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ABSTRACT

Mathematical modeling of the spectral characteristics of the coefficient of diffuse reflection of a layer of an aqueous medium with phytoplankton particles with a change in the pigment parameters is carried out. The functions of the probability density of errors occurring in the measuring channel of the multispectral environmental control are investigated. The dependence of the errors of the first and second kind and the reliability of the control of the pigment parameters of the phytoplankton on the threshold value of the diffuse reflection coefficient for a separate spectral channel of the monitoring instrument are analyzed. In particular, when using four channels with wavelengths of 530 nm, 590 nm, 620 nm and 730 nm in the multispectral environmental monitoring tool, the value of the reliability of the control of the ratio between chlorophyll a and total chlorophyll 0.939 is obtained, and when three channels with wavelengths of 450 nm are used, 470 nm and 660 nm, the reliability of the control of the ratio between carotenoids and total chlorophyll 0.972 was obtained. The working wavelengths and the number of channels of the multispectral environmental control are determined by the spectral characteristics of the phytoplankton pigments (chlorophylls and carotenoids), as well as the spectral characteristics of the radiation source and the photomatrix of the monitoring instrument.

Keywords: multispectral method, aqueous media, spectral characteristics, chlorophyll, phytoplankton

1. INTRODUCTION

For environmental monitoring of water bodies, multispectral monitoring methods can be used[1,2,3]. At the same time, the complex effect of pollutants on a water body is estimated using bioindication using certain aquatic organisms, for example, phytoplankton or higher aquatic plants[4-5]. The ecotoxicity of a mixture of unknown pollutants trapped in water bodies is quantified by changes in the parameters of bioindicators. When using phytoplankton bioindication, environmental monitoring can be carried out by changing such pigment parameters as the ratio between chlorophyll a and total chlorophyll, or the ratio between carotenoids and total chlorophyll. The aim of the work is to assess the reliability of multiparameter multispectral environmental monitoring of pigment parameters of phytoplankton in natural aquatic environments based on the results of the study of errors of the first and second types and the reliability of control in individual spectral channels[6-8].

2. MATHEMATICAL MODELING OF THE SPECTRAL CHARACTERISTICS OF THE LAYER OF THE AQUATIC ENVIRONMENT WITH A CHANGE IN PIGMENT PARAMETERS

Using the technique of mathematical modeling of light scattering in the small-angle approximation[2,7], we solve the direct problem of determining the spectral characteristics of natural water environments for such cases of changes in the pigment parameters of phytoplankton[9-11]:

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a) the ratio between chlorophyll a and total phytoplankton chlorophyll Chl_a/Chl in the aquatic environment varies from 0.8 to 0.9; the ratio between carotenoids and total chlorophyll Carot/Chl = 0.27 ± 0.027; phytoplankton biomass in aquatic environment B = 17.7 ± 1.77 mg / l;

b) the ratio between chlorophyll a and total phytoplankton chlorophyll in the aquatic environment Chl_a/Chl = 0.8 ± 0.08; the ratio between carotenoids and total chlorophyll Carot/Chl varies from 0.2 to 0.4; phytoplankton biomass B = 17.7 ± 1.77 mg / l[12-13].

At the same time, phytoplankton parameters have a normal distribution law. The spectral characteristics of the diffuse reflection coefficient on the surface of the aquatic environment when the pigment parameters of phytoplankton change are calculated in Fig. 1.

