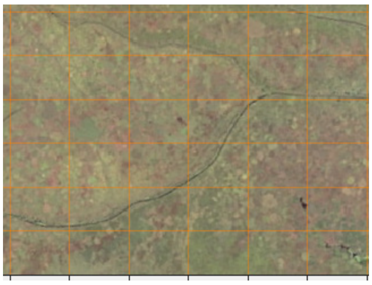


Fig. 7. Unprocessed image of the section of the Danube plavni taken on September 19, 2014

## 6. Discussion of results of modeling the character of ratio of the colorimetric parameters of natural bioplato

Differences in the values of SCP found when comparing the processed images taken at different periods of the vegetative season are due to the differences in the character of ratio between the production of live and the accumulation of dead biomass of SSHAP.

In June, in the middle of the vegetative season, the processes of accumulation of living plant biomass are most pronounced. These processes ensure the purification of water. Therefore, the processing of the reference image taken in June (Fig. 1) allows us to find the attributes of period with the maximum intensity of water purification.

In March, a large amount of dead biomass is accumulated in the plant community. This creates prerequisites for secondary water contamination as a result of the decomposition of this biomass. The processing of the reference image taken in March 2016 (Fig. 4) allows us to find the attributes of period with the maximum risk of secondary water pollution.

As a result of comparison of Fig. 1, 4 it was found that the greater degree of the photosynthetic production processes corresponds to a greater variety of the mean square deviation of index *C*.

This result allows us to formulate another working hypothesis on that the distribution of values of the mean square deviation of the values of index *C* makes it possible to remotely diagnose the state of the bioproduction processes in a SSHAP massif. Such an analysis may include comparison with the processed images of any reference plant communities and the stages of their functioning. A comparison of the images shown in Fig. 5–7 confirms given working hypothesis.

A change in the state of SSHAP massif registered in Fig. 5, *a* and Fig. 6, *a* corresponds to the processes occurring at the end of the vegetative season. During this period, the production of living plant biomass is replaced with the accumulation of dead biomass. Removing dead biomass from temporary bioplato is a prerequisite for preventing the threat of secondary water pollution.

The difference in the character of processed images (Fig. 1, *b*, Fig. 4, *b*, Fig. 5, *b*, Fig. 6, *b*) allows us to register existence of a tendency toward the accumulation of dead plant biomass. The further development of this trend is shown quite clearly in Fig. 7. The shift of the colorimetric parameters towards the red component, characteristic for the dying off plant biomass, is seen in Fig. 7 even without processing. Image processing (Fig. 6) makes it possible to register this shift a week earlier, which is an undoubted advantage when operating temporary natural bioplato.

However, it should be noted that present work employed only one possible approach to solving the problem, using the results of a formalized description of the structure of relations and the dynamics of comparatively simple measured colorimetric parameters of the phytocenosis. The use of index *C*, in comparison with known vegetative indices, implies a certain roughening of the resulting relations of plant pigments. Nevertheless, the possibility of determining the vegetative period of the bioplato only according to the RGB model of its image is a confirmation of the expediency of further research in this field.

The obtained results testify to the prospects of the presented approach in the development of methods and information systems that allow determining the state of bioproduction processes in communities of semi-submerged higher aquatic plants by aerospace methods.

The capability to remotely diagnose the state of natural bioplato significantly improves the effectiveness of biosecurity strategies for both drinking and other type of water use. This is especially true under extreme situations and for the implementation of certain types of agricultural technology. An example of such agrotechnology is the breeding of waterfowls with the use of a natural feed base of water reservoirs and watercourses.

## 7. Conclusions

1. By using DMDS, the reference space photographs of the plavni in the mouth of the Danube were processed. Matrices and graphs of intercomponent relations were constructed to analyze the structure of the ratios of colorimetric parameters. To analyze the dynamics of ratios of colorimetric parameters, idealized trajectories of the analyzed biosystems were constructed.

