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Application of light attenuation measurement for the determination of vertical plankton distribution in seawater

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Abstract

The investigation of the horizontal and vertical distribution of phyto- and zooplankton communities is extremely important for the assessment of the ecological status of the marine environment, especially in the conditions of increasing anthropogenic influence. There is much evidence that during the last 20 years the Black sea coastal ecosystem is under the severe impact of eutrophication. As a response a dramatic increase of phytoplankton blooms was registered, accompanied by serious changes of its species succession; biological cycles and biomass, with corresponding alterations in zooplankton too. The high time-space variability, the patchiness of its horizontal distribution and vertical aggregation stress the necessity of reliable express methods for monitoring to be developed.

The increased abundance of plankton under the influence of high eutrophication of the Black Sea as a stratified basin, results in a dramatic change of the optical properties of the water masses especially in the coastal regions. Light attenuation in the water could be used for determination of vertical plankton distribution, abundance assessment and community aggregation down the water column.

A specially constructed device based on measuring of an optic system directed light beam attenuation in water has been used. The relationship between light attenuation (extinction) and total plankton abundance and chlorophyll 'a' fluorescence is evaluated in laboratory experiments on sea water samples with modelled plankton biomass. A good relationship between extinction coefficient as a measure of light attenuation and total phyto- and zooplankton biomass as well as chlorophyll 'a' fluorescence has been established. The experimental results were used for calibration of the device for *in-situ* application.

Two series of *in-situ* measurements were accomplished in the region of Varna Bay canal connecting Varna Lake and Varna Bay. During the first one five points were sampled and during the second – three points. At each point light attenuation was measured at depths from 0.5m to 8.5m with a step of 1m and water bottle samples were taken at three depths 0.5, 4.5 and 8.5m. The samples were processed by classical methods. In addition the chlorophyll 'a' (as a measure of total phytoplankton biomass) was analyzed on a Turner Design Fluorometer (model 10-000R).

As a result of the study a well-expressed and steady relationship between vertical distribution of extinction coefficient and chlorophyll 'a' measurement has been established. This gives ground to suggest that light attenuation could be used as an express method for determination of vertical plankton distribution in seawater. Applying 'express' and 'classic' methods of measurement in parallel could obtain more detailed results.

Keywords: Plankton; Chlorophyll 'a'; Optical properties; Light attenuation; Seawater.

Introduction

The investigation of the horizontal and vertical distribution of both phyto- and zooplankton communities is extremely important for the assessment of the ecological status of the marine environment especially in conditions of increasing anthropogenic influence. There is much evidence that during the last 20 years the Black sea coastal ecosystem is under the severe impact of eutrophication. As a response, a dramatic increase of phytoplankton blooms is registered, accompanied by serious changes of its species succession, biological cycles and biomass (Moncheva, 1991), with corresponding alterations in zooplankton too. The high time-space variability, the patchiness of its horizontal distribution and vertical aggregation stress the necessity of reliable express methods for monitoring to be developed (Cachru *et al.*, 1989).

The application of some hydro-optical measurements proves to give satisfactory results Karabashev *et al.* (1986). Among them the most reliable seems the assessment of light attenuation in the water column. Karabashev *et al.* (1986) for example have constructed and experimentally tested an autonomous underwater transparencymeter based on the measurement of collimated light beam attenuation. Li (1980) also focusses on light attenuation in the construction of an underwater transparencymeter. Lieberman *et al.* (1984) has established a good relationship between light transmission and chlorophyll 'a' fluorescence in the coastal waters off South California.

This paper presents the results of the application of light attenuation measurement for the determination of vertical plankton distribution in seawater.

Methods and materials

Method of measurement

The method of the plankton biomass determination is based on the light attenuation measurement from a source of a collimated beam and an optical system. At a distance from the light source, called optical base, there is a sensitive element for measuring the illumination. The transmission coefficient K is determined by comparison of the luminous flux passed through the air and sea water:

$$K = F / Fo$$

Where: Fo = the luminous flux through the air and F = the luminous flux through the water. The relationship between the illumination E and the normal incidence luminous flux F on a surface S is:

$$E = F / S$$

As the surface of the light beam in this case is constant then:

$$K = E / Eo$$

Where: Eo = illumination in the air and E = illumination in the water.

