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REMOTE SENSING OBSERVATIONS OF THE PHYTOPLANKTON DISTRIBUTION IN LAKE KINNERET

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ABSTRACT

Reflectance spectra from 400 to 750 nm were measured in Lake Kinneret, when low phytoplankton stock prevailed, with chlorophyll concentrations from 3.1 to 7.3 µg/l. Algorithms for estimation of chlorophyll (CHL) concentration were devised using reflectances in the blue and green region of the spectrum and natural solar induced fluorescence. The fluorescence was calculated either from the reflectance height above a baseline drawn between 650 and 715 nm or between 670 and 730 nm, and also from the sum of reflectance above the base line through 670 and 730 nm. This paper presents experimental evidence showing that fluorescence can be successfully used as indicator of CHL content.
Key words: Radiance, optical properties.

INTRODUCTION

Considerable effort has been expended on phytoplankton studies in Lake Kinneret. The chlorophyll-a concentration in the lake ranges between 2 and more than 200 µg/l, with the highest values when a thick bloom of the dinoflagellate _Peridinium gatunense_ occurs. The spatial distribution of _Peridinium_ sp. is highly irregular, thus leading to the formation of patches. The horizontal variability increases from about 1:4 at the beginning to more than 1:20 at the end of the bloom.

The most reasonable way to estimate the spatial and temporal distribution of phytoplankton in the lake would be the use of remote sensing technique. However, lack of data on specific inherent optical properties of water constituents in the lake, spectral features of radiance, as well as fluorescence efficiency of phytoplankton hampered the application of remote sensing technology to lakes.

Increased use of chlorophyll fluorescence has been made in recent years [1-3] to investigate natural phytoplankton. However, the interpretation of remotely sensed data is not simple because many sources contribute to signal variability: phytoplankton concentration, composition, and physiological status, as well as concentrations of detritus and dissolved compounds. The knowledge of this variability is therefore critical for understanding the measurement results and developing biooptical models of photosynthetic production.

In this paper we present several algorithms used to estimate CHL from radiometric measurements acquired on board ship as a first step in using remote sensing technology to estimate chlorophyll concentrations in Lake Kinneret. This study was conducted when chlorophyll concentration was exceedingly low and with homogeneous horizontal distribution.

METHODS

Twenty locations were sampled on the 26th and 27th of October 1992, in the northern part of the lake, where water depth ranged between 8 m and 43 m.

Reflectance spectra were measured above and below water surface with a portable LI-1800 spectrometer from 400 to 750 nm. The instrument measured the upwelling radiance above the water surface and (indirectly) the downwelling radiance with the aid of a reflectance standard white plate. Radiance measurements were taken using telescope with FOV=15°. The spectra of downwelling radiance were determined after each measurement of upwelling radiance. Each observed radiance spectrum of water was divided by the appropriate downwelling radiance spectrum to give a reflectance spectrum.

Water was taken with a 5 L Aberg-Rodhe sampler 0.0 to 0.5 m below surface. CHL content was measured fluorometrically.

Surface CHL concentrations can be deduced from reflectance spectra either by using the green to blue reflectance ratio as a measure of chlorophyll-a absorption near 440 nm [4], or by using the fluorescence line height (FLH) at 685 nm above a linear base line that intersects the reflectance spectrum at
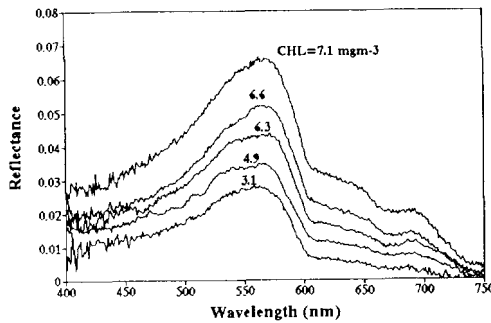
Figure 1. Reflectance spectra of Lake Kinneret. CHL indicated by numbers.

650 and 715 nm [2,3]. We also suggested and tested two another methods to quantify CHL concentration: FLH at 690 nm above a base line drown between 670 to 730 nm and a sum of reflectance above the base line.