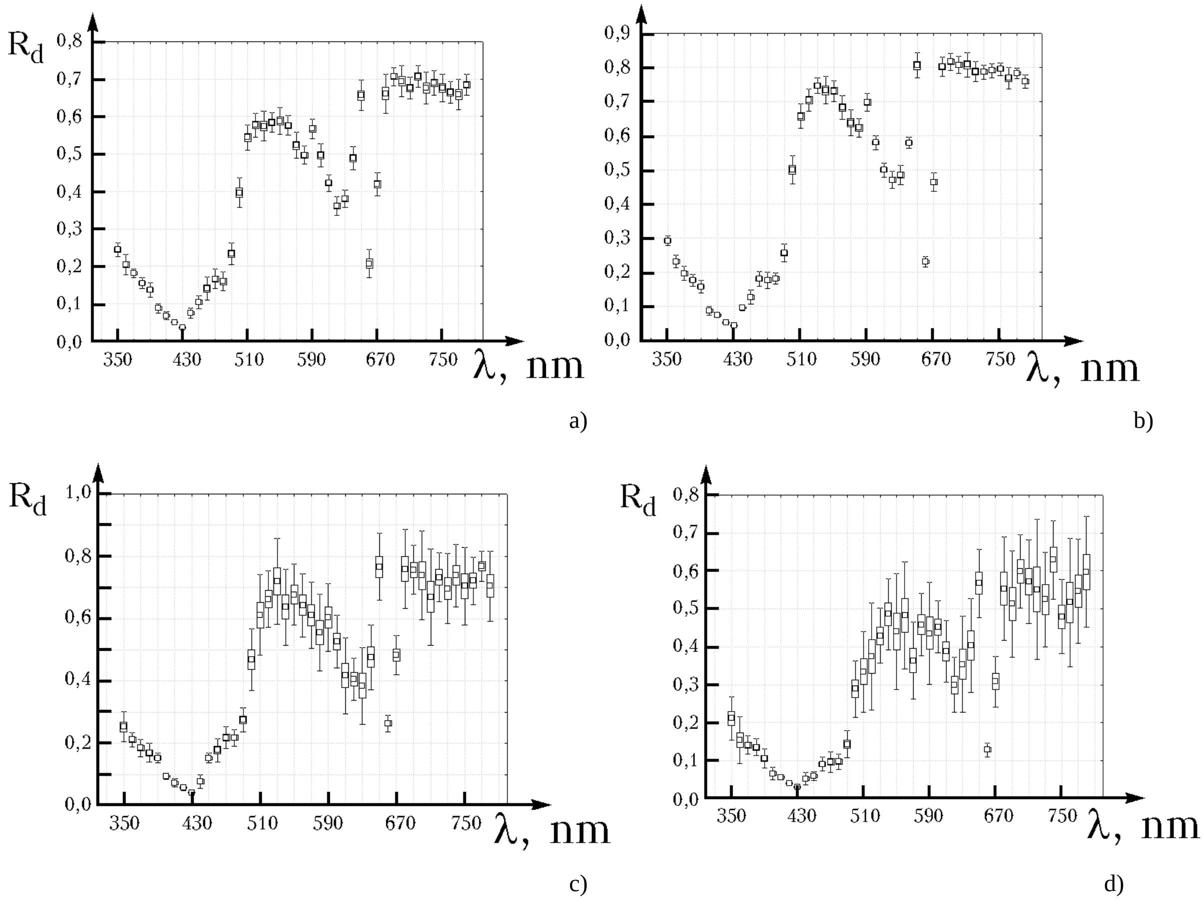

Figure 1. Spectral characteristics of the total diffuse reflection coefficient on the surface of the natural aquatic environment when the pigment parameters of phytoplankton change:

a) $Chla / Chl = 0,8 ; Carot / Chl = 0,27 \pm 0,027$; b) $Chla / Chl = 0,9 ; Carot / Chl = 0,27 \pm 0,027$;

c) $Chla / Chl = 0,8 \pm 0,08 ; Carot / Chl = 0,2$; d) $Chla / Chl = 0,8 \pm 0,08 ; Carot / Chl = 0,4$

To make a decision on the state of the test object according to the results of multispectral measurements in a laboratory model of the multispectral environmental monitoring facility, measurements are made at wavelengths corresponding to the characteristics of the radiation source. The diagrams of the magnitude of the diffuse reflection coefficient on the surface of the aquatic environment obtained as a result of a change in the pigment parameters of phytoplankton at these wavelengths are shown in Fig. 2 [14,15,16].

Consider making decisions about the state of the test object at a wavelength of 510 nm. The distribution of the measured value, that is, the diffuse reflection coefficient on the surface of the aquatic environment when the ratio between chlorophyll a and total phytoplankton chlorophyll varies from 0.8 to 0.9, corresponds to the normal distribution law [17,18,19].