The transmission coefficient K is closely related to light absorption and dispersion in seawater and is identified also with the extinction coefficient. At a proper selected source power and optic base the illumination due to the natural sun light in seawater (both direct and dispersed) can be ignored.

Hydro-optical device

The panel diagram of the hydro-optical device used for light attenuation measurement Palazov (2001), is shown on Fig. 1. Power source (1) supplies the collimated light beam source (2), which consists of a lamp, a reflector and an optical system. At a given pathway L (optical base), a dry photocell (sensitive element) is fixed (3), which changes its resistance proportionally to illumination. A measuring device (4) measures dry photocell resistance. The optical base L of the hydro-optical device can be changed to obtain optimal measuring condition.

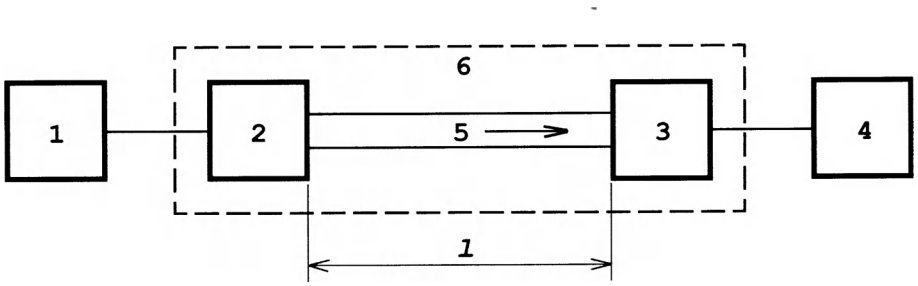

Fig. 1. Panel diagram of the hydro-optical device.

The device was constructed in the Institute of Oceanology, Varna and calibrated in the air by illuminometer type PU 150 through controlling the intensity of light source and measuring the illumination of the cell. The calibration curve and the corresponding equation are plotted on Fig. 2. As expected it is a power function.

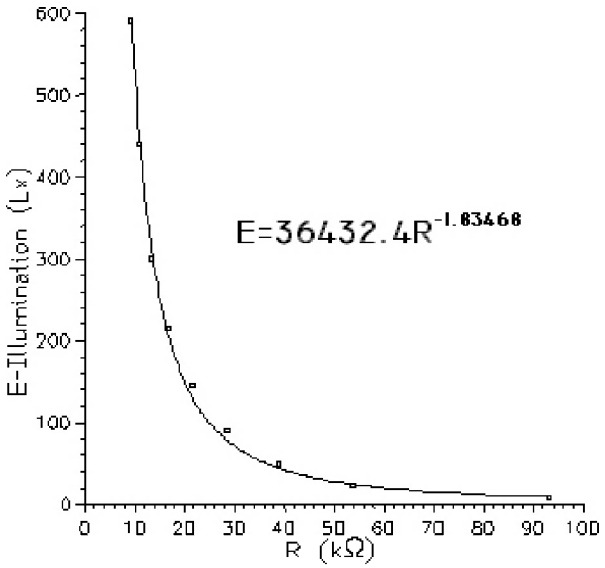

Fig. 2. Calibration curve of the hydro-optical device.

Optical device specifications are:

Range:	from 0 to 3200Lx
Resolution:	0.5Lx
Accuracy:	± 1Lx
Output signal:	max 6V
Resistance of the sensitive cell:	from 1 to 100kΩ

Laboratory experiments

The laboratory experiments with a constructed hydro-optical device were conducted on natural seawater with experimentally controlled phyto- and zooplankton biomass (Slabakov *et al.*, 1996; Palazov, 2001). The plankton was sampled in Varna Bay (by a Jeddy net for zooplankton) on the day of the experiment and diluted with filtered sea water several times, step by step, until the biomass becomes negligible. For each step, light extinction, total biomass and chlorophyll 'a' fluorescence were measured and estimated. Extinction coefficient was estimated by means of the constructed hydro-optical device, zooplankton biomass by Dimov's method (1959) and phytoplankton biomass by Soumia's method (1978). The total biomass is the sum of phyto and zooplankton biomass. Chlorophyll 'a' fluorescence (as a total phytoplankton biomass parameter) was measured by a Turner Design Fluorometer (model 10-OOOR).

The experimental medium covered the range of the natural plankton concentration. Temperature and salinity in the experimental bath were controlled during each experiment. The influence of temperature and salinity on the light extinction was also experimentally tested and was found to be practically negligible. The salinity range was between 10-35 in experimental series decreasing stepwise by 5 units and the temperature range was between 5-25°C, set by 5°C intervals.