RESULTS AND DISCUSSION

Although we tried to sample as wide a range CHL and suspended matter concentrations as possible, the horizontal distribution of these constituents was rather homogeneous. The reflectance spectra acquired in the 20 sampling stations were all very similar (Fig. 1). A sharp decrease around 440 nm corresponded to CHL absorption. A week minimum at 520 nm was also observed. Maximum near 560-570 nm was caused by minimum absorption by all phytoplankton pigments. Subsequently there was a sharp decrease of reflectance to ~ 600 nm. Near 600 nm the slope of spectral reflectance changed very sharply. The two latter features are due to spectral behavior of absorption coefficient of water. In the red region of spectrum a weak minimum between 620 and 630 nm was observed. This

could correspond to phycocyanin absorption. From 670 to 675 nm a reflectance minimum was recorded. This was evident for CHL content > 4 µg/l, and hardly distinguished for CHL < 3.5 µg/l. A small peak which position varied from 685 to 695 nm was found in all spectra; at 685 nm it was found only once. That was at the station with maximum water transparency. In most spectra the peak was positioned close to 690 nm. The spectra converged to a common reflectance value at 750 nm, suggesting that we had effectively blocked a high percentage of the surface reflected light.

Lake Kinneret is a typical representative of Case II waters, where CHL and suspended matter concentrations are not closely correlated (in this experimented series the determination coefficient $r^2 < 0.3$). The ratio $R(520)/R(550)$ plotted versus CHL concentration resulted in a following function [4]:

$$CHL=19.35-17.42[R(520)/R(550)], \ µg/l \quad (1)$$

with $r^2 > 0.57$. This permitted estimation of CHL with a standard error 0.79 µg/l.

The maximum of reflectance at 685 nm was exploited to estimate CHL concentration in several ways. First, the FLH at 685 nm above the linear base line which was drawn between 650 and 715 nm was measured [2,3]. The relationship:

$$CHL = 0.934 + 1.496*10^3 FLH, \ µg/l \quad (2)$$

gave $r^2=0.64$ and allowed the CHL estimation with an error of less than 0.71 µg/l.

Considering rather high variability of CHL estimation associated with the use of eq. 2, two alternative calculations were used to estimate CHL concentration. A linear base line was fixed at 670 and 730
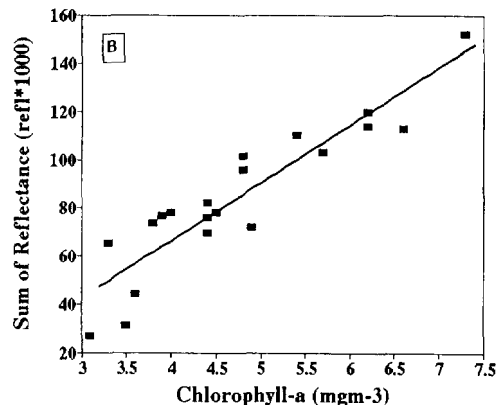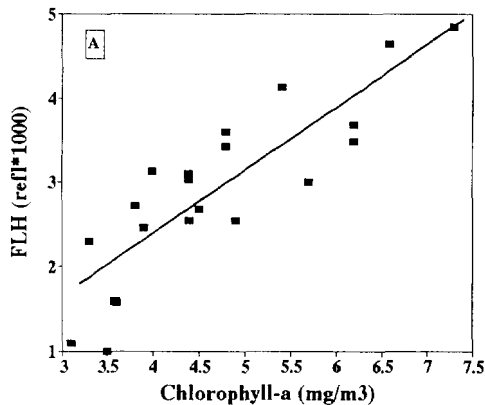

Figure 2. Chlorophyll-a concentration plotted versus (A) fluorescence line height (FLH) at 690 nm through reflectances at 670 and 730 nm, (B) sum of reflectance above the base line through 670 and 730 nm.

nm and FLH at 690 nm was measured above the base line. The relationship FLH versus CHL is shown in Fig. 2A. Scattering was considerably less than for either of the previous algorithms. A regression in the form:

$$CHL = 1.84 + 0.98*10^3 \ FLH, \ \mu g/l \qquad (3)$$

described the relationship with $r^2 >$ 0.73, and lowered the estimation error of CHL to 0.6 $\mu g/l$.