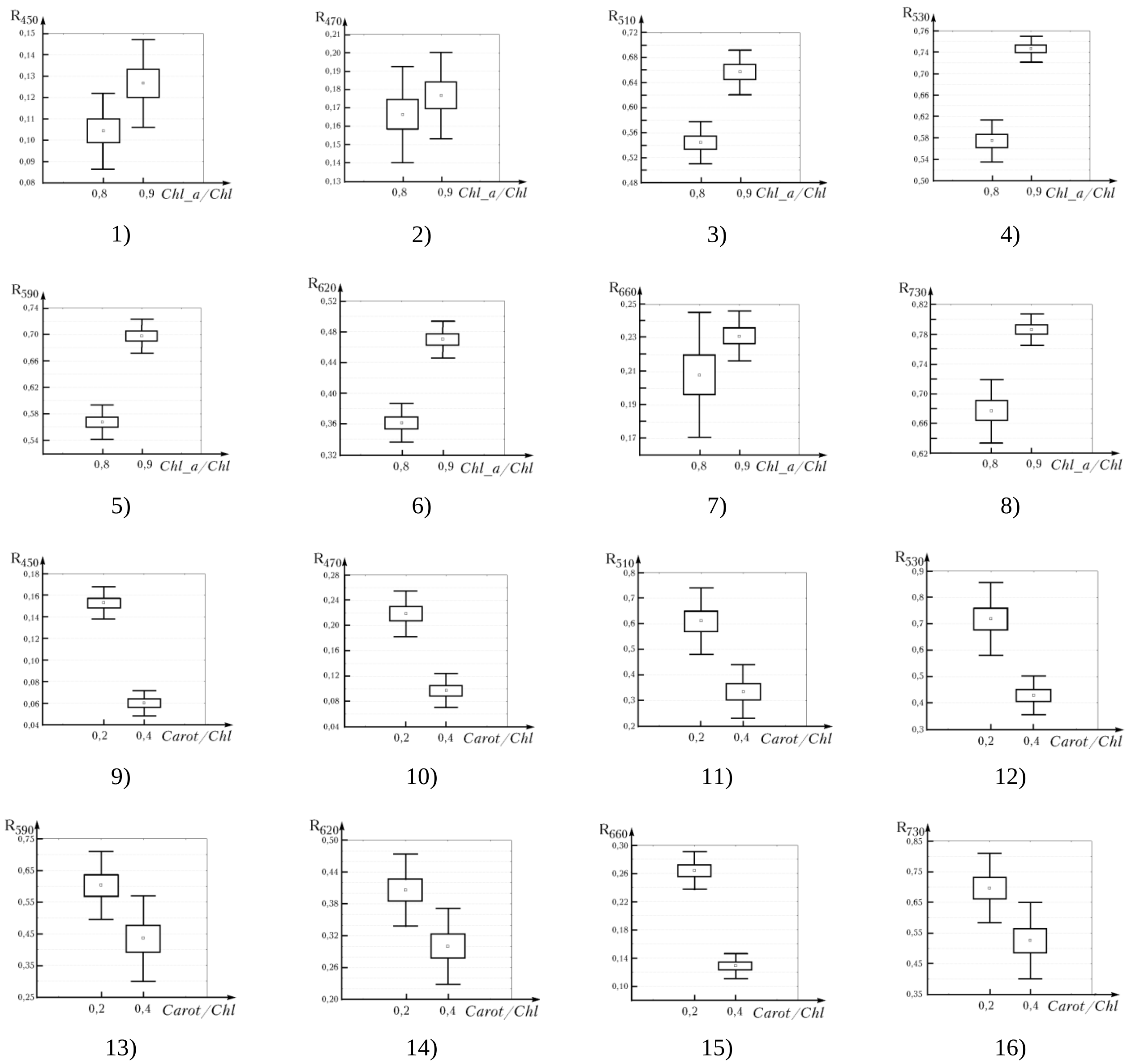

Fig. 2. Diagrams of the magnitude of the diffuse reflection coefficient on the surface of the aquatic environment with a change in the ratio between chlorophyll a and total chlorophyll (1-8) and carotenoids and total chlorophyll (9-16)

When used in a control device CCD camera the instrumental component of the error of multispectral measurements is determined by two components of the error, namely, the error caused by the presence of noise and random noise in the CCD camera and the quantization error associated with analog-digital conversion. The probability density functions of the errors due to the presence of noise and random noise in the CCD camera and quantization errors when using a camera of the type MDC140BW based on the Sony ICX285AL photomatrix are analyzed in[20-21].

3. ESTIMATION OF THE RELIABILITY OF MULTISPECTRAL ENVIRONMENTAL MONITORING OF PHYTOPLANKTON PIGMENT PARAMETERS IN THE AQUATIC ENVIRONMENT

Let us analyze the reliability of monitoring the pigment parameters of phytoplankton in the aquatic environment using the multispectral method. As a result of monitoring the pigment parameters of phytoplankton at a wavelength of 510 nm, it is necessary to determine the threshold value, that is , to distinguish samples from the ratio between chlorophyll a and total chlorophyll 0.8 and 0.9[22-24]. Comparison of the results of the control and the actual value when processing the results of multispectral measurements was carried out according to the method described in[20]. When the threshold value of the diffuse reflectance changes, the probability of errors of the first and second kinds, as well as the reliability of the control, changes as follows (see Fig. 3).