The results of the two experiments are presented in Figs 3 to 6. On Fig. 3 the relationship between extinction coefficient and total plankton biomass is depicted and on Fig. 4 -the relationship between extinction coefficient and chlorophyll 'a' fluorescence for the first experiment.

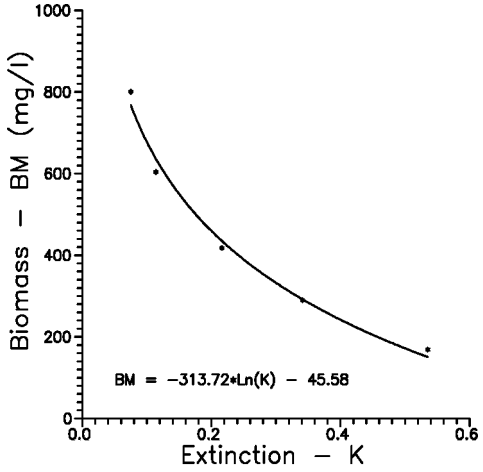

Fig. 3.
Relationship between extinction coefficient and total plankton biomass (first experiment).

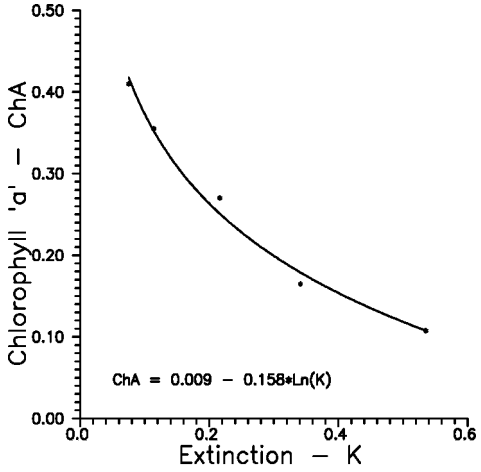

Fig. 4.
Relationship between extinction coefficient and chlorophyll 'a' fluorescence (first experiment).

Of the second experiment the relationship between extinction coefficient and total plankton biomass is presented in Fig. 5 and the relationship between extinction coefficient and chlorophyll 'a' fluorescence – in Fig. 6.

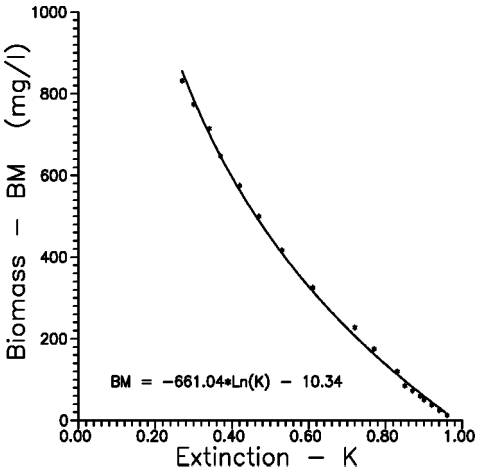

Fig. 5.
Relationship between extinction coefficient and total plankton biomass (second experiment).

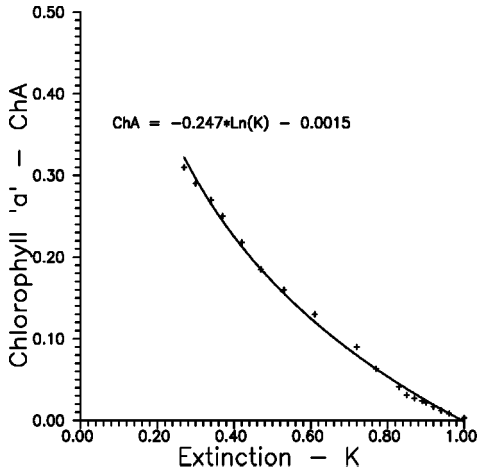

Fig. 6.
Relationship between extinction coefficient and chlorophyll 'a' fluorescence (second experiment).

In-situ *measurements*

Two series of *in-situ* measurements were accomplished in Varna Bay and in the canal connecting Varna Lake and Varna Bay. During the first one five stations were sampled and during the second – three stations, selected to cover a wide range of plankton concentration. The stations from 1 to 5 and from 6 to 8 are located along a line from open sea to Varna Lake. The scheme of sampling stations is shown in Fig. 7.