The accuracy of CHL estimation could be further improved by determining the sum of reflectance above the base line in the region from 670 to 730 nm (SUM). The linear relationship shown in Fig. 2B:

$$CHL = 1.8 + 0.03*10^3 \ SUM, \ \mu g/l \qquad (4)$$

had a correlation coefficient, $r^2 > 0.84$ with an estimation error of CHL < 0.48 $\mu g/l$.

These algorithms avoid to a certain degree the problems of variation in peak position and shape. Both models (3) and (4) accounted not only for CHL fluorescence, but also for the CHL absorption at 670 nm, and allowed enhancement of sensitivity of the measurements.

In order to assess fluorescence efficiency of CHL, radiances were calculated according to the optical properties of water, yellow substance, suspended matter and the absorption spectrum of CHL [2,5]. The fluorescence peak is centered around 685 nm, with a Gaussian distribution [6]. A good agreement was found between the measured and calculated radiance spectra yielding fluorescence efficiency of 0.7%.

We also observed higher amount of FLH at 685 nm for small phytoplankton cells (nanoplankton content of more than 70 %) than in samples having the same pigment concentration but containing < 60% nanoplankton. Possibly this is due to higher quantum yield of fluorescence for small particles [7]. In addition, small particles scatter more light such that a greater amount of energy leaves the water [3]. This effect is strongly controlled by the real part of the complex refractive index, which should be smaller for larger particles [3,5].

CONCLUSIONS

The results presented in the paper principally address inland waters and the diverse and highly variable biooptical properties that exist there. These findings serve to complement and expand the previous Case I and Case II waters findings [1-4].

The fluorescence line height at 690 nm above the base line through 670 and 730 nm and a sum of reflectance above the base line were shown to be directly proportional to chlorophyll concentrations in near surface lake water. An accuracy of CHL estimation of about 0.5 $\mu g/l$ can be achieved.

Even though the fluorescence intensity was low in comparison with the reflectance in the blue-green region, we found it to be adequate for a quantitative measurement of chlorophyll-a concentration at least as low as 3 $\mu g/l$ (the lowest value observed in these measurements).

Our data provide new evidence that naturally induced fluorescence can be a very sensitive and powerful tool for the estimation of CHL concentrations in near surface waters of lakes, reservoirs, and estuaries with a background of variable and relatively high suspended matter concentration.

REFERENCES

1. R. A. Neville and J.F.R. Gower, "Passive remote sensing of phytoplankton via chlorophyll-a fluorescence," J. Geoph. Res., Vol. 82, pp. 3487-3493, 1977.

2. J. F. R. Gower, "Observations of in situ fluorescence of chlorophyll-a in Saavich Intel", Boundary-Layer Meteorol. vol. 18, pp. 235-248, 1980.

3. J. Fischer and V. Kronfeld, "Sun-stimulated chlorophyll fluorescence. 1: Influence of oceanic properties", Int. J. Remote Sensing, vol. 11, pp. 2125-2147, 1990.

4. H.R. Gordon and A. Morel, Remote assessment of ocean color for interpretation of satellite visible imagery, New-York: Springer-Verlag, 1983, 114 p.

5. A. Vasilkov and A. Gitelson, "Spectral dependence of the light scattering characteristics of absorbing organic hydrosol", Izvestiya, Atmospheric and Oceanic Physics, vol.24, pp. 968-972, 1988.

6. H. R. Gordon, "Diffusive reflectance of the ocean: the theory of its augmentation by chlorophyll-a fluorescence at 685 nm", Appl. Opt., vol. 18, pp. 1161-1166, 1979.

7. A. Alpine and J.E. Cloern, "Differences in in vivo fluorescence yield between three phytoplankton classes," J. Plankton Res., vol. 7, pp. 381-390, 1985.