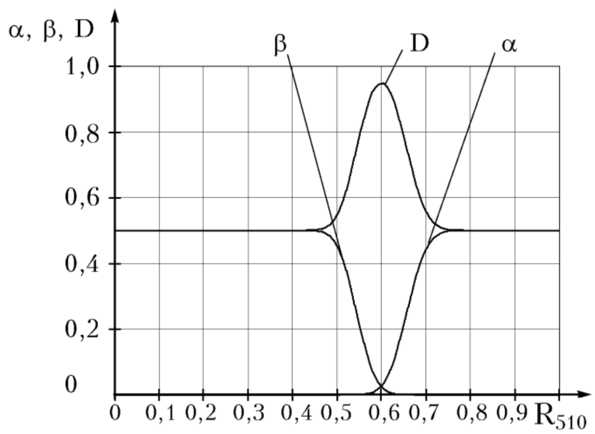

Fig. 3. The dependence of the errors of the first and second kind and the reliability of the control of the ratio between chlorophyll a and total phytoplankton chlorophyll by the multispectral method [11,25-26]

In tab. 1 shows the results of calculating the errors of the first and second kind and the reliability of monitoring the pigment parameters of phytoplankton by the multispectral method for other spectral channels[27].

Table 1. The results of the calculation of errors of the first and second kind and the reliability of control of pigment parameters

Wavelength, nm	R_1	R_2	α_i	β_i	D_i
The change in the ratio between chlorophyll *a* and total chlorophyll					
450	0.104370±0.017873	0.126655±0.020524	0.16	0.12	0.72
470	0.166366±0.026141	0.176787±0.023573	0.138	0.279	0.582
510	0.544284±0.033573	0.657209±0.035814	0.028	0.023	0.949
530	0.574745±0.039096	0.746518±0.023698	$9.5 \cdot 10^{-4}$	$2.5 \cdot 10^{-3}$	0.997
590	0.567362±0.025644	0.697673±0.025153	$3.2 \cdot 10^{-3}$	$2.25 \cdot 10^{-3}$	0.995
620	0.361308±0.024896	0.470147±0.024491	$5.35 \cdot 10^{-3}$	$7.55 \cdot 10^{-3}$	0.987
660	0.207780±0.037154	0.231058±0.014849	0.037	0.243	0.72
730	0.677084±0.042336	0.786341±0.020961	0.017	0.024	0.959
The change in the ratio between carotenoids and total chlorophyll					

450	0.153039±0.015293	0.059885±0.011417	$3\cdot10^{-4}$	$5\cdot10^{-5}$	0.9997
470	0.218642±0.035898	0.097021±0.026919	0.014	0.012	0.974
510	0.611659±0.129234	0.334817±0.106452	0.063	0.058	0.88
530	0.719055±0.137789	0.429759±0.073175	0.052	0.026	0.922
590	0.603915±0.107821	0.435920±0.134695	0.084	0.153	0.764
620	0.405982±0.067827	0.299850±0.072270	0.102	0.118	0.781
660	0.264222±0.026946	0.128925±0.018270	$1\cdot10^{-3}$	$3\cdot10^{-4}$	0.9987
730	0.696641±0.112632	0.525412±0.124805	0.097	0.137	0.766

In the case of multiparameter multispectral monitoring of phytoplankton pigment parameters, reliability will be determined by the product of the reliability of selected spectral channels. When using four channels with wavelengths of 530, 590, 620 and 730 nm in the multispectral environmental monitoring tool, the significance of multiparameter control of the ratio between chlorophyll a and total chlorophyll 0.939 was obtained[28-29]. When using three channels with wavelengths of 450, 470 and 660 nm in the multispectral environmental monitoring tool, the significance of multiparameter control of the ratio between carotenoids and total chlorophyll 0.972 was obtained. For processing multispectral images of polluted water bodies and using bioindication using phytoplankton or higher aquatic plants, it is convenient to use neural networks or fuzzy logic[20,30-33].

4. CONCLUSION

When the pigment parameters of phytoplankton change in the course of mathematical modeling, the diagrams of the magnitude of the diffuse reflectance at the working wavelengths of the spectral channels of the monitoring facility are obtained. Taking into account the influence of errors on the measured value, namely the diffuse reflection coefficient at the working wavelengths, errors of the first and second kind, as well as the reliability of the control in each of the spectral channels, are estimated. In order to obtain an acceptable value of the reliability of control, it is necessary to choose such spectral channels, using which the total authenticity will not be less than the required value. In particular, when using four spectral channels (530, 590, 620, 730 nm), the obtained value of the reliability of the control of the ratio between chlorophyll a and total chlorophyll was 0.939, and using three spectral channels (450, 470, 660 nm), the value of the control reliability was obtained the ratio between carotenoids and total chlorophyll was 0.972.

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