2. As a result of structural parametric modeling, the values of the mean square deviation of the values of index *C*, which reflects the range of the alignment level of the values of the parameters G/(R+G+B) and R/(R+G+B), were proposed as SCP. The chosen structure of the index *C* is due to the presence of a unique inverse relationship between the parameters G/(R+G+B) and R/(R+G+B) in each of the possible matrixes of ratios of colorimetric parameters.

3. A comparison of results of the processing of space photographs of the plavni in the mouth of river Danube, reflecting the various bioproduction processes of plant communities, made it possible to identify features of a risk of secondary water pollution. It was found that the high values of the proposed SCP (exceeding 10,000) indicate the intensity of photosynthetic production processes. Low values of the mean square deviation of values of index *C* are the markers of the destruction of biomass. The identified attributes allow remote diagnosis of the state of natural bioplato and enable timely response to emerging threats to biosafety of water use.

## References

1. Kozlova, T. V. Ispol'zovanie muskusnoy utki v integrirovannom rybovodstve na meliorativnom vodoeme Pripyatskogo Poles'ya [Text] / T. V. Kozlova, A. I. Kozlov, M. V. Shalak, O. A. Glushakov // Rybovodstvo i rybnoe hozyaystvo. – 2014. – Issue 1. – P. 40–45.
2. Wikramaratna, P. S. Contact between bird species of different lifespans can promote the emergence of highly pathogenic avian influenza strains [Text] / P. S. Wikramaratna, O. G. Pybus, S. Gupta // Proceedings of the National Academy of Sciences. – 2014. – Vol. 111, Issue 29. – P. 10767–10772. doi: 10.1073/pnas.1401849111
3. Titova, T. A. Effektivnost' primeneniya infil'tratsionnyh bioplato pri ochistke kommunal'nyh stochnyh vod [Text] / T. A. Titova // Vestnik Rossiyskogo gosudarstvennogo agrarnogo zaochnogo universiteta. – 2013. – Issue 15 (20). – P. 67–70.
4. Matyushenko, V. A. Otsenka vegetatsionnogo indeksa geosistem rechitskogo rayona [Text]: VIII Vseros. stud. nauch. konf. / V. A. Matyushenko // Tvorchestvo yunyh – shag v uspeshnoe budushchee. – Tomsk, 2015. – P. 528–530.
5. Cherepanov, A. S. Vegetatsionnye indeksy [Text] / A. S. Cherepanov // Geomatika. – 2011. – Issue 2. – P. 98–102.