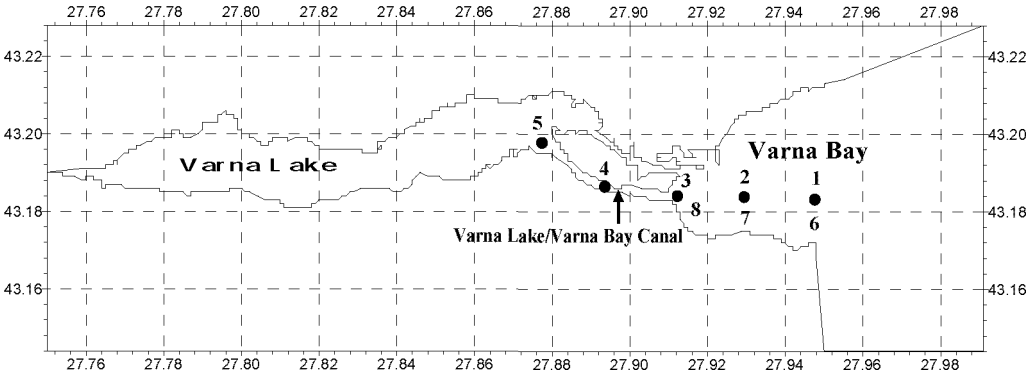

Fig. 7. Scheme of sampling stations.

At each station light attenuation was measured at depths from 0.5 to 8.5m with a step of 1m down the vertical profile. Water samples were taken by water bottles at depths of 0.5, 4.5 and 8.5m in parallel. The samples were processed in the biological laboratory of the Institute of Oceanology, Varna, on the day of sampling. The phytoplankton biomass was estimated by the method of Sournia (1978). Chlorophyll 'a' was estimated by the method of SCOR UNESCO (1966). The chlorophyll 'a' fluorescence (as a total phytoplankton biomass parameter) was measured on a Turner Design Fluorometer (model 10-000R).
The taxonomic composition of phytoplankton in Varna Bay at the time of the first experimental series is presented in Table I.

Table I. Phytoplankton taxonomic composition

Class/Species	Numerical abundance [cells.l^{-1}]	Biomass [ml^{-1}]
Bacillariophyceae		
Ditylum brightwellii	15000	1.530
Skeletonema costatum	320000	0.096
Thalassiosira parva	27000	0.054
Cyclotella caspia	14000	0.008
Thalassionema nitzschioides	8000	0.010
Cerataulina pelagica	7000	0.046
Pseudosolenia calcar-avis	1000	0.330

Class/Species	Numerical abundance	Biomass
Pseudonitzschia delicatissima	2000	0.001
	394000	2.075
Dinophyceae		
Scripssiella trochoidea	2000	0.026
Prorocentrum minimum	166000	0.332
Prorocentrum micans	1000	0.013
Gyrodinium fusiforme	200	0.009
Oxyphysis oxytoxoides.	13000	0.585
	182200	0.965
Cyanophyceae		
Phormidium sp.	5000	0.001
TOTAL:	581200	3.041

The results of the first series of measurements (stations 1 to 5) are presented in Table II. Table III lists the results of the second series of measurements (stations 6 to 8).

Table II. Results of the first series of *in-situ* measurements

Point	1	1	2	2	3	3	4	4	5	5
Depth	1- K	Chl*10	1- K	Chl*10	1- K	Chl*10	1- K	Chl*10	1- K	Chl*10
0.5	0.2087	0.130	0.2819	0.260	0.3262	0.300	0.3195	0.285	0.2742	0.250
1.5	0.2094		0.2812		0.3376		0.2673		0.2533	
2.5	0.2032		0.2483		0.3016		0.2533		0.2232	
3.5	0.1912		0.1944		0.2388		0.2008		0.2164	
4.5	0.1732	0.079	0.1699	0.090	0.2086	0.150	0.1732	0.150	0.211	0.140
5.5	0.1597		0.1415		0.1952		0.1631		0.2032	
6.5	0.1529		0.1500		0.1511		0.1700		0.1900	
7.5	0.1597		0.1326		0.1500		0.1335		0.1600	
8.5	0.1424	0.048	0.1250	0.040	0.1400	0.080	0.1200	0.098	0.1550	0.095

1-K: measured extinction coefficient subtracted from one.
Chl*10: measured chlorophyll 'a' fluorescence multiplied by ten.
The transformations were made for better illustration of the results (Figs 8 to 15).

Table III. Results of the second series of *in-situ* measurements

Point	6	6	7	7	8	8
Depth	1- K	Chl*10	1- K	Chl*10	1- K	Chl*10
0.5	0.2117	0.140	0.2954	0.250	0.2352	0.165
1.5	0.2277		0.3070		0.2410	
2.5	0.2086		0.3170		0.2381	
3.5	0.2613		0.3195	0.288	0.2694	0.250
4.5	0.2673	0.160	0.3213		0.3213	
5.5	0.2742		0.3100		0.3006	
6.5	0.2468		0.3006		0.3041	
7.5	0.2388		0.3177		0.3177	
8.5	0.2200	0.120	0.3133	0.280	0.3300	0.300

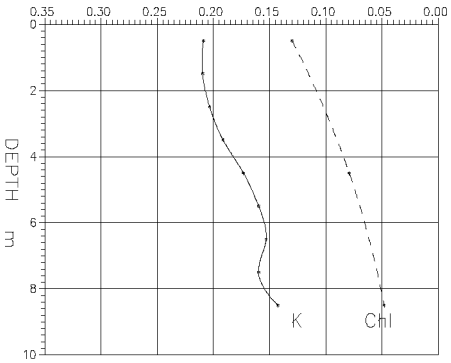

Fig. 8. Station 1.

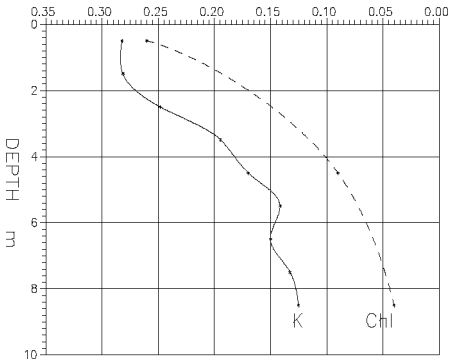

Fig. 9. Station 2.

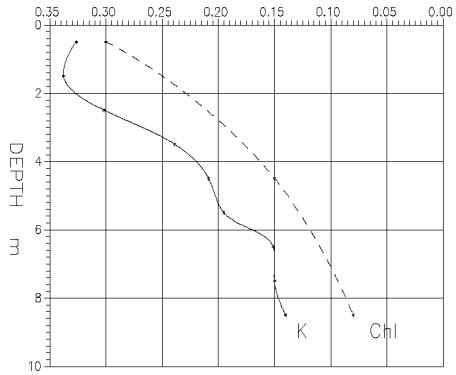

Fig. 10. Station 3.

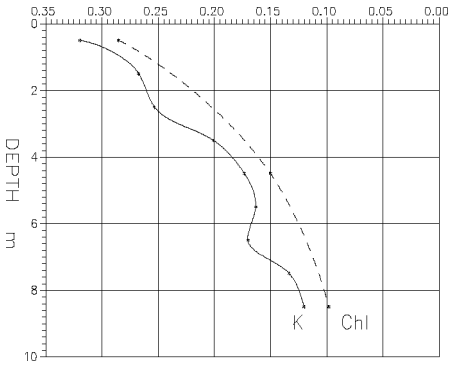

Fig. 11. Station 4.

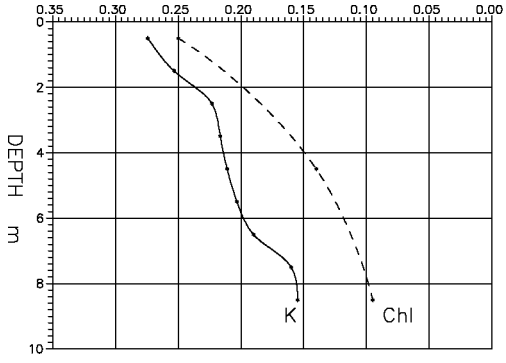

Fig. 12. Station 5.