6. Antipov, T. I. Primery avtomatizirovannyh metodov analiza geoizobrazheniy dlya agroekologicheskoy otsenki zemel' [Text] / T. I. Antipov, A. I. Pavlova, V. A. Kalichkin // Izvestiya vysshih uchebnyh zavedeniy. Geodeziya i aerofotos'emka. – 2012. – Issue 2/1. – P. 40–44.
7. Hohm, T. A Dynamic Model for Stem Cell Homeostasis and Patterning in Arabidopsis Meristems [Text] / T. Hohm, E. Zitzler, R. Simon // PLoS ONE. – 2010. – Vol. 5, Issue 2. – P. e9189. doi: 10.1371/journal.pone.0009189
8. Lee, Y.-S. Forecasting time series using a methodology based on autoregressive integrated moving average and genetic programming [Text] / Y.-S. Lee, L.-I. Tong // Knowledge-Based Systems. – 2011. – Vol. 24, Issue 1. – P. 66–72. doi: 10.1016/j.knosys.2010.07.006
9. Anderson, T. W. The statistical analysis of time series [Text] / T. W. Anderson. – John Wiley & Sons, 1994. – 704 p. doi: 10.1002/9781118186428
10. Dupont, F. A NEMO based modelling system for the Great Lakes [Text] / F. Dupont, C. Padala, H. Anning et. al. // 15th Workshop on Physical Processes in Natural Waters. – Burlington, 2011. – P. 46–52.
11. Gal, G. Implementation of ecological modeling as an effective management and investigation tool: Lake Kinneret as a case study [Text] / G. Gal, M. R. Hipsey, A. Parparov, U. Wagner, V. Makler, T. Zohary // Ecological Modelling. – 2009. – Vol. 220, Issue 13-14. – P. 1697–1718. doi: 10.1016/j.ecolmodel.2009.04.010
12. Hernandez-Clemente, R. Carotenoid content estimation in a heterogeneous conifer forest using narrow-band indices and PROSPECT+DART simulations [Text] / R. Hernandez-Clemente, R. M. Navarro-Cerrillo, P. J. Zarco-Tejada // Remote Sensing of Environment. – 2012. – Vol. 127. – P. 298–315. doi: 10.1016/j.rse.2012.09.014
13. Feret, J.-B. PROSPECT-4 and 5: Advances in the leaf optical properties model separating photosynthetic pigments [Text] / J.-B. Feret, C. François, G. P. Asner, A. A. Gitelson, R. E. Martin, L. P. R. Bidel et. al. // Remote Sensing of Environment. – 2008. – Vol. 112, Issue 6. – P. 3030–3043. doi: 10.1016/j.rse.2008.02.012
14. Chavez, R. O. Modelling the spectral response of the desert tree Prosopis tamarugo to water stress [Text] / R. O. Chavez, J. G. P. W. Clevers, M. Herold, M. Ortiz, E. Acevedo // International Journal of Applied Earth Observation and Geoinformation. – 2013. – Vol. 21. – P. 53–65. doi: 10.1016/j.jag.2012.08.013
15. Ruiz-Verdu, A. An evaluation of algorithms for the remote sensing of cyanobacterial biomass [Text] / A. Ruiz-Verdu, S. G. H. Simis, C. de Hoyos, H. J. Gons, R. Pena-Martinez // Remote Sensing of Environment. – 2008. – Vol. 112, Issue 11. – P. 3996–4008. doi: 10.1016/j.rse.2007.11.019
16. Zholtkevych, G. N. Discrete Modeling of Dynamics of Zooplankton Community at the Different Stages of an Antropogeneous Eutrophication [Text] / G. N. Zholtkevych, G. Y. Bespalov, K. V. Nosov, M. Abhishek // Acta Biotheoretica. – 2013. – Vol. 61, Issue 4. – P. 449–465. doi: 10.1007/s10441-013-9184-6
17. Zholtkevych, G. N. Descriptive models of system dynamics [Text] / G. N. Zholtkevych, K. V. Nosov, Y. G. Bespalov et. al. // 12th International Conference on ICT in Education, Research and Industrial Applications, ICTERI 2016. – Kyiv, 2016. – P. 57–72.
18. Vysotska, O. Modeling the dynamics of the cardiovascular system parameters coherence at different stages of the adaptation syndrome [Text] / O. Vysotska, Y. Bespalov, L. Rak et. al. // Bulletin of NTU "KhPI". Series: Mechanical-technological systems and complexes. – 2016. – Issue 4 (1176). – P. 79–84.
19. Vysotskaya, E. V. Unmasking the soil cover's disruption by modeling the dynamics of ground vegetation parameters [Text] / E. V. Vysotskaya, G. N. Zholtkevych, T. A. Klochko et. al. // Visnyk Natsionalnoho Tekhnichnoho Universytetu Ukrainy «KPI». Seriya: Radiotekhnika. Radioaparatobuduvannia. – 2016. – Issue 64. – P. 101–109.
20. Landsat collections. Provding a stable environmental record [Electronic resource]. – Available at: https://landsat.usgs.gov/
21. Vysotska, O. V. Using of Margalef succession model in remote detection technologies for indications of human impact on vegetation cover [Text] / O. V. Vysotska, Y. G. Bespalov, A. I. Pecherska, D. A. Parvadov // Radioelektronni i kompiuterni systemy. – 2016. – Issue 2 (76). – P. 15–19.