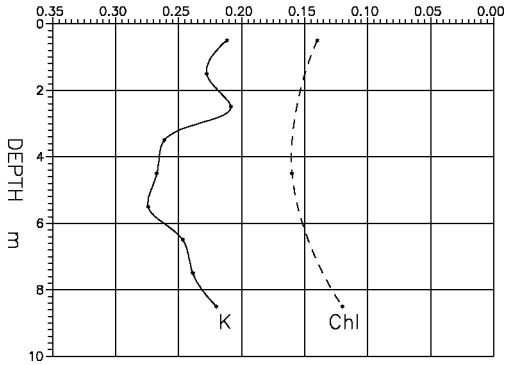

Fig. 13. Station 6.

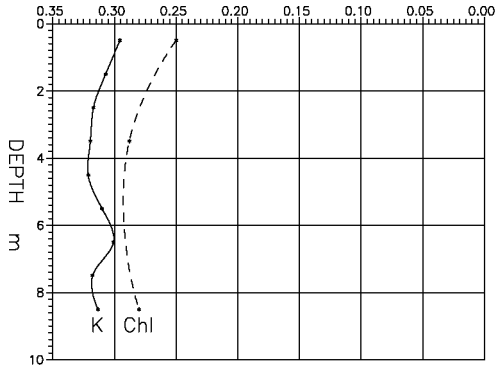

Fig. 14. Station 7.

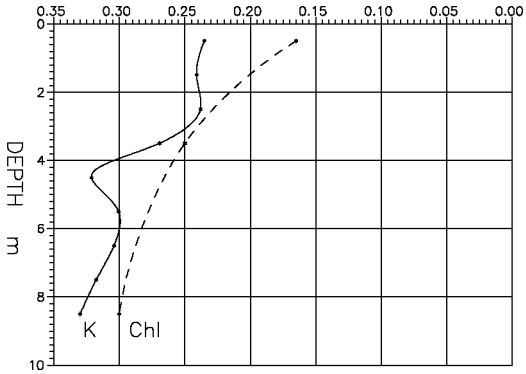

Fig. 15. Station 8.

K (solid line): measured extinction coefficient; Chl (dashed line): measured chlorophyll 'a' fluorescence.

Results and conclusions

During the laboratory experiments a well-expressed steady relationship between extinction coefficient and both total plankton biomass and chlorophyll 'a' fluorescence was established. The relations are logarithmic, which is in conformity with the results of other investigations (Lieberman *et al.*, 1984). The differences between the two experiments may be related to the differences of the species composition (different size composition) as well as to the differences in the phyto/zooplankton ratio. A probable reason could be the presence of the Ctenophore *Mnemiopsis leidyi*, which has not been estimated.

The results from *in-situ* measurements manifest generally a good agreement between variation of extinction coefficient and chlorophyll 'a' fluorescence. During previous experiments it was demonstrated that the phytoplankton influence on the extinction is much stronger than that of zooplankton (Palazov, 2001).

The established relationships between the total plankton biomass and chlorophyll 'a' fluorescence with extinction coefficient give ground to consider the method applicable for determination of the phyto/zooplankton ratio.

Acknowledgements

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References

Cachru M.S., S. Chesmann and E. Allickas. 1989. Complete equipping for investigation of the space distribution of phytoplankton. Moscow. Oceanology XXIX(4):670-674.

Karabashev G.S., A.F. Culeshov and S.A. Shanaaev. 1986. Autonomous transparencymeter. Moscow. Oceanology XXVI(6):1028-1032.

Li M.E.1980. Submersible autocollimated transparencymeter. p.2911-295. In: Optical methods for studying oceans and land basins. Talin Inst. of Thermo and Electrophysics AS USSR.

Lieberman S.H., G.D. Gilbert, P.F. Seligman and A.W.Dibelka. 1984. Relationship between chlorophyll-a fluorescence and underwater light transmission in coastal waters off Southern California. Deep Sea Research 31(2):171-180.

Moncheva S. 1991. Eutrophication/Plankton blooms/Hypoxia. Rep. Int. Workshop on the Black Sea: Focus on the Black Sea Shelf, Varna, 30 Sept.-4 Oct., Coast. Res. Center WHOI

Palazov A.V. 2001. An express method for plankton abundance detection in sea water. Proceedings of the Institute of Oceanology 3:180-184. Varna.

Slabakov Ch., S. Moncheva, A. Palazov, A. Konsulov, T. Trayanov and N. Nickolov. 1996. A possible express method for plankton abundance in sea water. p.253-258. In: Coastal management and habitat conservation. Salman A.H.P.M., M.J. Langeveld and M.Bonazowntas (Eds). EUCC, Leiden, The Netherlands.